MCEN 5151: Flow Visualization

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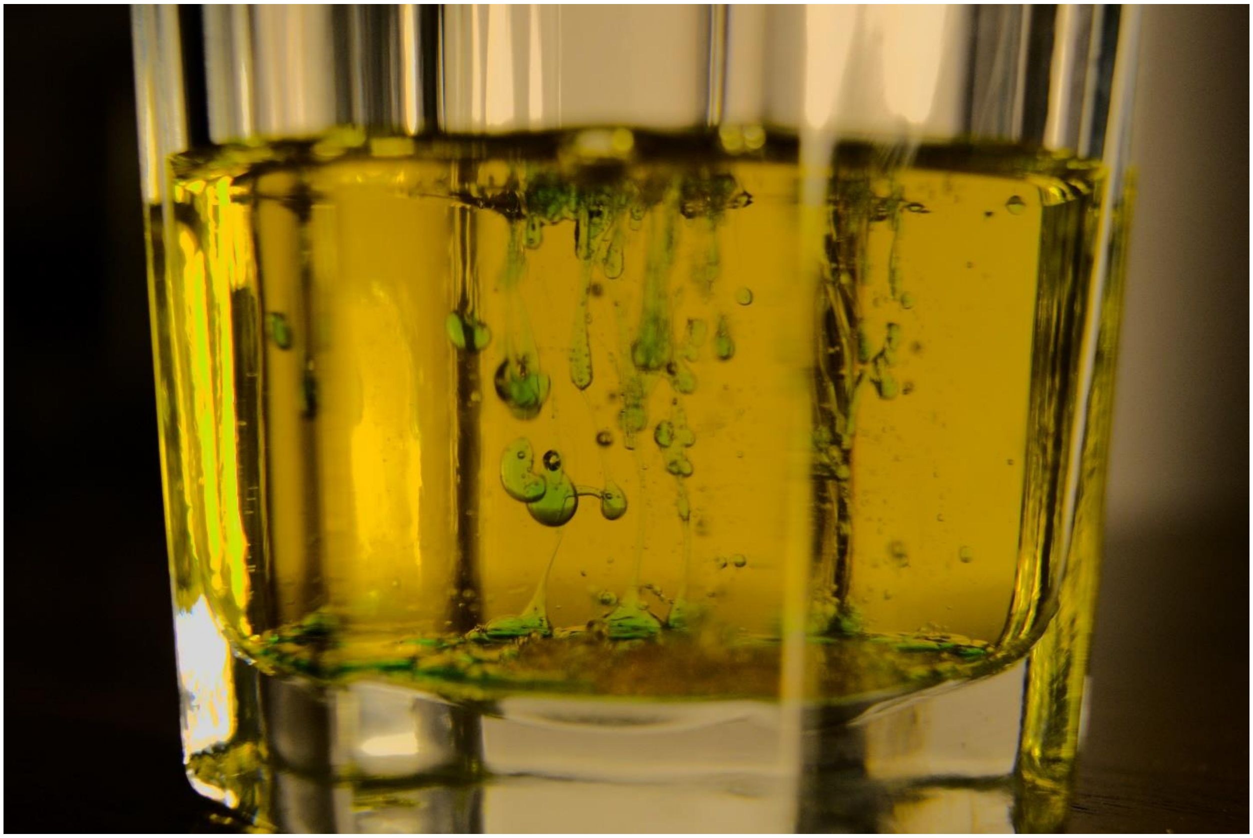

Flow Visualization 3rd Assignment

Purpose

The motivation for this image was to try to create and photograph of the interaction to two immiscible fluids. In this case I decided to photograph dish soap falling through olive oil. I was interested in observing how droplets of soap fall through the oil, for example, the speed at which it falls and the shape and trail of the droplets. The report attempts to describe how the picture from the previous page can be recreated.

Visualization Techniques:

Materials:

- Trader Joes Extra Virgin Olive Oil
- Dawn Blue Dish Soap
- Target Tremont Tall Drinking Glass

Imaging Technique:

Camera: Nikon D3300

Image Size: 5232 x 3482

Focal Length	Exposure	f/	ISO
38 mm	1/50	5.6	200

To take the picture I rested my camera on the table, slightly less than a foot away from the glass, and adjusted the angle by hand. I could get a clear image because I used a high shutter speed. I used a bight lamp behind a wall of standard printer paper to diffuse the light and to avoid creating glare on the glass. I placed the light only to one side of the glass so that there is light on one side of the glass and dark on the other side.

After the photograph was taken, I did some post processing using darktable. My primary goal for most photographs has been to avoid editing too much. I try to make the photographs maintain a realistic look while highlighting the important flow features. I this case I made the yellows and greens brighter. I also made the background a bit darker. The purpose of this was to increase the contrast between the foreground and background. I also rotated the image slightly to improve the alignment between the edges of the glass and the edges of the glass.

Flow Apparatus:

The flow apparatus was very simple for this project. I took a container of dish soap (in a squeeze bottle) and released several droplets into the glass of olive oil. As previously stated, to avoid glare, I kept my light source behind paper, which effectively diffused the light. I also played with light placement, i.e., light source only on one side vs multiple sides, ultimately choose to place a light source only on one side.

