Vortex Pairing and Surface Tension Induced Flow of Food and Milk

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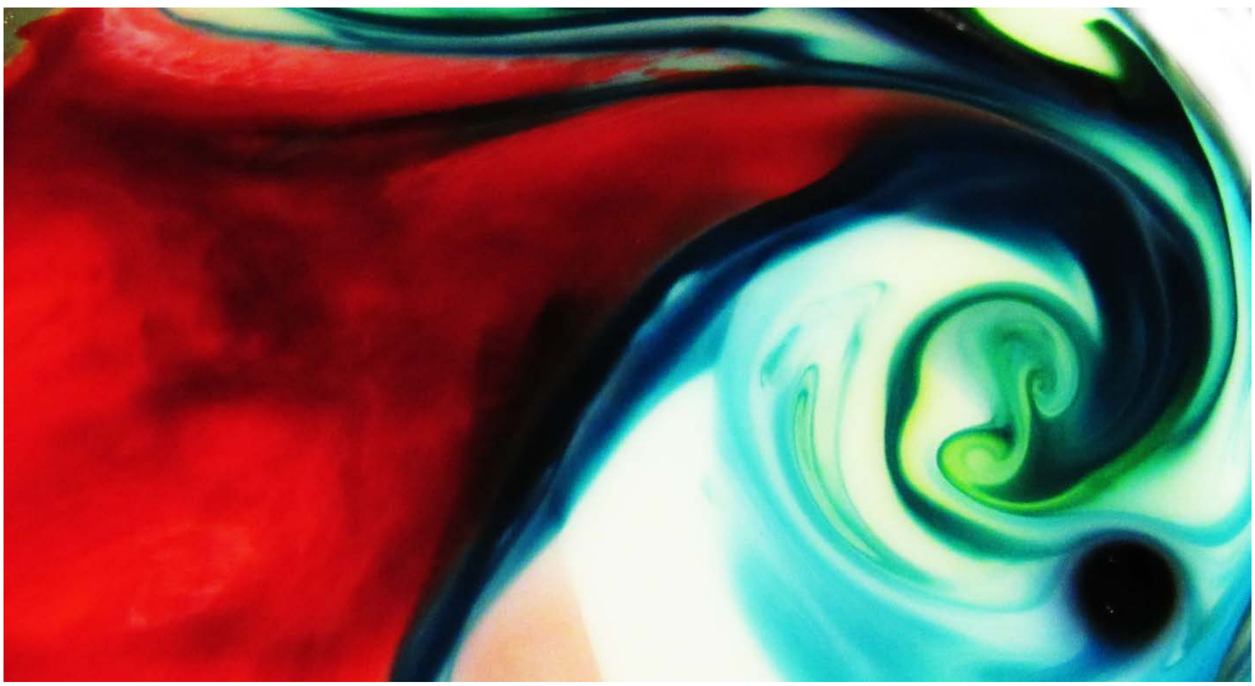

Erick S Pena | Flow Visualization | September 28, 2015

The goal of this flow Visualization is to capture the fluid motion of food dye coloring on top of milk by applying soap and additional forces to the dye. This idea came from looking at pictures on the Flow Visualization[1] web galleries. The movement that created the vortex pairing was from playing and experimenting to create more movement in the fluid.

The setup to create a similar flow visualization photograph is shown by *Figure 1* and *Figure 3*. The small cylindrical dessert cup is a height of 37 mm and a diameter of 72 mm. Milk was poured into the cup at a depth of 21 mm. In *Figure 1* demonstrates the placement of where the Water Gel crystal spheres that were soaked in food dye was placed. Before any drops of food dye were placed, a drop of dish soap was positioned on the top of every sphere. The different colors are from the food dye drops that were paced in certain locations in the cylindrical cup. In *Figure 1*, the colored arrows indicate the direction of where a force was applied. The blue arrows indicate a force on the location of the blue drops of food dye, and the red arrows indicate a force on the red drops of food dye. *Figure 2* shows the color and the diameter of each sphere. *Figure 3* shows the setup of the camera in relation to the cylindrical dessert cup.

