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Flow Visualization: Team First
MCEN 5151
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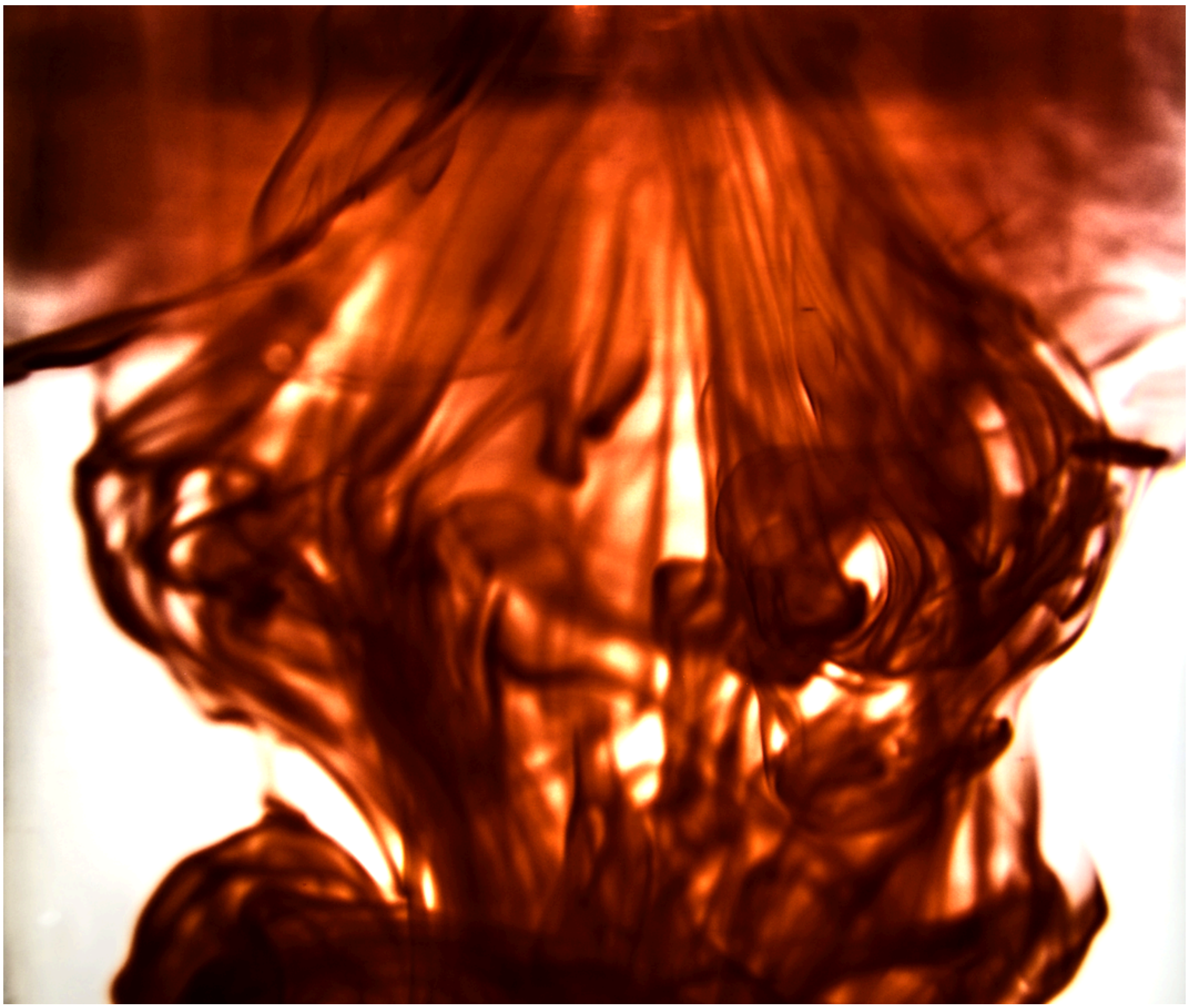

For the first team assignment of this course, I worked with Cort Sommer to capture the diffusive effect of using a whisk to fix two liquids. To do this, we dropped dye into water, and then influenced the water from above with a standard kitchen whisk. I intended for this photo to well illustrate the diffusive effects that whisk creates, as well as to create an artistically-pleasing image. Additionally, this was my first time utilizing my camera, so I hoped to gain experience using it and learning its different settings.

