THE UNIVERSITY OF COLORADO

Group Image 3 Report

Formation and Violent Collapse of Dry Ice Generated CO2 Bubbles in Oobleck

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Flow Visualization

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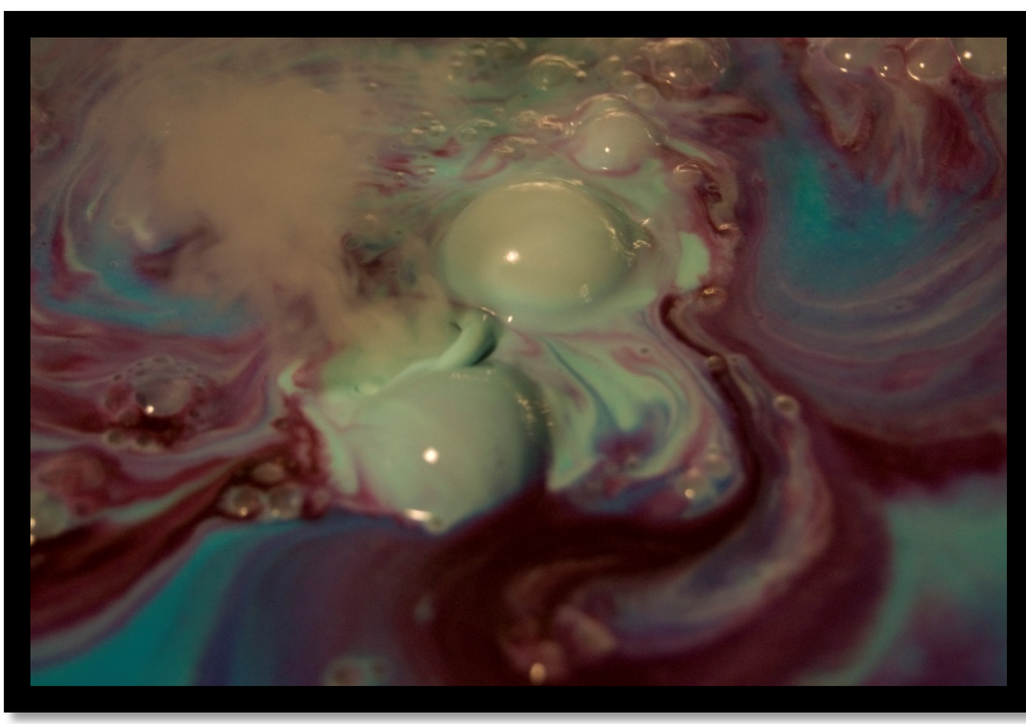

1. Purpose of Image

The image for this report was captured for the final group assignment for The University of Colorado, Boulder's MCEN 4151: Flow Visualization course. The class is designed to encompass multiple disciplines ranging from engineers to visual arts students. For the final group assignment, students were asked to observe a fluid phenomenon of interest and document it through whatever visual medium he or she thought best represented the fluid flow. For the image taken, the group wanted to observe the outcome of introducing dry ice (which forms CO2 gas in the presence of water) into Oobleck. Oobleck – a non-Newtonian fluid – is a shear thickening fluid which becomes more solid with increasing kinetic movement. In the case of the image, the team was hoping to generate large CO2 bubbles that would be supported by the non-Newtonian nature of the Oobleck. Dye was added to the experiment to provide a contrast and to further capture the turbulent flows that were developed as the gas bubbles evolved and failed. Faith Batrack and Jiffer Harriman were co-producers of the experiment.