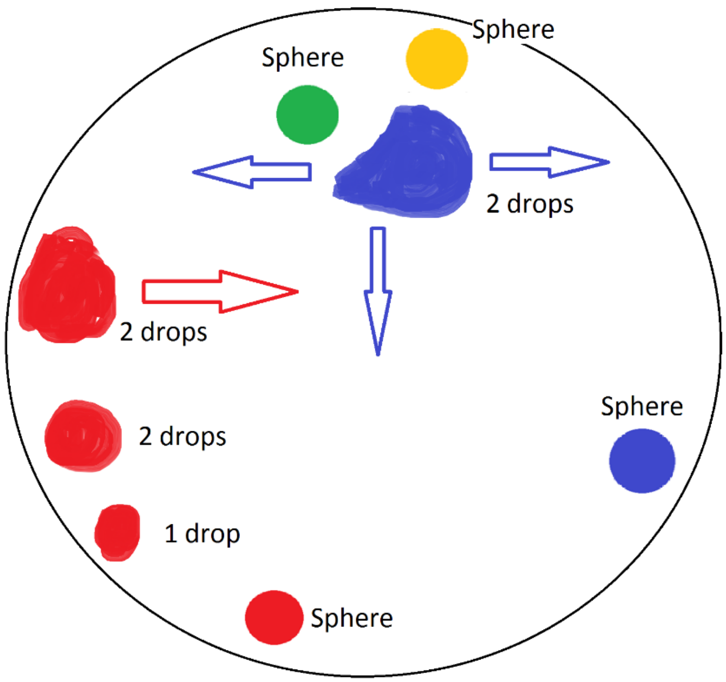

Figure 1: A bird eye view of how the experiment was set up.
The arrows indicate the force direction that was applied to the specific color

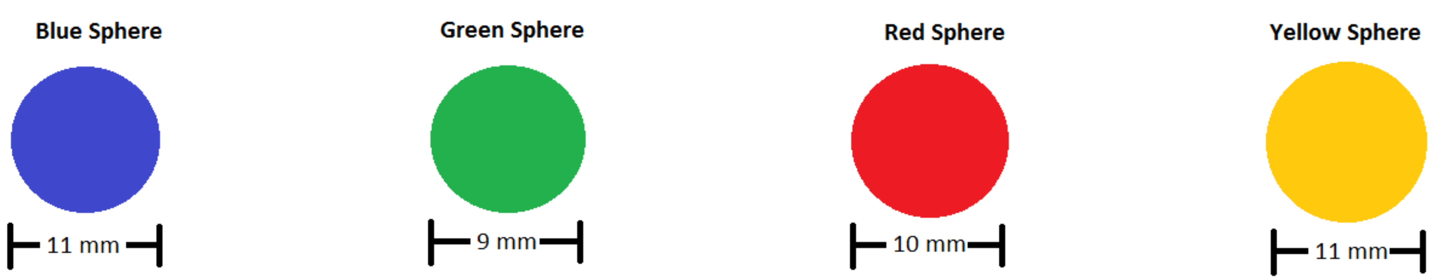

Figure 2: This are the diameter of Water Beads Pearls d'eau (Water Gel crystals) that were placed in the milk.