We created our set-up by first propping the camera on several boxes and books, so that it was level with where our fluid interaction was occurring, and faced toward the glass mug we used as a vessel. We used both of our computers as lighting and backdrops by propping them up and taping white paper over a bright screen setting. This allowed us to have a plain white background with diffusive lighting. We then filled the mug with water and took turns dropping drops of dye into the fluid to focus the camera. Once the camera focus was set, we took our photos by dropping different colors of dye into the water and whisking the water from above.

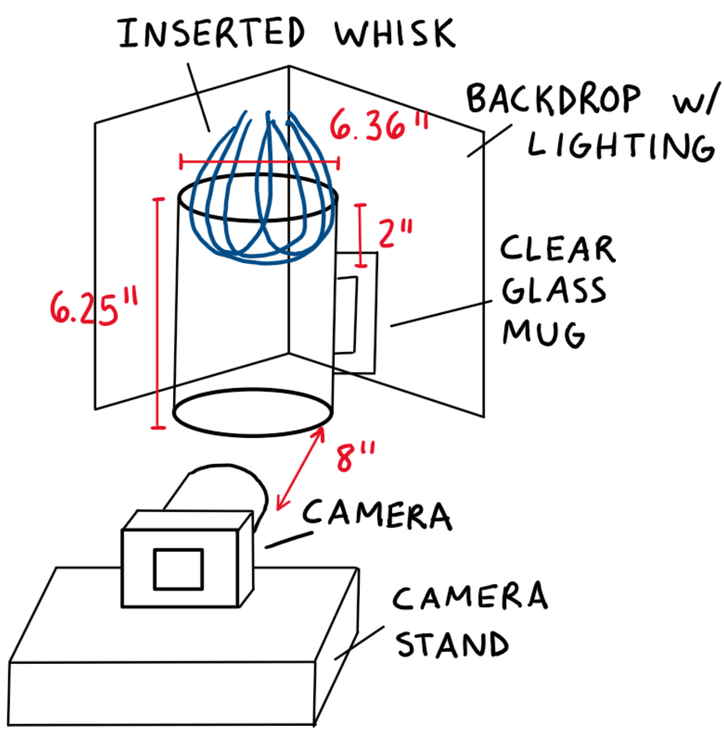

Fig.1. Set-Up Schematic

The fluid phenomena can be examined by first noting that the dye is pulled upwards into the diffusize area by the whisk. Further down in the image, the dye continues to fall. The very top of the image contains the diffusive area, where the whisk is causing the dye to mix with the water. Because diffusion a slow process, the whisk is not actually causing the dye to diffuse, but is rather speeding up the diffusion process. This demonstrates the apt usage of the whisk to increase the mixing time of the two fluids. A whisk would be classified as an intrusive flow agitator, but the set-up used to photograph this flow is a non-intrusive method, and could be used ot further calculate the mixing time of the fluid if desired[1]. Additionally, both the water and dye have similar densities, with the density of water being 1.0 g/mL and the density of the dye being approximately 1.14 g/mL. These similar densities allow for an ease of mixing.

A Reynold's number was calculated for the dye moving upwards towards the diffusive area. The speed of the dye in this area was approximated to be 0.02m/s and a characteristic length of 2in, or 0.0508m, was used. This characteristic length was based off of the approximate length of the upward's moving section of the dye plume. Using these estimates, other known fluid properties, and Equation 2, the Reynold's number for this section of the flow was found to be 1158. This means that this section of the flow would be classified as laminar flow. This would make sense because the flow here is generally smooth as it transitions to the upper diffusion area.

As the dye enters the diffusion area, the Reynolds number would be expected to increase due to the increased fluid speed from the whisk. This increased speed would change the flow from laminar to turbulent, and is the reason that whisks are so effective at mixing liquids. This fluid system is a macroscale mixing system, where the effect of inertia on diffusion is significant. A Reynolds Number greater than 100 indicates that inertia plays a role in the mixing of the system[4]. This inertia is a result of the whisk and its mixing effect on the fluid, and makes sense that it would have a considerable affect on the fluid.

