Visualizing Viscosity in a Slow Moving Fluid

MCEN 5151

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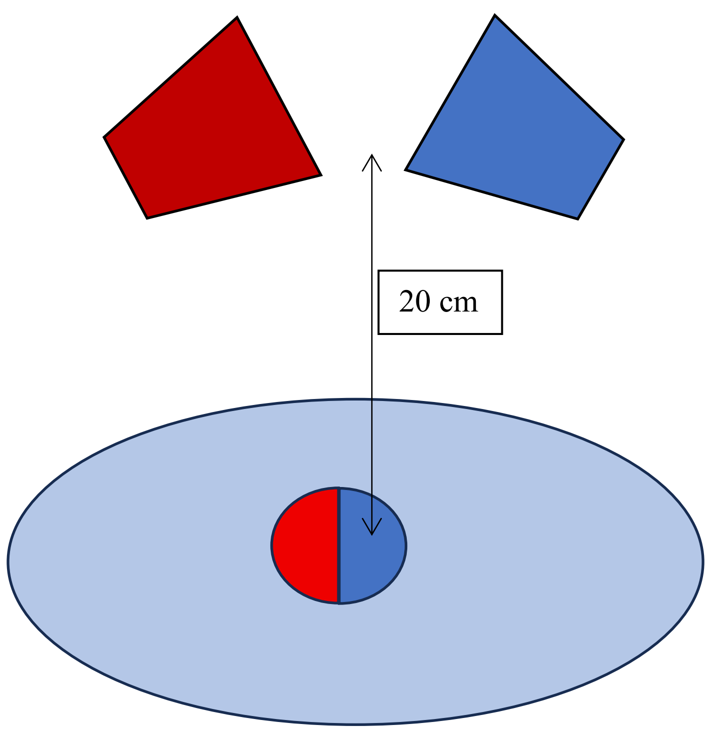
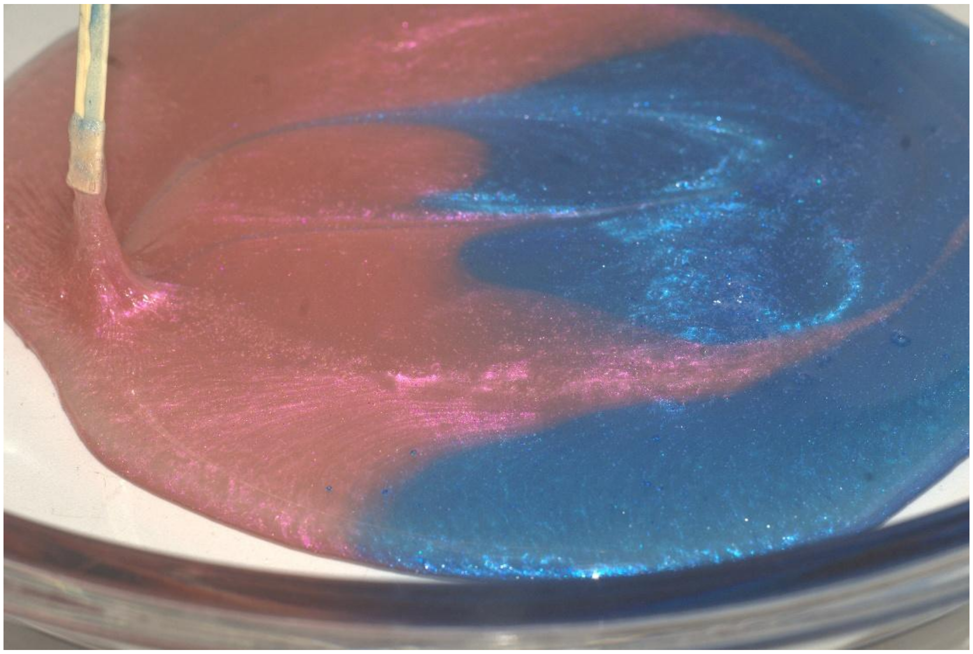
For the Team First project in Flow Visualization I worked with Avery Calloway to explore the mixing of corn syrup with itself. Different colors of mica powder were mixed with corn syrup and then poured onto a flat surface. This was done two different times. The first time, the corn syrup was not quite tinted enough and there was only one color of corn syrup that was poured out. In the second attempt, the corn syrup was tinted red and blue in separate cups and then poured such that the streams impacted a flat glass plate very close to each other. This ended up making a circle that was nearly perfectly split into two halves. To better see viscous mixing, the two halves were mixed with a wooden stir stick. Avery and I split up who was pouring the corn syrup and who what focused on imaging between the two attempts. Avery mixed the two halves while I took pictures after the second pour. Mica powder in this case helped more with the artistic side of the project and only had a slight improvement on the flow visualization; the same physics could be observed with syrup that was simply dyed instead.