[1] Course Flow Visualization Website

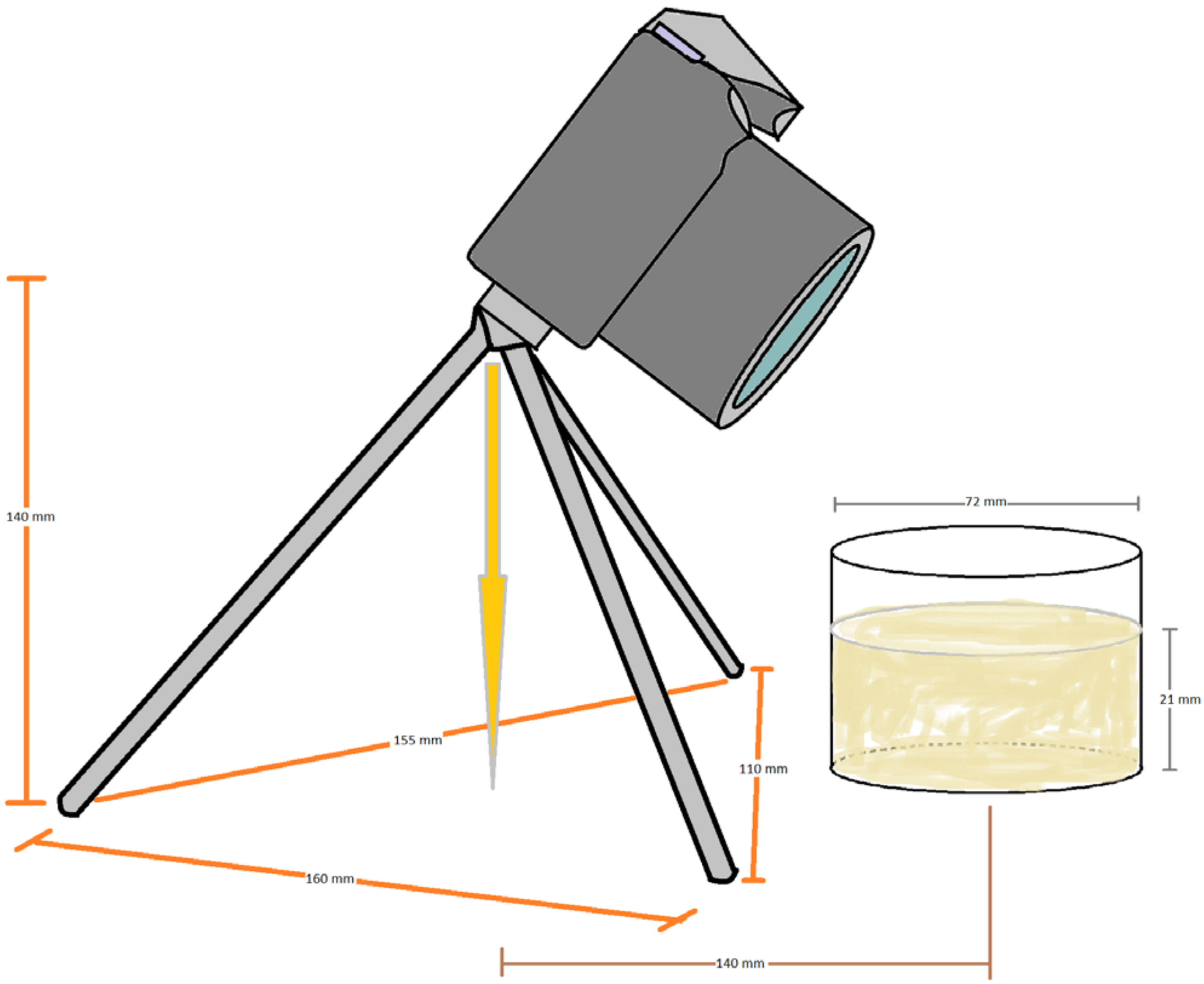

Figure 3: Setup

In the photograph the soap that was applied to the spheres is acting as a surfactant which is a substance that reduces the surface tension of a liquid[2]. As seen on a leaf when a droplet of water is almost spherical, surface tension is a fluid property caused by the attraction of the particles on the surface layer that tends to reduce the surface area. In summary it is an attractive force that holds the fluid together. When the soap is applied to the spheres it reduced the surface tension that kept the color dye together and made it dispersed. Then by applying more food coloring after a few seconds and introducing a force to the fluid a vortex was created. As you can see in the photograph there are two smaller vortex within the larger one, were a vortex is a section where the flow is mostly rotating around an axis[3]. The two smaller vortexes can be classified as vortex pairs which contain of two regions of vorticity that are drifting together as a single body; this is a very important coherent structure of fluid dynamics that appears in a lot of physical areas in nature[4]. You can see this phenomenon in *Figure 4* when a force was applied on the food coloring.

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[2] Definition on google

[3] Vortex definition on Wikipedia (https://en.wikipedia.org/wiki/Vortex)

[4] Barotropic vortex pairs on a rotating sphere by Mark T. Dibattista and Lorenzo M. Polvani, 1998 http://www.columbia.edu/~lmp/paps/dibattista+polvani-JFM-1998.pdf

Figure 4 is where the initial blue dye propagates, moving away from the blue sphere due to the soap that was put on it reducing the surface tension. In the second picture down to the left on *Figure 4* you can see more clearly the vortex pairing once the force was applied. Going on the second picture down to the right you see how quickly the flow dispersed, but it continues to be pushed away from the blue sphere.

