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Flow Visualization
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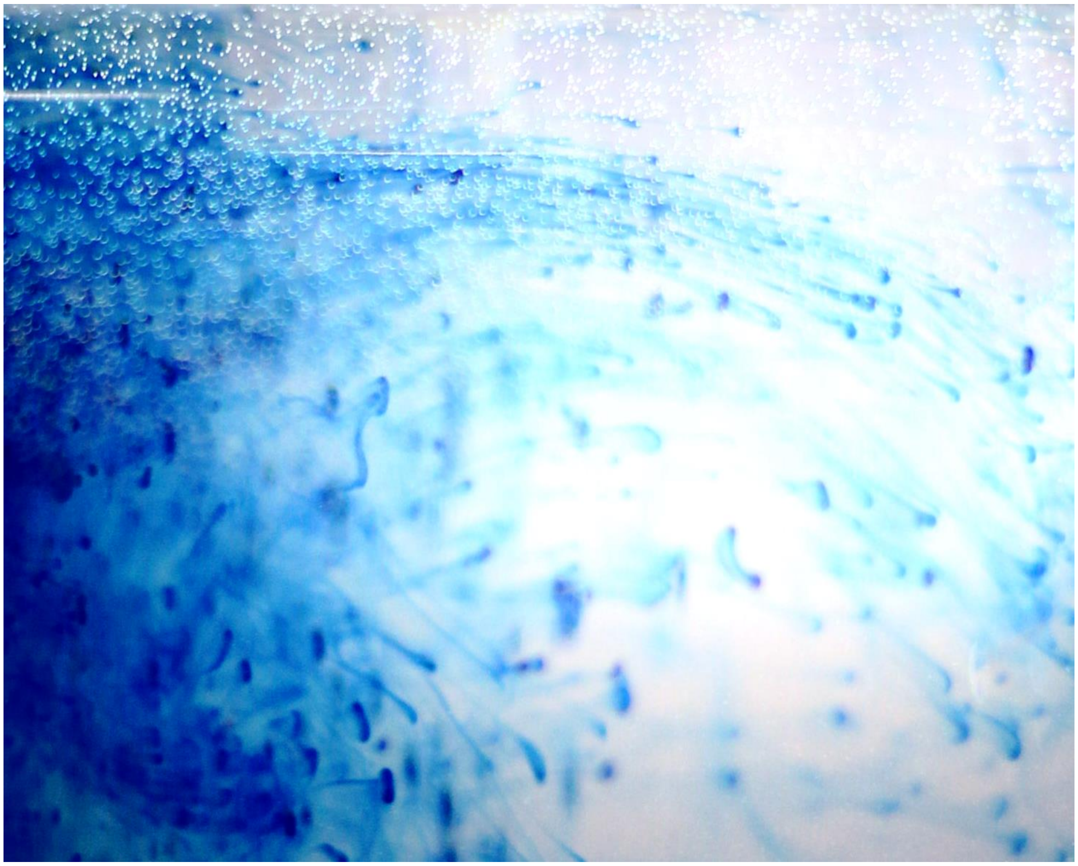

# Blizzard Billows

*Figure 1. The final image from Team Third*

Team Third Report
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A myriad of interesting properties can be exhibited using  simple oil, water, and food dye. Our team's intent was to explore new features using everyday materials. We wanted to practice laboratory photography setup and shooting. Behind the scenes, we were testing different backgrounds and lighting situations, as well as different methods of pouring the oil into the water. Appreciation goes out to the whole team; we each played a part in making this happen. Special thanks goes to Philip Nystrom for taking the lead on this particular project. Not only did he keep the project simple and accessible, he supplied the camera as well.

