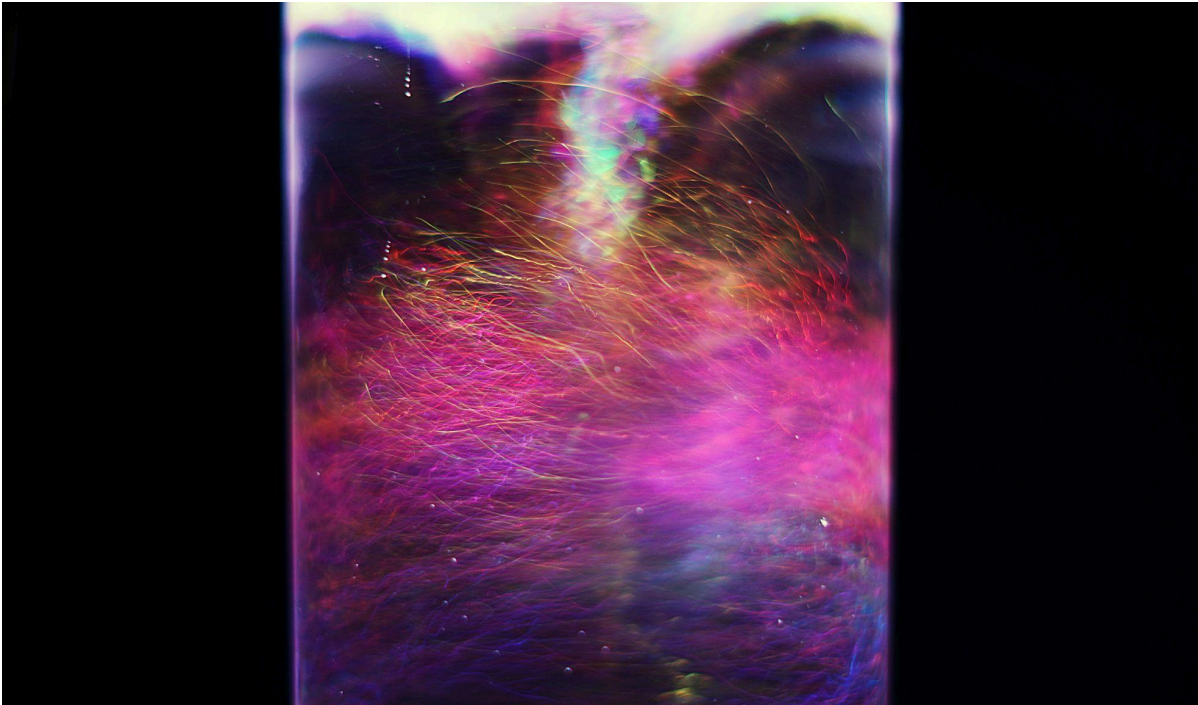


Flow Visualization: Get Wet Report



The main goal of this assignment, as I understood it, was to try and capture an interesting image of fluid flow. For my specific project, rather than trying to capture a particular flow phenomenon, I focused on investigating a particular flow visualization technique known as pathline particle tracking. This involved using long exposure shots to trace the paths of particles, and the twist I put on it was to use a dynamic lighting setup in which the hue of the light changed over time. I completed this assignment entirely on my own.

The flow for this image was made in a cylindrical glass container with an inner diameter of approximately 74mm (give or take approximately 0.5mm due to a slight eccentricity), and a depth of approximately 127mm. The vorticular flow was created using a milk frother which was placed with its end near the bottom of the cup, and which was pulled out of the water within what I estimate was around 3-5 seconds of the image's being taken. Though I did not measure this, I would guess the water was around a room temperature of 23°C ($\approx 74^{\circ}\text{F}$), as the container I was drawing it from had been sitting in my house at that temperature for a multiple hours.