The flow apparatus was simply two paper cups that had ~100ml of corn syrup tinted with about 0.9 cm^3 of tinted mica powder in each cup. The syrup was poured from a height of ~20 cm onto a glass dish.



The stir stick that was used to mix the two was approximately 2mmx5mmx15mm. The red part and the blue part were mixed together as can be seen in the original image:



The tapered shape of the mixing shows how viscous forces drag the syrup behind the stir stick. The stir stick was moved relatively slowly at about 1 revolution in 5 seconds with about a 5 cm radius. This gives a velocity of 0.01 m/sec. For the characteristic length, 1 cm is used as that was the approximate thickness of the pool of corn syrup. The Reynolds number is the most useful nondimensional number in understanding the forces at play in this mixing:

$$Re = \frac{\rho U L}{\mu} = \frac{1400\frac{kg}{m^3} * 0.01\frac{m}{sec} * 0.01\, m}{12\frac{N * sec}{m^2}} = 0.012$$

Since Re < 1, it can be seen that viscous effects dominate this flow. Analyzing viscous mixing is important for industry as high viscous liquids like corn syrup are often encountered. Nagata (1957) found that viscosity had a significant effect on how mixing impellers should be designed, favoring small, thin impellers for low viscosity liquids, and large, thick impellers for highly viscous fluids. Kuboi (1985) additionally found that using multiple smaller impellers were favorable as together they required less power than a similarly sized single impeller.

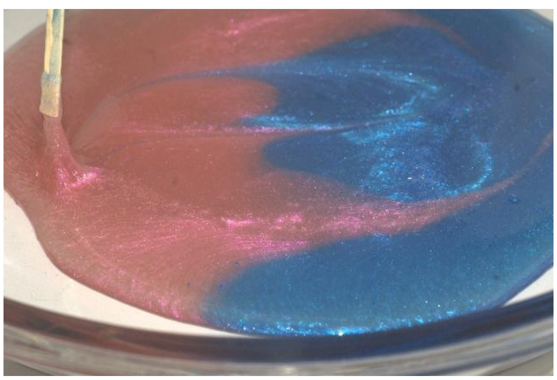
In order to see the mixing of the corn syrup. ~0.9 cm^3 of tinted mica powder was added to ~100 ml of corn syrup per cup. The particles that were used were edible luster dust. By weight, the ingredients are: 86-90% Potassium Aluminum Silicate, 10-14% Titanium dioxide. The gold color was used. The exact product used can be found here:

https://www.amazon.com/dp/B0CTCJZR9H?ref_=ppx_hzsearch_conn_dt_b_fed_asin_title_1. For lighting, the built in flash on the camera was used.

For the photographic techniques, I chose a field of view that would clearly show the flow without having distracting elements. The camera was ~30cm from the flow. The lens is a Helios 44-2 with a focal length of 58mm, but a 16mm extension tube was added to be able to get a better field of view. The camera itself was a Sony α 5100 with a 24.3 MP sensor. The image was captured at 1/160 and ISO 100. The aperture was set to the smallest at F/2 in order to have the largest depth of field. This meant that the flash was needed in order to have enough light. The image's lighting was adjusted in darktable for artistic effect with the following settings:

- Local Contrast:
    - Detail: 458%
    - Highlights:148%
    - Shadows: 29%
    - Midtone Range: 0.444
- Exposure:
    - Black Level Correction: +0.0171

The original image had a resolution of 6024x4024 and was exported at 1300x900 for flowvis.org.




The image reveals how viscous forces drag a fluid as it is moving. I like how I edited the image to be compelling artistically while still maintaining the fidelity of the physics at play. I wonder if there are governing equations as to the shape of the swirls and their thickness compared to distance from the parent fluid.

NAGATA, Shinji; YANAGIMOTO, Masamichi; YOKOYAMA, Tōhei. Studies on the Mixing of High Viscous Liquids. Memoirs of the Faculty of Engineering, Kyoto University. 1957, 18(4): 444-460.

R. Kuboi, A.W. Nienow, Intervortex mixing rates in high-viscosity liquids agitated by high-speed dual impellers, Chemical Engineering Science, Volume 41, Issue 1, 1986, Pages 123-134, ISSN 0009-2509,