The flow apparatus used was a large 4L glass beaker. Water was first poured in, then some colorless oil. A condiment squirt container was used to mix oil and red dye, while a small 500mL beaker was used to mix oil and blue dye (See Fig. 2). The blue dye and oil mixture had perceptible droplets while the red one appeared well-mixed (note that oil cannot mix with food dye; the red droplets were too small to be visible). This was important because the blue food dye did not linger as long in the oil mixture and sunk below the water/oil interface. This aspect is what is seen in the image. Approx. 1 mL of food dye was put into each container. The squirt container was sealed by thumb and shaken vigorously at about 4 cycles per second for about 8 seconds, while the fluids in the beaker were stirred at 4 cycles per second for 25 seconds. Although the blue dye and oil was stirred for a longer duration, the red dye and oil was shaken with a higher amount of energy input. From these characteristics, a Weber Number can be estimated. The Weber Number is a non-dimensional number that estimates whether droplets form in an interface between two different fluids (Arnold Frohn). It can be thought of the ratio of kinetic energy to surface tension energy. Higher Weber numbers lead to smaller droplets. As seen in the analysis below, the stirred mixture had a lower Weber

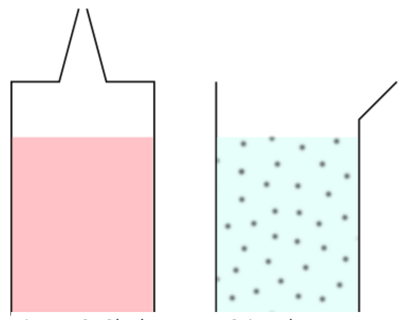

*Figure 2: Shaken AND Stirred oil/food dye mix.*

GOVERNING EQUATIONS:

$$We = \frac{E_{kin}}{E_{surf}}$$

$$E_{kin} = \frac{\pi \rho l^3 U^2}{12}$$

$$E_{surf} = \pi l^2 \sigma$$

VARIABLES:

| *Symbol* | *Description* | *Stirred Result* | *Shaken Result* |
|---|---|---|---|
| $We$ | Weber Number | **2.4E-4** | **3.47E-10** |
| $E_{kin}$ | Kinetic Energy | 1.32E-2 nJ | 1.93E-8 nJ |
| $E_{surf}$ | Surf. Tension Energy | 55 nJ | 55 nJ |
| $\rho$ | Oil Density | 0.92 g/cm$^3$ | 0.92 g/cm$^3$ |
| $l$ | Droplet Diameter | 7.0E-4 m | 2.0E-5 m |
| $U$ | Mixing Velocity | 4.0E-1 m/s | 1.0E-1 m/s |
| $\sigma$ | Surface Tension | 3.6E-2 N/m | 3.6E-2 N/m |

*Figure 3: Governing Equations, Variables, and Results*

number. The droplet diameter was estimated from memory: On average, the blue diameter was about 0.7mm and the red diameter was smaller than the human eye could see, so about 0.02mm (Wong). The velocity was estimated from the length that the bottle was shaken through, and the average speed of the blue fluid while being stirred. Surface tension was approximated by the interfacial tension between water and oil, which is approx. 36mN/m. (F. Peters)

We used a gallon of canola oil bought at Costco as well as the dye. We used standard red and blue food dyes. About 1mL of food dye was used per 200mL of oil. Water came from tap. The visualization technique involved much experimentation with professional-grade lights, although we found that a simple cellphone flashlight would do the trick: glare was reduced significantly and the light could be held in close proximity. This photo was taken under ISO 2500, an aperture of f/1.8, and an exposure time of 1/60 sec. These settings were achieved via Aperture Priority exposure program on -0.7 exposure step. The focal length was set to 50mm. Having a short lens amounted to a very low aperture setting, allowing for more light to enter the image sensor: a short exposure time was able to capture a well-resolved image through time with little light. The image shown was rotated 90 degrees clockwise, as shown in Figure 4.