To characterize this flow, I think Reynold's number is a useful quantity to use, since this looks to be nearly laminar, but with some slight turbulence. To calculate this, we use the equation:

$$Re = \frac{vL}{\mu}$$

Where I will consider the characteristic velocity (v) to be the tangential velocity at the outermost edges of the vortex, the characteristic length (L) to be the cup diameter, and, still assuming 23°C water, the kinematic viscosity (μ) to be $0.9344 \frac{mm^2}{s}$ (IAPWS 2008, cited in Anton Paar n.d.). I did not collect measurements on the viscosity, but by eyeballing it, I may be able to get some rough values. Knowing that the shutter speed was a half second, and noting from the image that some of the particles' paths seem to make between $\frac{1}{6}$ to $\frac{1}{2}$ rotations around the edge, we can take those fractions of the cup's inner circumference and divide by the time elapsed:

$$v_{low} = \frac{\frac{1}{6}\pi(0.074m)}{0.5s} \approx 77.5 \frac{mm}{s}$$

$$v_{high} = \frac{\frac{1}{2}\pi(0.074m)}{0.5s} \approx 232 \frac{mm}{s}$$

** Though the values shown above are rounded, no intermediate rounding was actually performed in calculating the final Re values*

Using those values in our Reynold's number calculations yields:

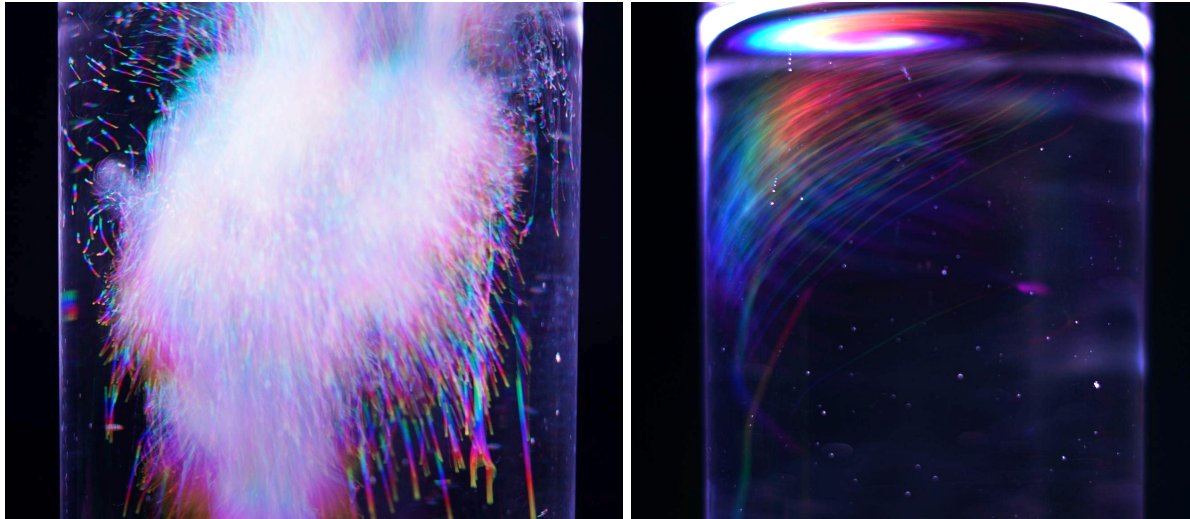
$$Re_{low} = \frac{77.5 \frac{mm}{s} (74mm)}{0.9344 \frac{mm^2}{s}} \approx 6,140$$

$$Re_{low} = \frac{232 \frac{mm}{s} (74mm)}{0.9344 \frac{mm^2}{s}} \approx 18,400$$

Both of these values, being well over 4,000, indicate that the flow here is turbulent. Now, the particle paths in the image do not seem to be particularly turbulent, though there is some evident bumpiness. I am not sure exactly why this might be, but my main suspicion is that it is the particles' nonnegligible masses resulting in a smoothed out path, as their inertia resists potentially small-scale turbulences. It could also be the case that the turbulence, though present, is occurring on a large enough scale that the bulk flow pattern is not too distorted.

To visualize the flow, I used granulated potassium chloride, KCl, whose granules were rounded cuboids ranging from 0.2mm to 0.6mm (a rough measurement gathered

using some calipers accurate to 0.01mm). The water was filtered water taken from my fridge and left out to let any particles settle, and to let any bubbles escape. The illumination was provided by a single WS2812B pixel set to cycle through all hues at full brightness and full saturation every 0.5 seconds. The evolution of the particles' positions was then taken by matching the shutter speed to that cycle time of 0.5s. This synchronized the color-cycle interval with the exposure time, with the intended effect being to have each particle trace out a full rainbow. The images below display this effect much better than that I selected as my main picture:



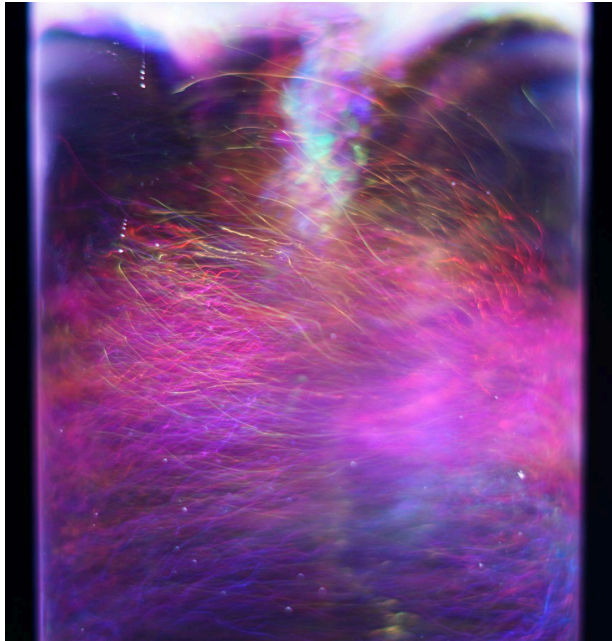
Two reject photos which show the intended “rainbowy path” effect.

To capture the image, I used a Sony Alpha 6000 digital mirrorless camera with a Sony FE 50mm f/1.8 lens. That particular lens was chosen simply because it was the only one I had which could take such close-up photos within the space I had. On that note, the camera was placed approximately 34 centimeters from the closest part of the cup, because I wanted to maximize the detail captured, and that was near the lens's minimum focus distance. In taking many of my rejected images, I actually had the camera focused on the center of the cup, but that ended up causing issues as the tight depth of field caused the foreground particles to obscure everything behind them. Due to physical constraints required for my camera to sit stably on the countertop it was on, I was forced to take my photos in landscape, leading to the cup only taking up around half of the field of view.

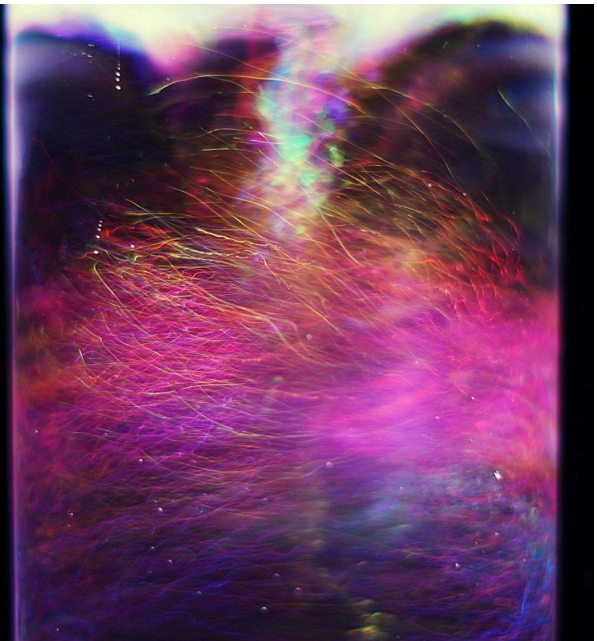
As mentioned previously due to its relevance in capturing the rainbow effect, the shutter speed was set to 0.5s, and due to my lens' inability to do anything else, the aperture was set to f/1.8. The ISO was set to 100 simply because that was the lowest my camera could go, and I wanted to minimize sensor noise.

For post-processing, I just used the Windows Photos application, in which I slightly increased the brightness and contrast to bring out some of the fainter particles and sharpen the paths, while keeping the background as solid a black as I could. The

original image was 6000x3376 pixels, while the final posted version was half that resolution at 3000x1688 (though a full resolution edit was made). Below are cropped versions before and after photos:



Raw Photo



Edited Final Version

Overall, I really enjoyed the picture I got, and ended up capturing a lot of others which I liked just as much! I think this one is really interesting because you can see the overarching vorticular flow quite well, but zooming in, you can see little bits of turbulence. I particularly like this section of the photo, where that effect is most clear:



A closeup showing the small effects of turbulence on the particle paths.

As mentioned earlier, though, the main thing I didn't like in this photo was the lack of a full rainbow spectrum: though we see some of the yellows near the top of the vortex, a lot of those and almost all of the greens and cyans ended up obscured. I would have liked to perhaps take this from a higher angle and with a larger f-stop, but I was not able to get a good setup for that, with what I had at the time. I've also, in looking through the hundred or so other photos I got, found others that have grown on me a lot more than this one.

References:

Anton Paar (n.d.) <https://wiki.anton-paar.com/en/water/>