Team First

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Group 7

MCEN 5121: Flow Visualization

Fall 2015

November 6, 2015

Purpose

The purpose behind this experiment was to capture an interesting flow phenomenon for the Flow Visualization class taught at the University of Colorado at Boulder by Professor Hertzberg in the Fall semester of 2015. In addition to just capturing a flow and presenting it in an aesthetically pleasing way, the goal was to also encourage teamwork and benefit from working in a group of people. My personal goal was to experiment with recording a movie instead of taking still photography, and to experiment with both dry ice and the non-Newtonian fluid known as oobleck.

Experimental Setup

The experimental setup for this project was relatively simple. The first requirement was to divide the work amongst all the of the group members, namely Kelsea Anderson, Sam Ballard, Haleigh Cook, and myself. Sam brought the black backdrop for the photograph, while Kelsea and Haleigh brought different containers to try the experiment in. Each one of us brought at least one standard 16-ounce package of corn starch, and I supplied the location and a standard box of food coloring. Sam and I also obtained 10 pounds of dry ice immediately before beginning the experiment. Upon arriving at the destination the first task was to make the oobleck. To do this, cornstarch was mixed into room temperature tap water. The ending ratio was 3 16 oz. boxes of ornstarch suspended in 2 quarts of water. These ingredients were combined using a variety of methods to account for the thickening and increasingly non-Newtonian aspects of the suspension. To begin the corn starch was whisked into the water with first a whisk, and then a fork. Upon becoming too thick to handle, the remainder of the mixing was performed using bare hands. Through experimentation, it was selected that the ideal container for the experiment would be a Sterilite plastic shoe box that measured 13" x 8" x 5" (L x W x H). The entirety of the oobleck solution was then placed into the plastic container filling it approximately to the 2.5" mark in height.

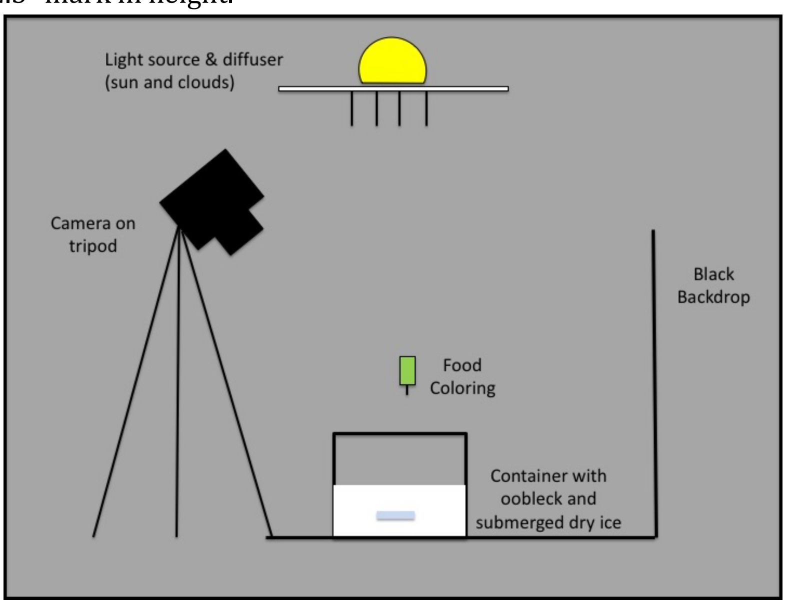

Figure 1: The experimental setup used to capture the flow phenomenon

Next the container was placed outside with a black backdrop both underneath and behind it. The outdoor lighting was deemed optimal for photographing because not only was it near noon when the photography began, but the sunlight was also diffused by the overcast weather of the day. The dry ice was handled with a combination of coolers for storage, gloves for moving large chunks, and tongs for moving small chunks.

To break the dry ice into small pieces a simple hammer was used. By experimentation, it was determined that smaller pieces of dry ice performed better for our desired aesthetic. Too large of a piece and either the pressure created by sublimation was too great for it to remain submerged, or the temperature drop caused by the dry ice was great enough to freeze the oobleck. After breaking off small chunks approximately .5” x .5” or smaller, they were submerged into the oobleck to let the flow begin happening. Typically around 4-5 of these small pieces were submerged to have multiple bubble formations developing throughout the entire container. After it was determined that the flow was satisfactory, a few drops of food coloring were added to the main bubble formation locations and filming was allowed to occur. The entire experimental setup can be seen in Figure 1.