To visualize this flow, we used vibrant dyes against a well-lit white backdrop. The mug had a diameter of 6.36 inches, was filled to approximately 6 inches, resulting in a volume of tap water of $190.6\ in^2$. The dye used was red "Market Pantry Food Coloring & Egg Dye", and 3 drops were placed for this experiment. The whisk was from the brand "Thyme & Table", and had a width of 2.75 inches in its thickest section. The whisk was submerged approximately 2 inches into the water, where it was slowly rotated above the dye. We began rotation after the dye had fallen to the camera's height, which took 2-3 seconds. We created diffusive lighting by utilizing a plain white screen on our computers, with white paper taped over. Both computers were turned onto full brightness. We also had all overhead lights on their full setting in the room where the photograph was taken.

This fluid motion was captured on my Nikon D80 camera with an ISO of 100, a shutter speed of 1/10, and an aperture of F5. This was taken with an 18-135mm lens with a focal length of 50mm. The field of view is almost exactly equal to the width of the mug, and is approximately 6inches wide, by approximately 5.5 inches tall. The flow phenomena was approximately 8 inches from the camera lens. The original image before cropping and post processing is shown below.

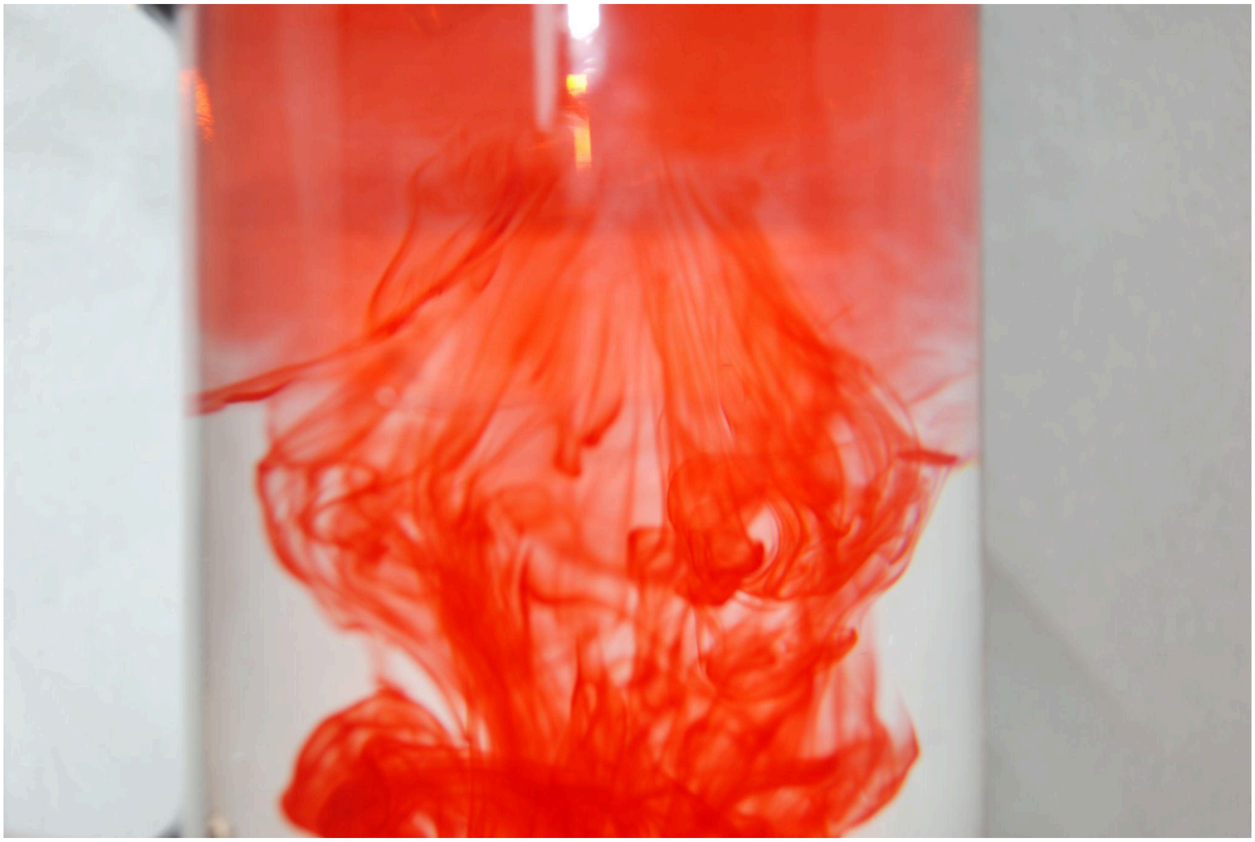

Fig. 2. Original Image for Team First

The original image had pixel dimensions of 382x2592 and the post-processed image had pixel dimensions of 2359x1991. During post-processing I cropped the image, altered the image using Darktable's "color balance rgb", altered the sigmoid, increased the contrast, and altered the tone and rgb curve. This was my first time experimenting with image post-processing, so several of these alterations were done in an experimental manner. My primary intent with post-processing was to increase the flow's saturation to allow for better visibility.

Overall, this image reveals the diffusive effect of using a whisk to mix fluids of similar densities. The image allows the user to see how a fluid can be pulled into diffusion by the whisk, and the resulting increased diffusive effect. I like how well this image shows the physics behind mixing using a whisk, along with the image aesthetics. In particular, I enjoy that the image has symmetry both horizontally and vertically. I feel that I have fulfilled my intent with this image, by capturing the diffusion that whisks enhance, learning how to use my camera