2. Image Set Up and Approach

The image set up included five main components, namely: Oobleck, dry ice, dye, a baking sheet, and stand lights. The Oobleck was composed of two medium size containers of corn starch, and a corresponding empirical amount of water to generate a moderately viscous Oobleck. It was desired that the Oobleck be able to flow at low inertial forces, but dense enough to shear thicken into actual solids with increasing applied inertial load. This was intended to allow for the formation of moderately stable gas bubbles in the surface of the Oobleck. This Oobleck was mixed and contained within a disposable 13 x 9 x 4 inch aluminum baking pan. For the actual experiment, a one pound block of dry ice was purchased. This block was then chipped into smaller pieces, with the largest being approximately 2x1x1 inches in size. Initially, these chips of dry ice were placed on top of the Oobleck with the hope that the less viscous liquid form of the Oobleck would let them slide to the bottom. This was found to not be the case, so the dry ice had to be slowly pushed towards the bottom with the use of a screwdriver. Also, large chunks of Oobleck were often pulled from the center of the baking sheet so that dry ice could be quickly placed on the bottom surface of the pan. The Oobleck that had been removed (still in a semi

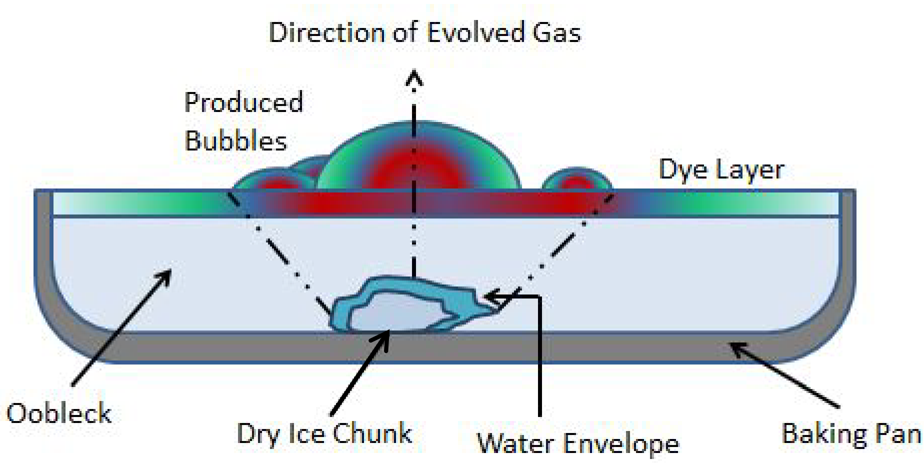

Figure 1: Schematic of Experimental Set-Up

solid form if done quickly enough) was then placed over top of the ice. Dye was then added over the area where bubbles were emerging.

In the later experiments, the Oobleck had become diluted enough that it was predominately in liquid form. However, a thin layer of Oobleck remained at the bottom of the pan. As the dry ice reacted vigorously with the watery Oobleck around it, the rising bubbled pulled some of the Oobleck towards the surface. The bubbles ended up forming a stable circulating flow, which was beautifully visualized by the addition of dye drops of different colors to various parts of the circulating flow. As the Oobleck from the bottom of the pan rose, it brought with it the lighter, homogenously colored teal material, which when mixed with the swirling colors on the surface, provided a very nice laminar flow canvas. Very tight spirals of separated color were generated, which resulted in the beautiful patterns seen in some of the footage that was used.

3. The Physics behind the Flow

The flow in questions was driven by the formation of CO2 gas in the form of bubbles. These bubbles then either were trapped by the non-Newtonian Oobleck or served to mix the colored dye on the surface of the liquid. When dry ice interacts with water, it undergoes sublimation. Sublimation is the process through which a solid undergoes a direct phase shift to a gas, without ever entering the liquid phase. At room temperature and pressure, dry ice converts to a cold gas, which causes water fog to form.

This process can be rapidly increased through the introduction of water to the dry ice environment. When dry ice is submersed in water, it is completely surround on all sides by the liquid. Intrinsically, any liquid has more molecules than gas in a comparable spatial volume. With respect to the dry ice, it means that more collisions are occurring between the molecules in the water with the surface of the dry ice than when the dry ice is surrounded by a gas. Every time a water molecule contacts the dry ice, it transfers energy in the form of heat. This heat in turn produces the sublimating effect that is the hallmark of dry ice. More collisions from the water molecules means that more of the dry ice is rapidly converted into a gas. The result of this is that far more gas is produced when dry ice is surrounded by a liquid than when it is in air.

