Dye Fingers

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Team Third Assignment, MCEN 4151

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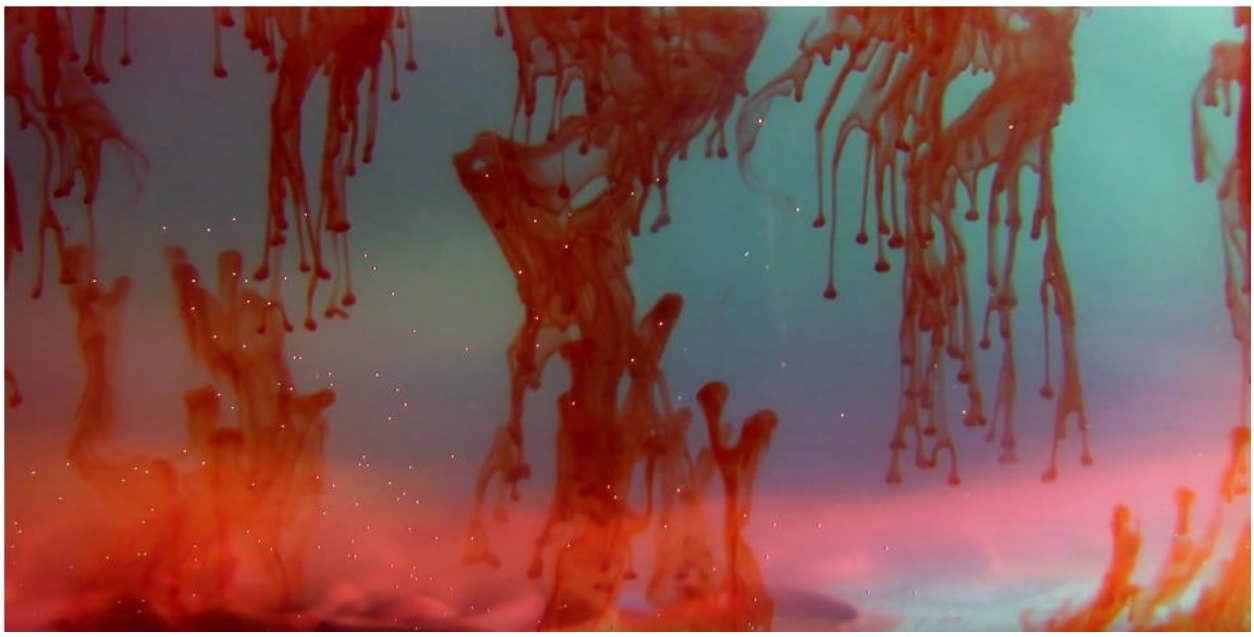

This video, titled “Dye Fingers,” demonstrates two primary flow phenomena: the rope coiling and Rayleigh-Taylor instabilities. Though the original intent of this flow experiment was to create a “cloud tank,” a simulation of a cloud inside a tank containing a layer of fresh water atop a layer of saltwater, due to limited time and resources this was not successful. The fresh and salt water could not be adequately separated and thus the tank ended up being entirely saltwater. However, with the addition of some food dye and creative lighting, an unexpected but equally interesting phenomenon was observed. The red paint poured into the tank fell to the bottom, creating “ropes” due to the rope coiling instability, and the food dye formed unusual “fingers” as it diffused through the water due to the Rayleigh-Taylor instability. Michael Sandoval and Seunghwa Park assisted with the setup and lighting.

The setup for this flow was quite simple and is outlined in Figure 1. A medium-sized plastic fish tank was first cleaned to remove spots that would interfere with capturing images through the plastic, and was then filled with tap water. Approximately a gallon and a half of water was added to the tank, and this was mixed with about two cups of salt, giving a salt concentration of about 0.083%. A bottle of red tempera paint was then positioned 3-5 cm above the surface of the water and squeezed, depositing coiled ropes of paint into the bottom of the tank. After this appeared unsatisfactory, a bottle of red propylene glycol food dye was

positioned 1-2 cm above the surface of the water and several drops were deposited into the water. The video captures drops of dye being added after the tempera paint had already been in the tank for about 20 minutes.

