Milkshake

Anthony Johnson

Team Photo 3 Report

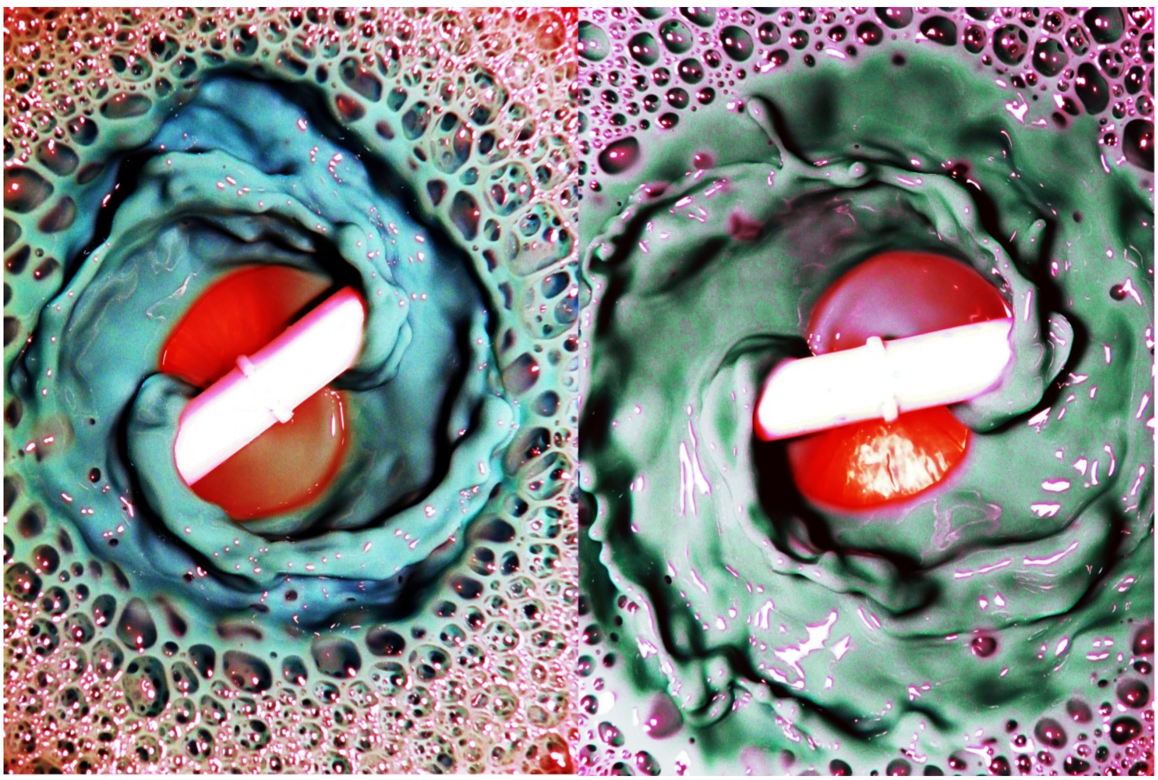

Image description:

Milk is a liquid that is a part of many peoples daily lives, including my own. Whether you are pouring it over your cereal in the morning or drinking a glass of chocolate milk for dinner, it is often overlooked and ignored as something that can be used to demonstrate many phenomenon in the world of fluid flow and dynamics. This fact was the inspiration behind the cover photo. One morning while pouring milk into a bowl of cereal it was realized that due to the increased viscosity and white coloration of the milk, it demonstrated fluid phenomenon that were easy to visualize and interpret apart from those of clear, less viscous fluids such as water. The intent of this image was to capture the flow phenomenon that occur in agitated milk using a high shutter speed to have little or no motion blur as well as produce an image that is visually appealing and of high artistic quality.

Method for capturing Phenomenon:

The method used to capture the high-speed photograph of agitated milk was fairly straightforward and is easily reproducible. To begin the photograph, 2% milk was removed in a large glass and allowed to reach room temperature. It was discovered that the room temperature milk mixed faster and more complete with the room temperature dye than that of cold milk. Once the milk reached room temperature a large amount of blue dye was added to the milk with a few drops of green to develop turquoise milk as seen in the original image located at the end of the report. A small amount of this milk was placed in a glass salad bowl with a base diameter of 3 inches to a depth of ¾ of an inch. This bowl with the dyed milk was then placed over a magnetic stirrer with the 1.5 inch stirring bar placed inside of the glass bowl. A magnetic stirrer is a device that used a small stirring bar placed inside the device containing the liquid to be stirred. This stirring bar is then rotated by way of a magnet rotation below the magnetic stirrer plate resulting in the liquid contained in the vessel to be rotated and subsequently stirred. An image of a magnetic stirrer with stirring bar can be seen below.