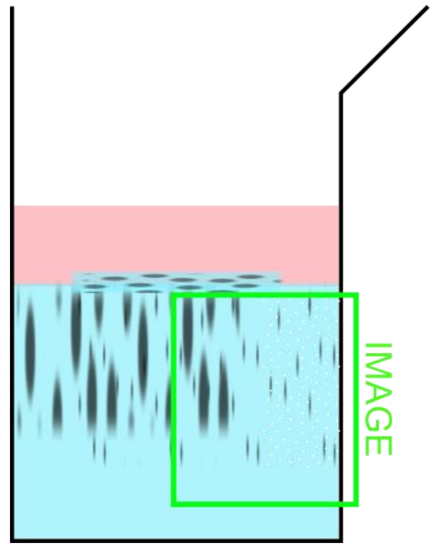

*Figure 4: A diagram of the setup*

The field of view is estimated to be about 10 cm. This was provided by the scale of the smartphone in the original image (Fig. A1). The camera was about 0.5m away from the image (Fig. A2). The camera was focused on the white specks (which are miniscule bubbles stuck to the beaker) but not on the dye itself. This may have been due to the aberration caused by the beaker and water refraction. Unfortunate as this may be, it does play into the idea that the image represents a cloudy sky with flocks of birds (the bubbles). Post-processing was done in GIMP: The original image was 5472x3648 or 20MP, so a lot to work with. It was cropped down to 1181*1476 and rotated, then color balance settings were applied as well as brightness/contrast (See Fig. A3). When editing the brightness and contrast, I like to start with "Brightness/Contrast…" then edit settings as Levels then edit as Curves if needed. This allows me to start simple then fine-tune the brightness/contrast histogram.

As mentioned, I tried to portray a feeling of a turbulent storm moving in and birds flying away. I am pleased that one can see miniature vortex rings. They look like some sort of jellyfish. Further experimentation could lead to sharper images with the dye being in focus. In class, there were varying opinions on how the colors turned out, but many students agreed that the focus could improve. I enjoyed the colors and was saved by the Color Balance tool. In conclusion, the abstract forms create a whole aesthetic using simple elements.

# Works Cited

Arnold Frohn, Norbert Roth. "Dynamics of Droplets." *Springer Science & Business Media* (2000): 15-. Online.

F. Peters, D. Arabali. "Interfacial tension between oil and water measured with a modified contour method." *Colloids and Surfaces A: Physicochemical and Engineering Aspects* (2013): 1-5. Web Version.

Wong, Yan. "How small can the naked eye see?" 24 January 2016. *Science Focus: The online home of BBC Focus Magazine.* 7 May 2018.