Figure 4: time laps of the fluid over a minute

Figure 5 is the original photograph without any photo processing that shows more of the flow due to the surface tension and vortex pairing phenomenon. As you can see on *Figure 4* from the time stamp you only have a few seconds until the fluid flow changes once again.

Figure 6: Original picture (size 4608 X 3456)

Table 1 gives the properties of the fluid that were found on the footnote below. The Re number was calculated by estimating the velocity to be approximately 7 in/s or .1778 m/s and a length that the vortex travels about half of the cylindrical desert cup 36 mm. the diameter of the soap was about 5 mm in diameter which gave us a smaller Re number. To the side of the table is the equation to solve the Re number that was found in Engineering toolbox[5] website.

Table 1: Properties of the Fluid [6] (0.1778 m/s or 7 in per second)

Material	Density (kg/m^3)	Viscosity (m^2/s)	Surface Tension (N/m)	Re #
Food coloring	1002.2	9.97805E-07	0.0728	6.41E+03
Dish Soap	932	0.000001	0.045	8.89E+02
Milk	1033	1.45208E-06	0.0728	4.41E+03

$Re = (\rho u^2) / (\mu u / L)$

$= \rho u L / \mu$

$= u L / v$

Where

Re = Reynolds Number (non-dimensional)

u = (m/s, ft/s)

L = characteristic length (m, ft)

v = kinematic viscosity (m2/s, ft2/s)

This is a list of materials that will be needed to produce a similar photograph as seen on the cover. The instruction to producing a spherical food coloring balls are on the bullet points below.

Materials

- Water Beads Pearls d'eau (Water Gel crystals /Walmart)
- Kroger Food coloring Red, Blue, Yellow, Green
- Black construction paper 8 ½ by 11 ½
- 40 WATT Lamp
- Canon PowerShot SX530 HS
- Dessert cylindrical cup 72 mm in diameter at a depth of 37 mm
- Q tips
- Ziploc bags

Red, Green, Blue, Yellow colored sphere

- Soaked for about 24 hours in pure food coloring.
- Then put in 4 - 5 drops of food coloring in a Ziploc bag (one bag per sphere)
- The concentration of the colored dye made the sphere smaller than the rest of the spheres that I tested in combination with purified water.

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[5] Engineering Toolbox http://www.engineeringtoolbox.com/reynolds-number-d_237.html

[6]

- http://hypertextbook.com/facts/2005/VirginiaAllard.shtml
- https://www.uoguelph.ca/foodscience/book-page/physical-properties-milk
- http://www.engineeringtoolbox.com/absolute-viscosity-foods-d_1827.html
- http://jeb.biologists.org/content/211/2/267.full
- http://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html

All of the photos that were shown are taken inside, with the blinds down, and with a 40 WATT lamp that is directly above the cylindrical desert cup. The settings for the camera were as fallows.

- No flash
- Distance from lens to object: about 80 mm
- Shutter priority
- Exposure Compensation: $-\frac{1}{3}$
- Focal length 6.705 mm
- Aperture f/4
- Exposure 1/30
- ISO: 1250
- Original Dimensions: 4608 X 3456
- Cropped Dimensions: 2728 X 1474

The image reveals a random motion due to a surface tension instability as well as pairing vortex phenomenon when a force other than the soap surfactant is applied on the fluid. I had a lot of fun capturing this image, I would say that I took over 500 pictures for every experiment that I made. From all of the experiments that I tried this one was my favorite. I really like that I can see the fluid physics, and that I was able to capture two phenomenon. One was the pairing vortex and the other was the surface tension instability. What would make this image better is if I could get a lot closer to the fluid to really capture the flow clearly. The direction that I would take to develop this idea further would be to try to measure the velocity that the vortex are created and dispersed into the fluid. As much as I learned from fluid motion, I also learned a lot about my camera and how to take better pictures. I feel more confident that the next fluid photograph will be better than the last. I wanted this picture to look like a piece of art and I believe that I captured it, this photograph reminds me of Starry Night painted by Vincent Van Gogh. I feel that this painter did a good job of capturing fluid visualization in his oil painting.