Fluid Physics

When the dry ice is submerged into the oobleck, it begins to sublimate and creates an increased pressure within the oobleck. This causes a pocket of high pressure gas to form, and thus rise to the surface. As the pocket of gas rises to the surface, it forms a large bubble that eventually bursts letting out a stream of carbon dioxide and water vapor that appears as a geyser of fog. As soon as the bubble bursts, though, there is already another bubble being formed beneath and so the flow actually looks like it is “breathing.” Adding food coloring onto the top of the bubble also creates an interesting effect. Since the density of the food coloring is so much less than that of the oobleck, it remains stratified for some time and is just moved around by the bubble growth. Essentially, it creates a thin colored film on the surface that then rolls off of the fluid as it grows due to gravitational effects leading to a ring to form around where the bubble was. This ring then has portions pulled back in with the bubble and it begins to slowly by repeating this process.

The difficulty with working with non-Newtonian fluids is that they are defined by a changing viscosity, so getting a measurement for important non-dimensional parameters for bubble flows such as the Reynolds and Morton numbers is impossible without having a way to measure viscosity, and with the view of the camera being top down, measurement of the contact angle between the bubbles of oobleck and the surrounding air is also practically impossible making it impossible to estimate the surface tension of the fluid for calculation of the Eötvös number. Fortunately, though, by comparing the apparent shapes of the bubbles we see in the video to results from Li Zhang we can get a rough estimate of the Reynolds number. According to their findings, a rounder bubble having a lower radius of curvature will have a lower Reynolds number somewhere in the vicinity of 2.0 which shows itself a in an almost spherical bubble shape. On the other hand, a higher radius of curvature leads to the bubble to appear flatter and thus we can only see a fraction of a sphere, but this corresponds to a higher Reynolds number on the order of about 20. Based on the idea that the bubble shape is determined by Reynolds number, we can then see that we are potentially experiencing the whole aforementioned range of 2-20 [1].

Based on other research, we can also attempt to explain the phenomenon of sometimes having bubbles quickly formed one right after another versus having a significant gap in time between two bubbles. Studies have shown that there exists a critical bubble volume above which leads to a negative wake to develop, meaning that instead of entraining the fluid behind the bubble to continue moving upwards with the bulk flow, the flow will actually be forced to moving downwards in the opposite direction. This critical bubble volume is expected to change with Reynolds number and fluid composition, and unfortunately, we have no convenient way of estimating this critical volume. I do believe, though, that this negative wake explains the behaviors we witness in the video. In general, the smaller bubbles tend to form more quickly after each other, even sometimes appearing to have a second bubble formed inside of the first, and this is explained by the continuous upward flow in that region. The larger bubbles, in general, tend to have quite a bit of a time gap between bubble formation, and this would be because of the negative wake forming causing a slight indentation and change in flow direction [2].

Finally, part of my hope in running this experiment was that the force exerted by the gas onto the oobleck would lead to solidification of the bubble surface, since it is well known that non-Newtonian suspension based fluids experience this solidification phenomenon when under shear. Unfortunately, to experience solidification, the pressure is required to be on the order of MPa. In this instance, though, with the oobleck exposed to two air surfaces, it is expected that it never exceeds 10 kPa, meaning that there is never enough of an instantaneous pressure to cause true solidification to happen [3].

Photographic Technique

In order to film this flow, a Sony DSC-H90 point and shoot camera was utilized. The camera was placed approximately 3' above the container on a tripod. The film was shot in 720p (1280x720 pixels) at 30 frames per second. For post processing, the movie was edited using Apple's iMovie program. Firstly, the domain size was cut to approximately 1/6 of the total shot, but it was re-encoded to keep the playback resolution at 720p. Slight color correction was added to boost the contrast, and it was played back at half speed. The only other modifications made were the adding of music for the background, and additions of titles in the beginning and the end.

Conclusion

Overall, my intent was realized and the job was made significantly easier through ample and efficient team work. For future work, I would like to have multiple cameras set up so that I could gain information from different angles so values for the contact angle could be estimated. Also I would be interested in seeing if I could repeat the experiment in a deeper container but with a clear non-Newtonian fluid so that the actual full path and development of the bubble could be seen. Finally, I would also be interested in repeating the experiment with better film equipment. The ambient daylight providing excellent lighting for the film, but the movie suffered from the auto-focus of the camera. Having a camera with a manual focus that I could set and keep constant for the video would vastly improve the end result. Also, instead of having to rely on interpolation and encoding to make the movie play smoothly and in higher definition, I would like to reshoot it but with a camera that has the capabilities of having a high frame rate but maintaining a good resolution. Lastly, instead of filming the entire domain, I would go back and choose one series of bubbles to focus on so that the domain that was of interest would be all that was captured instead of trying to see the multiple bubble formations that were happening at once.

Bibliography

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