and post-processing, and creating a visually-pleasing image. Now that I have photographed this image, I am curious as to what diffusion and mixing would look like with two fluids of different densities using a whisk. If I were to develop this idea further I would explore the diffusion of liquids of different densities or explore the application of different types of whisks, such as a bread whisk.

REFERENCES:

[1]Ascanio, G. (2015). Mixing time in stirred vessels: A review of experimental techniques. *Chinese Journal of Chemical Engineering*, *23*(7), 1065–1076. https://doi.org/10.1016/j.cjche.2014.10.022

[2]*Color versus Concentration*. (2021). Robert Koch Industries. https://www.kochcolor.com/PDF%20Collection/2000-TDS/2532-tds-v6e.pdf

[3]Engineering ToolBox. (2004). *Water - Dynamic and Kinematic Viscosity*. Engineeringtoolbox.com. https://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html

[4]*Microfluidic Mixing Synonyms*. (2016). Micro/Nano Engineering Laboratory. https://ocw.mit.edu/courses/2-674-micro-nano-engineering-laboratory-spring-2016/f28f8672e6386d65276d2e6776ae8611_MIT2_674S16_MicrofluidcMix.pdf

APPENDIX:

A. Calulations
   a. General Properties, Assumptions, and Notes:

Property (With reference #)	Name	Value
$\rho_{water,\, 20\circ C}$	Density of water	1g/mL
$\rho_{dye,\, 20\circ C}$ (2)	Density of red 40 dye	1.14 g/mL, 1140 kg/m^3
$U_{dye,1}$	Velocity of dye	0.02 m/s
L	Characteristic length of the system	2 in = 0.0508m
$\mu_{dye,\, 20\circ C}$ (3)	Dynamic viscosity of	0.0010005 Pa*s

	dye	
D	Diameter of mug	6.36in = 0.162m
r	Radius of mug	3.18in

Assumptions:

- The experiment was conducted at room temperature, which can be approximated as $20°C$
- The experiment was conducted at 1atm and the atmospheric pressure does not have a significant effect on the droplet's fall through the mug
- The acceleration of gravity is $9.81\ m/s^2$
- The dynamic viscosity of food dye is approximately that of water
- The characteristic length of the system where the dye moves upwards is assumed to be approximately 2in, or the approximate height of the upwards dye plume

Notes:

- The approximate speed of the dye was estimated for the dye traveling upwards into the diffusive area

b. Volume Calculation:

Equation 1:

$$V = \pi r^2 h$$

$$V = \pi(6.36/2)^2(6)$$

$$V = 190.6\ in^2$$

c. Reynold's Number Calculations:

Equation 2:

$$Re = \frac{(\rho_{dye,\,20°C})(U_{dye})(L)}{\mu_{dye,\,20°C}}$$

$$Re = \frac{(1140\ kg/m^3)(0.02\ m/s)(0.0508 m)}{0.0010005\ Pa*s}$$

$$Re = 1158$$