As the CO2 bubbles rose through the Oobleck, the inertial forces increased, which resulted in a shear thickening of the Oobleck. Oobleck is composed of dense networks of polymers suspended in water. As an object is slowly pushed through the suspension, the particles have time to slide around each other and rearrange to allow relatively easy pass through of the applied force. However, when a sudden force is applied (as is the relative case of the rising gas bubble), the polymers do not rearrange as quickly, and the force is slowed or trapped as the liquid suspension becomes more solid like. In the case of the rising gas bubbles, the Oobleck became stretched out, allowing it to support fairly large bubbles. Since the primary forces within the Oobleck are not surface driven based but rather polymer friction and steric repulsion based, rather than violently pooping, the expanded bubbles developed weak points and tore, allowing the trapped gasses to escape. These weak points most likely occurred in areas of the Oobleck where the concentration of suspended polymers was less than the surrounding area. Because these areas have less polymers it points to the fact that the structural support of the bubble wall is lower, which would most likely result in a likely location for static failure. Sometimes after generating a weak spot that tore open, the bubbles remained slightly inflated and quickly reflated and deflated rapidly. This often occurred in smaller formed bubbles, and resulted in bubbles that flapped as the gas quickly escaped. Most likely, this is due to the fact that the Oobleck was not allowed enough time to relax to a liquid state to reseal the hole where gas was escaping from.

4. Visualization Technique

The flow phenomenon was visualized through the use of high definition video. Throughout the entire process, short sections of video were captured. While the still images that were taken during the experimental procedure are beautiful and stunningly show the detail in the bubble features and dye interactions, they speak little to the chaotic nature that was being produced. In order to accurately capture and represent the slow development and collapse of the dry ice bubbles, along with the beautiful mixing patterns that were being generated in the less viscous Oobleck, video was the only appropriate medium. It was able to provide nice temporal resolution, and enabled viewers to understand the various time scales associated with the experimental set up. Using video allowed the patterns and pathways that the mixing dye took to be seen throughout their entirety.

Figure 2: Dendritic Dye Fingers

To add depth and dramatic effect to the image, various food coloring dyes were employed. These dyes were typically added drop wise over the location that the covered CO2 ice was sublimating into gas. As the bubbles expanded under the dye droplets, the dye was beautifully stretched thin and generated very aesthetically pleasing marbled structures. One of the video sequences also nicely captured dendritic flowing of the dye down the walls of the raised Oobleck. See the image at right for a close up view. The dendritic structures can be seen at the boundary edge of the flowing dye.

5. Photographic Technique

The video sequences were captured using a Nikon Coolpix L810. The video was captured at 720dpi at 30 frames per second. The video was at an ISO of 80, a focal length of approximately 11.5 mm, and an aperture size of f/4.1. Two 100 Watt stand lights were used to illuminate the set up. These lights were mounted to the same stand, and were placed roughly two feet from the surface of the Oobleck, positioned at roughly a 30° angle to the surface of the Oobleck. Each video was taken for roughly thirty seconds and then trimmed down to length. In order to acquire the final videos that were used in the compilation, the team had to take a fair amount of video. The total experimental time was roughly 35 minutes, during which somebody was essentially always taking video, always taking still photos, or modifying the experimental set up. The final video was than compiled in windows movie maker (for lack of access to better software) where the clips were cut to length, organized, marked with transitions, and synced to music.

6. Conclusion

Overall, this image provided a creative and inspiring look into the ways in which two commonly available products can be combined to produce unique results. The video sequences of the expanding and collapsing Oobleck bubbles created an other-worldly feel. Syncing the video to matching music was also a large part in the inspirational power or effect that the piece had. This image sequence was a great culmination to a semester of improvement and creative development in the area of flow visualization.

Works Cited

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