Figure 1: Magnetic Stirrer and Stirring Bar

Once the salad bowl containing the milk was properly aligned over the magnetic stirrer, the device was turned on and the speed was adjusted to form visible agitation of the milk while avoiding large instabilities such as large splashing of the milk or un-uniform structure of the milk. The speed at which this agitation was achieved while maintaining uniformity and stability of the milk was determined through trial photographs. This consisted of taking several images at a high shutter speed a various speed settings of the magnetic stirrer. This speed was determined to be at the speed level of two or roughly 480 rotations per minute. The camera was then held directly overhead and images were captured at a shutter speed of 1/1600 sec. The only lighting used was the ambient lighting in the room with the addition of diffused light from the flash obtained by taping a tissue to the flash of the camera. Finally, each photographic session lasted approximately 5 seconds before too much air was introduced to the system and the milk became saturated with bubbles. This was then repeated several times until sufficient images were obtained. A representation of the photographic apparatus can be seen below.

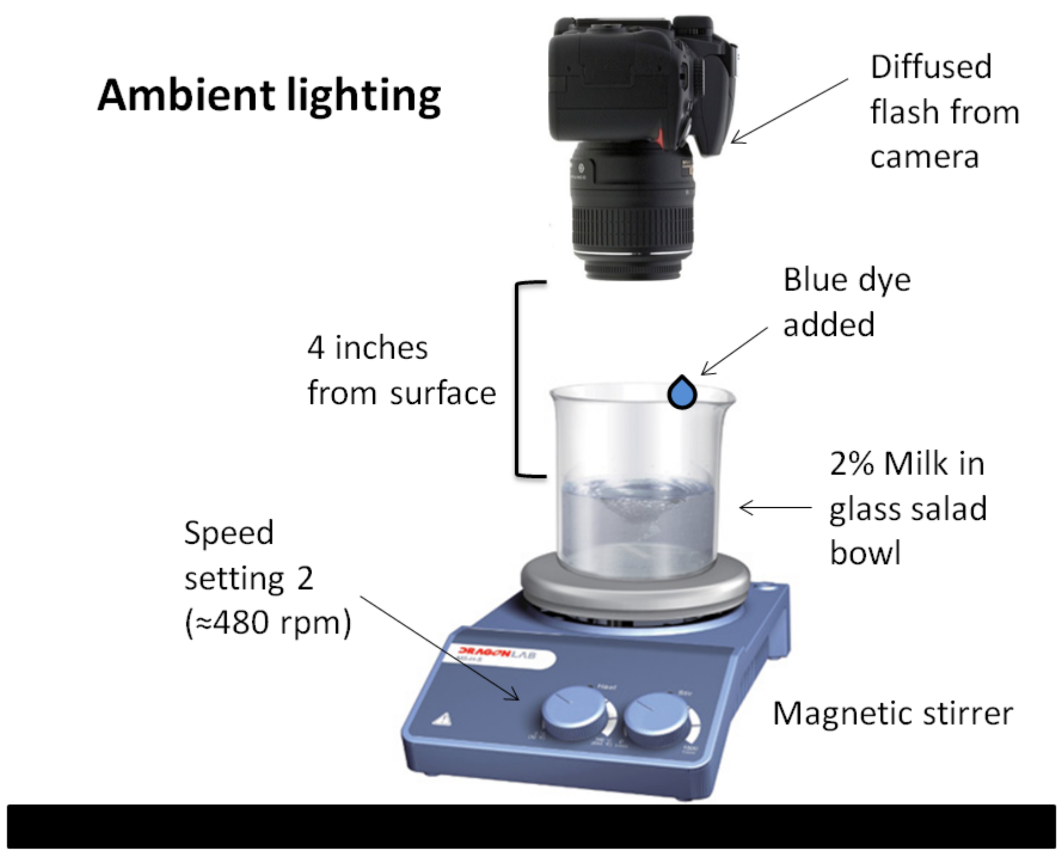

Figure 2: Photographic apparatus

Fluid dynamics and phenomenon:

The primary fluid dynamics presented in this image is that of viscous effects that develop trailing tails at the extremities of the stirring bar. In the image, these tails can be seen more profoundly in the image on the left in which the depth of the milk is slightly less than that of the right. These tails are visible due to milk's great viscosity (1.9×10^{-3} N s/m^2)[2] which causes them to not only be more visible, but actually causes the tails to extend further behind the tips of the stirring bar. These tails develop due to the centripetal forces developed as the stirring bars speed is increased from a resting position. As the bar begins to spin faster, greater forces are applied to the milk and therefore drive the milk at the center of the glass bowl to the sides. The milk that is being driven from the center of the glass bowl is continually being pulled from the center to the outer edges of the glass, yet as the actual shaft of the stirring bar moves from one location to another, the milk attempts to move radially into the center of the bowl driven by the force of gravity. As the shaft of the stirring bar comes back to the location where the milk is attempting to migrate, it is agitated and affected by the centripetal force. This causes the tails to be formed on the tip of the stirring bar. In addition these tails hold their shape as they are pulled away from the tips of the stirring bar because of surface tension of the milk[3]. This surface tension is great enough that the milk tails are formed and retain their shape. When the speed of the stirring bar is increased there is less time between rotations and therefore less time for the milk to migrate towards the center of the bowl. This greater speed would therefore not produce as symmetric and formed tails due to the fact that the centripetal and rotational forces would be greater than the surface tension keeping to tails formed and produce more instability in the tailing effects of the milk. To clearly define the fluid flow characteristics present, the Reynolds number can be calculated. This Reynolds number indicates whether the fluid is considered laminar or turbulent which in turn provides insight into whether there are viscous (laminar) or inertial (turbulent) forces primarily acting on the fluid. The Reynolds number calculation is seen below.

$$Re = \frac{\rho V L}{\mu}$$

- μ = Milk viscosity @ 21 ˚C [2] = 1.9×10^{-3} N s/m^2
- ρ = water density @ 20 ˚C [5] = 1029 Kg/m^3
- L = characteristic length = .508m (2 in)
- V = mean velocity ~ .957m/s

This results in a Reynolds number of 263291, which is greater than the critical value of 10000 where laminar flow translates into unstable turbulence. This indicates that the flow is considered turbulent which can be seen by the instabilities present in the image between. This value demonstrates that the tails produced by the agitation of the milk by the stirring bar is due in part to centripetal forces caused by the rotation of the stirring bar as well as is heighted by the fact that the flow is turbulent and therefore adds chaos to the system by the high Reynolds number.

Finally the velocity used in the Reynolds number calculation was obtained by taking the rpm's for the speed setting of 2, which happened to be 480 RPM. This RPM was then converted to m/s by way of knowing the circumference of the circle developed by the rotating stirring bar. this then resulted in the velocity seen in the calculation.

Photographic technique:

The photographic technique used to make this image was limited due to the use of a Kodak Easyshare Z981 which is in essence a point and shoot camera. The camera saves its pictures in a digital format with a pixel quality of 14.1 megapixels. Though the camera has the option to adjust the exposure time and ISO the two cannot be adjusted at the same time. The selection was made to use a faster exposure time in an effort to obtain a clear image of the milk agitation. The ISO setting was at 200, which seemed to be appropriate for the photograph and additional lighting. The exposure time selected was 1/1600 s, which after experimentation with slower speeds, proved to provided the least motion blue and produced the highest detail. The camera was placed approximately 4 inches away from the milk being agitated by the magnetic stirrer in the glass salad bowl. The original image has a frame size of roughly 2 inches wide by 3 inches tall.

The Post processing of the image was fairly straightforward considering the time spent to produce the desired effect. Originally both image were combined into one image by way of creating a new image in the GIMP software that was double the pixel width of a single image. Each image was then pasted into this frame as an individual layer so they could be edited individually. Through many attempts of altering the curves and the saturation, brightness, etc… it was determined that utilizing the color equalize tool in the GIMP software created the most visually appealing image while maintaining the integrity of the photograph. The equalize command in the software adjusts the brightness of colors in the image so that the histogram for the photographic channel is as flat as possible[4]. This results in the photograph having nearly equal number of colored pixels at equal brightness values[4]. This equalize tool along with a slight adjustment of saturation produced the cover image in which the colors are vibrant and appear in an almost psychedelic manner.