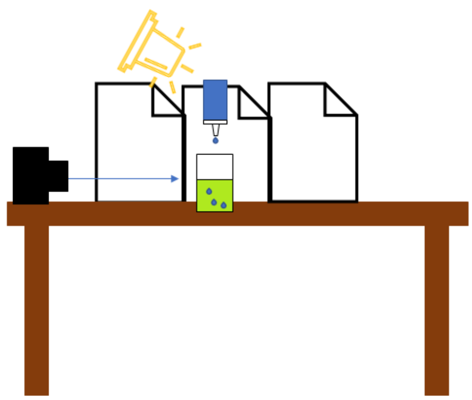

Figure 1

Flow Dynamics:

The phenomenon demonstrated in the image is related to the density and viscosity of the two fluids.

Droplets of soap landed in the olive oil and began to slowly fall. Some of them retained a spherical shape, others a teardrop shape, and there were some which took on more warped shapes similar to a kidney bean. Many of them had long thin tails trailing behind them.

The first round of analysis for this experiment was to look at the Reynolds number.

$$Re = \frac{\rho u x}{\mu} = \frac{8.95 \times 10^{2}\ (kg/m^{3}) \times 10^{-3}(m/s) \times 10^{-2}(m)}{8.4 \times 10^{-4}(kg/ms)} = 10.92$$

Here the soap flows at a velocity on the order of millimeters per second; the characteristic length is on the order of centimeters; the density of olive oil is about 895 kg/m^3 [1] ; the viscosity is about 0.00084 kg/ms [1]. So, this is a low Reynolds number flow. This supports what was observed as I was photographing the flow.

Soap and oil are often thought of with the context of water and cleaning. Soap contains both a hydrophobic end and a hydrophilic end[2]. While oil is purely hydrophobic. The soap molecules can break apart large regions of oil and pull the oils into the water region. It helps the two immiscible fluids mix. This is why soap is useful for cleaning. And removing oils from dishes.

In this experiment, I was purely interested in the interaction between oil and soap. Since the two were mixed with a small ratio of soap to oil it was interesting to see the soap maintain its shape. The primary force helping the soap maintain its shape was surface tension:

$$\gamma = \frac{F}{2L}$$

The general equation for surface tension measures force per unit length. The length used for a bubble is the circumference.

Buoyancy and Gravity were the driving forces causing the drop to fall. Because the two fluids have similar density the buoyant force has an important roll. The Buoyant force on the soap drops is given by the following equation:

$$F_b = V\boldsymbol{\rho}_{\boldsymbol{oil}}\boldsymbol{g} = (\mathbf{10^{-3}})^{\mathbf{3}}(\boldsymbol{m}^{\mathbf{3}}) \times (\mathbf{895})\left(\frac{\boldsymbol{kg}}{\boldsymbol{m}^{\mathbf{3}}}\right) \times (\mathbf{9.81})\left(\frac{\boldsymbol{m}}{\boldsymbol{s}^{\mathbf{2}}}\right) = \mathbf{3.7} \times \mathbf{10^{-5}}\boldsymbol{N}$$

Here V is the volume of displaced oil (the volume of a bubble), **ρ** is the density of the oil, and g is acceleration due to gravity.

The density of soap is similar – around 1060 kg/m^3 [3]. So the force of gravity acting on the soap is:

$$F_g = V\boldsymbol{\rho}_{\boldsymbol{s}}\boldsymbol{g} = (\mathbf{10^{-3}})^{\mathbf{3}}(\boldsymbol{m}^{\mathbf{3}}) \times (\mathbf{1060})\left(\frac{\boldsymbol{kg}}{\boldsymbol{m}^{\mathbf{3}}}\right) \times (\mathbf{9.81})\left(\frac{\boldsymbol{m}}{\boldsymbol{s}^{\mathbf{2}}}\right) = \mathbf{4.3} \times \mathbf{10^{-5}}\boldsymbol{N}$$

Here $\boldsymbol{\rho}_{\boldsymbol{s}}$ is the density of the soap. The difference between the buoyant force and force of gravity along with the drag force will cause the drops to fall slowly – with the downward acceleration closer to 1 m/s^2 rather than 9 m/s^2.

Results of Final Image and Revelations:

I was happy with the results of this image. I think in the end the choice of colors worked out well. I also think that the shapes of the soap droplets were artistic, especially since there was a variety of shapes and sizes. I had fun doing this experiment and was pleasantly surprised at how the images turned out.

Works Cited

1. Sarjadi, M. S., Ling, T. C., & Khan, M. S. (2019). Analysis and comparison of olive cooking oil and palm cooking oil properties as biodiesel feedstock. Journal of Physics: Conference Series, 1358(1), 012007. https://doi.org/10.1088/1742-6596/1358/1/012007
2. How does soap work? ChagrinValleySoapAndSalve.com. (n.d.). Retrieved November 27, 2021, from https://www.chagrinvalleysoapandsalve.com/blog/posts/how-does-soap-work/.
3. Seven-layer density column - science experiment. The Lab. (2021, July 26). Retrieved November 25, 2021, from https://www.stevespanglerscience.com/lab/experiments/seven-layer-density-column/.