# Appendix

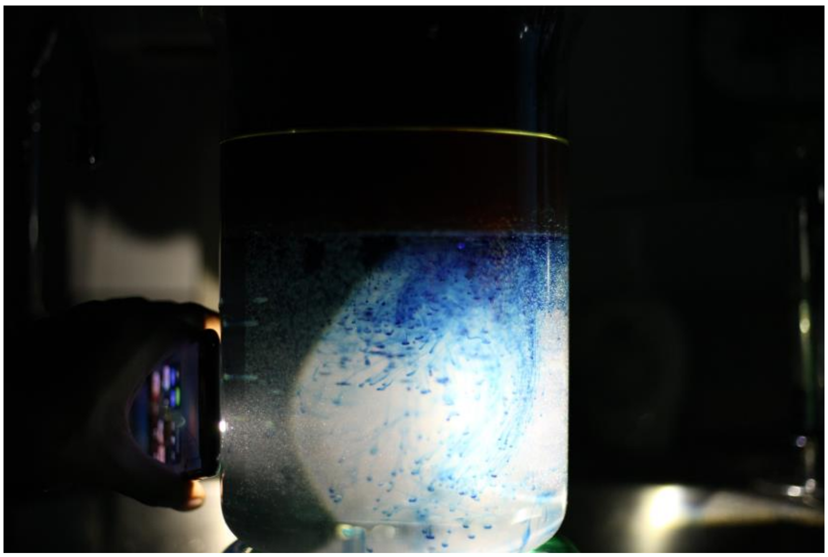

*Figure A1: Original Image*

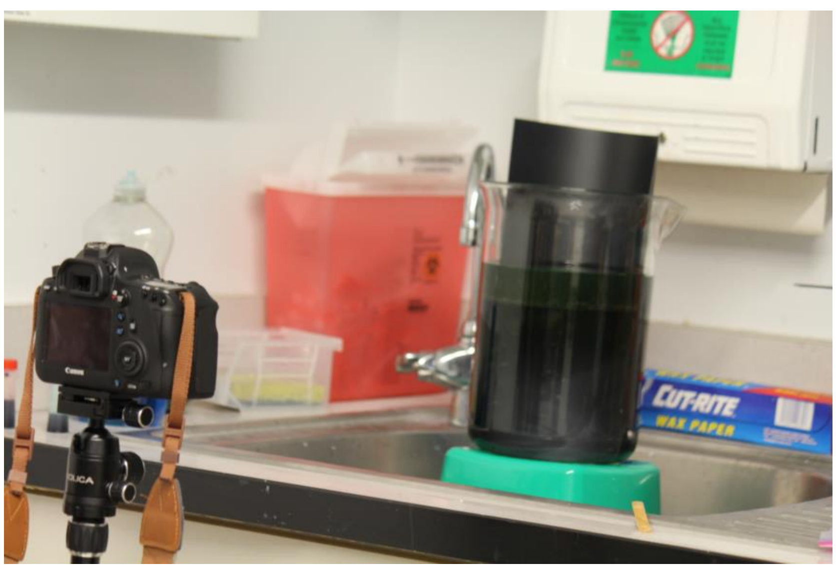


*Figure A2:Photography Setup*

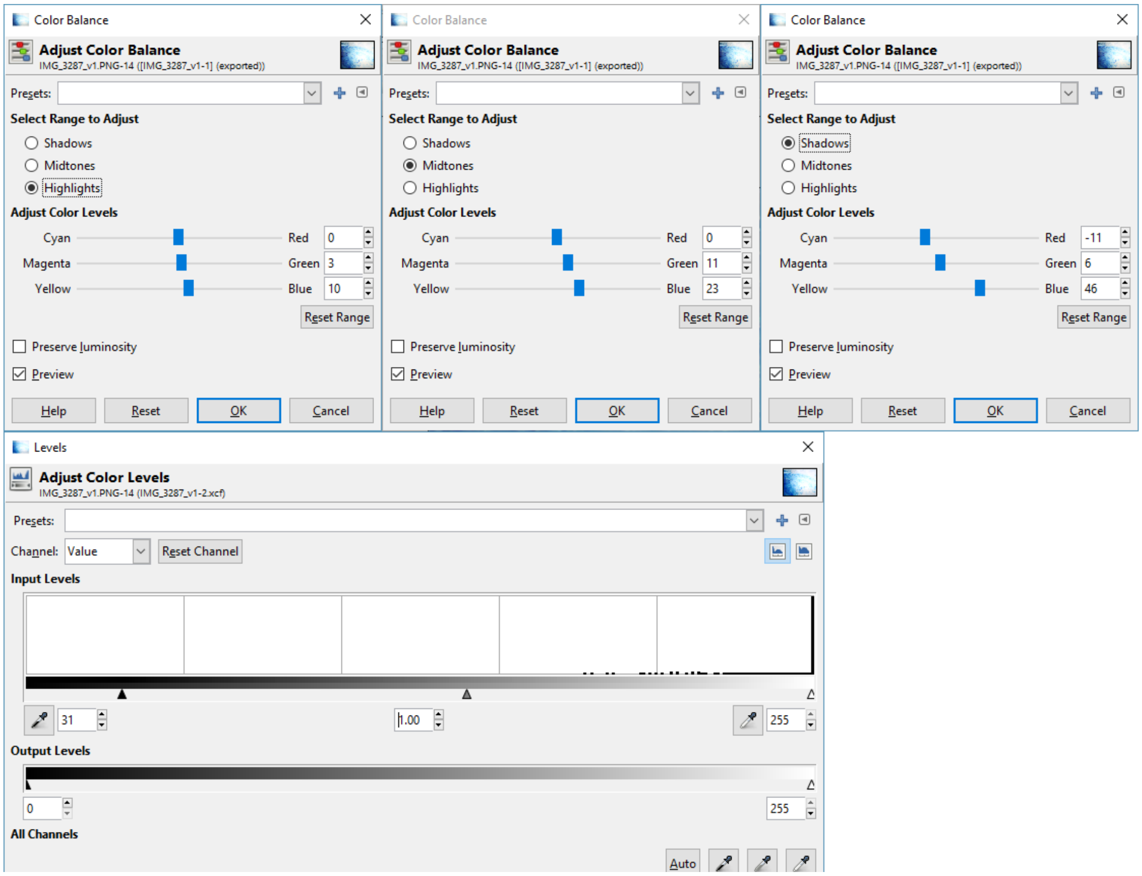


*Figure A3: GIMP Editing*