Conclusions:

All in all, I feel this image captured the beautiful effects that are present when milk is agitated as well as shows how something so common can be used to demonstrate the art of flow visualization. Though the particular image is not displaying complexities such as viscous fingering or Rayleigh-Taylor instability, it is demonstrating how a fluid behaves under circular agitation and how trailing rolls of fluid form on the exterior edges of the stirring bar or any other device used to create this agitation. These trailing rolls are my favorite part of the cover image and are particularly appealing in the left side of the image. Though I am pleased with the image there are a few things I would change if I were to attempt this photograph again. One thing I would change would be to utilize post processing techniques that achieved the same effect, yet reduced the graininess of the image. In addition I would try another fluid that is even more viscous then that of water such as pancake syrup or corn syrup. This would be interesting to see how exactly the viscosity of the fluid really effects the fluid flows. One question that I developed while taking the image is why the bubbles that are developed begin at the outer edges of the glass bowl when the agitation is occurring at the center? I believe the answer to this question simply that the centripetal forces caused by the rotating stirring bar drive the air that is being introduced to the edges of the bowl and up the sides as explained in the flow dynamics section. Overall I feel this image fulfills m intentions of having an everyday substance such as milk, demonstrate such interesting and beautiful fluid flows and fluid dynamics.

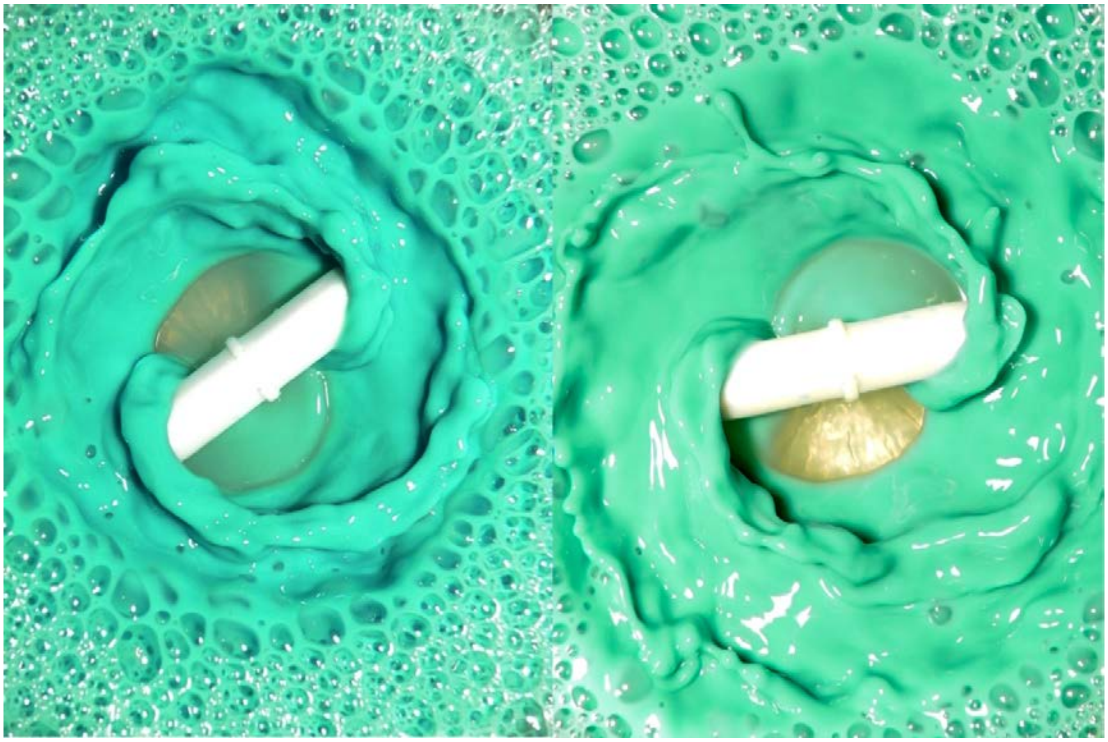

Figure 3: original Image

Bibliography:

[1]"Hotplate/Magnetic Stirrer." *Module*. Web. 24 Apr. 2012. <http://www.uwplatt.edu/chemep/chem/chemscape/labdocs/catofp/mixpour/mixing/hp_ms/hotstir2.htm>.

[2] "Milk (Whole and Skim)." *Brookfield Viscometers, Rheometers and Texture Analyzers for Viscosity Measurement and Control and Texture Analysis.* Web. 25 Apr. 2012. <http://www.brookfieldengineering.com/education/applications/laboratory-milk.asp>.v

[3] Nave, R. "Surface Tension." Web. 19 Feb. 2012. <http://hyperphysics.phy-astr.gsu.edu/hbase/surten.html>.

[4]"8.7.Â Equalize." *GIMP Equalize*. Web. 24 Apr. 2012. <http://docs.gimp.org/en/gimp-layer-equalize.html>.

[5]"Density of Milk." *Hypertextbook.com*. Web. 25 Apr. 2012. <http://hypertextbook.com/facts/2002/AliciaNoelleJones.shtml>.