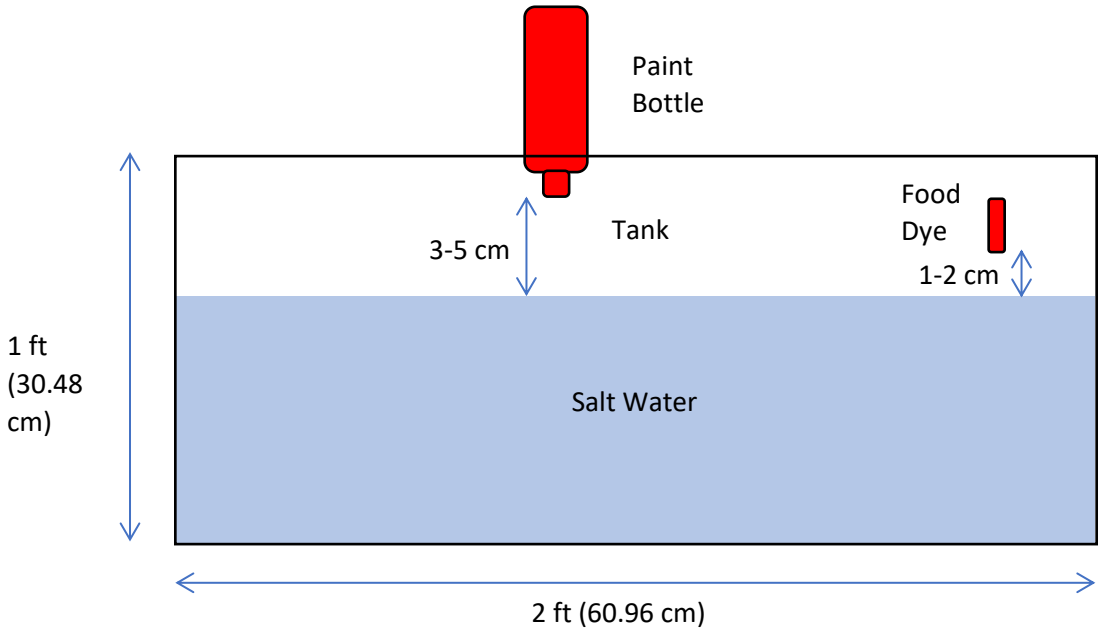

Figure 1. Diagram of Setup (not to scale)

The first flow phenomenon, the rope coiling instability, is visible in the coils of tempera paint at the bottom of the tank located in the background of most of the video. This phenomenon occurs when an elastic solid or viscous liquid is dropped from a critical height and impacts a solid surface. If the paint was dropped from a small height above the bottom of the tank, all of it would impact the bottom at the same location. However, when dropped from a height higher than the critical value, fluid buckling occurs and the paint stream does not continuously impact the same point, instead the impact point drifts around in a circular pattern. This is because the diameter of the stream increases as it falls from a larger height, which causes a normal stress perpendicular to the length of the stream (Habibi, 2007). When this normal stress is large enough, it causes the stream to displace parallel to the surface it lands on, which in turn causes a torque that leads to the circular motion of the impact point.

The other visible flow phenomenon is the Rayleigh-Taylor instability, which describes the interaction between two fluids of different densities. Figure 2 provides a diagram which will help to visualize the following discussion. This discussion will simplify the actual situation to make it easier to analyze by assuming that the salt water and food dye begin on top of one another with a perfectly flat interface between them and that both continue infinitely in the x and y directions. Gravity acts in the direction indicated by the “g.”

