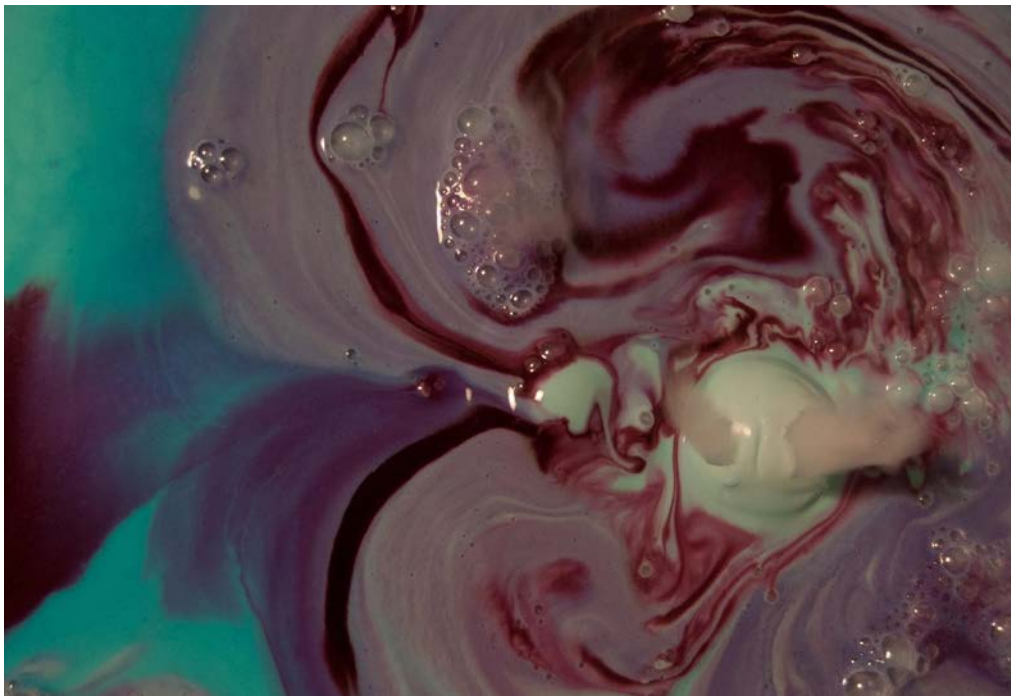


Introduction

For the final group image I worked with Chris Francklyn and Faith Batrack to capture images of the interaction of dry ice with a cornstarch and water mixture (also known as oobleck). We were curious to see how the shear thickening nature of the oobleck would affect the formation and popping of bubbles caused by the melting dry ice. We dropped food coloring onto the mixture which adds a vibrancy to the images and makes it easier to see the path of the flow. Finding the right balance between the oobleck thickness and amount of dry ice proved tricky. With a thick mixture and a small amount of dry ice there were bubble forming but not a very dynamic flow. The bubbles tended to slowly deflate at this stage. As we started working with larger pieces of the dry ice and loosened up the oobleck mixture the activity became much more interesting.



Submitted image showing a bursting oobleck bubble formed by dry ice

Setup and the Acting Forces

The setup for this image was very basic. We used a 9x13" aluminum pan as a reservoir for the oobleck. The mixture was mixed in the pan adding water "to taste" (no, nobody actually tasted it) until we felt we had a good viscosity. The dry ice which is frozen CO_2 sublimates[1] at room temperatures turning directly from solid to gas form. When submerged in water, or in our case oobleck, the gas forms bubbles which rise to the top. Dry ice is generally heavier than water and thus sinks when dropped into water. However with the oobleck we had to work a little bit

harder. Since this material is a “non-Newtonian” liquid it becomes like a solid when under a shear force. Thus we had to slowly lower the dry ice into the mixture which was done by pushing it with a screwdriver. The CO² has a lower density than the surrounding oobleck and so rises to the top. The temperature differential caused by the cold CO₂ and surrounding air causes condensation to occur and the visible fog popping out of the oobleck bubble.

After trying a number of experiments we started getting interesting behavior once the oobleck was a bit more diluted with water. With a couple of large pieces of dry ice submerged in the mixture a regular pattern appeared pulling the mixture through a cycle past the dry ice and circling back around. This pattern continued for several minutes and were were able to capture a number of interesting images.

The image appears to be in focus throughout most of the field of view, however the location where the bubble is bursting and letting out the cloud is a bit unclear, I believe this is mostly motion blur. At worst the image has at least 3 decades of spatial resolution

Mixture and Visualization

We initially mixed it with about two parts cornstarch and one part water with two 16 Oz. boxes of cornstarch from the grocery store. The dry ice came from good old King Soopers in Boulder. The dry ice was broken off in chunks and submerged in the oobleck mixture. We slowly added drops of “neon” food coloring to the oobleck, mostly where the bubbles were being formed. The hope was that the color contrast created would make it easier to visualize the flow. The smoke in the picture is of course fog caused by the dry ice. The vigorous cycle which eventually set-up created a circling pattern which can readily be seen in this image, although later it became even more prominent as more colors were pulled into this shape. Because of the high viscosity of the oobleck the shapes traced by the food coloring stayed put once the force of the dry ice was gone and did not become turbulent enough to become very homogenous.

Photographic technique

This picture was taken with a Nikon D-40 DSLR camera in raw mode with the following camera settings:

Shutter Speed	F-stop	ISO	Focal Length
1/500 sec.	f/5.3	800	42mm

The original image was nearly the entire pan, showing approximately 12” across. The cropped image I used was 2222 pixels wide by 1518 tall, compared to the original 3008x2000 making the cropped image between 8 and 9 inches. By comparison the bubble was about 340 pixels across or about 1.35”. This seems right in the realm of what I observed. Adequate lighting was achieved through the use of two high wattage work lights aimed directly onto the work table. The image was taken without the use of a tripod. With this slow of a shutter speed, this explains why many of my images came out blurry, but I feel this one mostly capture the motion of the flow.

Conclusions

While the popping bubble with two tears emitting fog are somewhat the focus of this image, I actually prefer the colors and shapes off to the left of this activity. The colors and interaction of the layers is quite apparent and I think beautiful. The dark streaks of dye are slowly being pulled into the active zone but at the region far removed they become elegantly stretched. Another thing I'm intrigued by about this is the pattern which formed as the dry ice caused the oobleck to blossom around the activity. The oobleck did not seem to have the strength to support very large bubbles as we were hoping but at this scale, still produced interesting flow.

[1] - [http://en.wikipedia.org/wiki/Sublimation_\(phase_transition\)](http://en.wikipedia.org/wiki/Sublimation_(phase_transition))