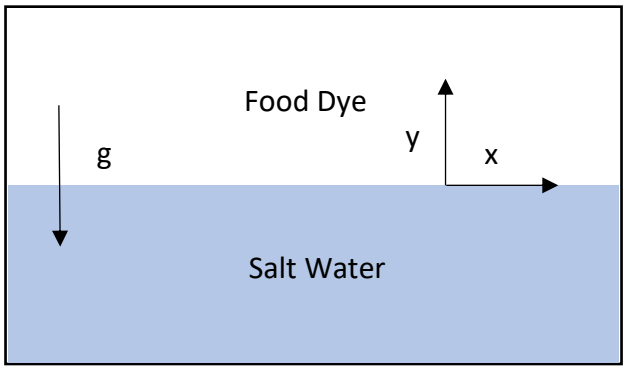

Figure 2. Fluid Configuration for Rayleigh-Taylor Instability

If the fluid on the top of the interface is less dense than the fluid on the bottom, no motion will occur as the interface is stable. However, if the opposite is true and the fluid on top has a higher density than the one on the bottom, as is the case with the food dye and salt water, the interface is unstable. When this is the case, any velocity perturbation in the interface will lead to mixing of the two fluids (Oakley, 2004). In the video, the impact of the dye droplet with the surface of the salt water causes a downward perturbation in velocity. This causes the dye to move downward while the water moves upward the take its place. As the dye moves downwards, it expands, creating the "mushroom" and "ring" shapes seen in the video. What is unusual in this particular case are the secondary "fingers" that form as they dye moves downward, as this is not seen when dye is dropped into fresh water. A possible explanation for this relates to the fact that the densities of propylene glycol, the primary ingredient in food dye, and salt water are much closer to each other than that of propylene glycol and fresh water. This causes the dye to only travel a short distance downwards, as the velocity generated by the difference in densities is small. However, once the dye stops a secondary instance of the Rayleigh-Taylor instability occurs, causing the dye to move downward again and thus forming the "finger" shapes.

When performing this experiment, the ambient fluorescent light in the room was first used, but this did not produce very interesting results. Later, the decision was made to turn off the lights in the room and use cell phone flashlights, and this produced far more aesthetically pleasing results. The number and location of these lights changed from shot to shot, but generally there were one or two placed either directly against the back of the tank shining towards the camera or against the side of the tank shining perpendicular to the direction the camera was pointing. The low light levels shining through the water to reach the camera really enhanced the feeling of being underwater which is an essential part of this video.

The video was taken with a Canon Vixia HF G20 digital camcorder, shooting a 1920 x 1080 pixel image at 24 frames per second. The camera has a fixed lens with a variable 4.25-42.5 mm focal length and a maximum aperture of f/1.8. The focal lengths used to capture the various shots in the video ranged from 20 mm to 30 mm; it is difficult to report the actual lengths because the camera does not display them. The camera lens was at most 4 in from the

front of the tank and was kept this distance or closer for all of the shots. The camera was kept this close to both ensure that the focus was correct given the limitations created by focal length and aperture of the camera and to endure that the edges of the tank would not be visible, enhancing the feeling of being immersed in water. The horizontal field of view was consistently about 5 to 6 inches. The aperture, shutter speed, and ISO gain were f/2.6, 1/12 s, and 9 dB, respectively, though their values varied slightly between shots. These settings were chosen to allow the subject and the colors to be clearly distinguishable in the low-light conditions I was filming in. The video was edited and post-processed using the Hitfilm 3 Pro software. Two forms of postprocessing were used on each shot, and this was consistent for each aside from small changes in the color values to ensure each shot looked the way I wanted. First, a "crush blacks and whites" effect was added, which allowed the dark and light pixel values of the image to be adjusted separately, effectively fine-tuning the contrast until the desired result was achieved. Next, the white balance of each clip was adjusted. Unmodified, everything in the images looked read, including the background. However, selecting a pink color to base the white balance off of changed the background color to a greenish-blue, again further enhancing the feeling of being underwater. A royalty-free music track, "Ambient Dark Synthesizer Drone," retrieved from Pond5.com was included in the video, as its mood matched what I was attempting to portray.

I was quite surprised at the way that this video turned out, as it was created under heavy constraints on time and resources. The original idea that I had of making a cloud tank failed miserably, but gave rise to something possibly more interesting and definitely more unique. During the actual execution of the experiment, I was mainly just filming things that looked interesting without much regard to a coherent intent or aesthetic. During the editing process, however, I realized that watching the dye travel slowly downwards was the most interesting aspect of what I had captured, so I edited the best parts of those clips together. After adjusting the white balance as discussed earlier, I realized that I had created something the evoked exploring some kind of alien ocean or lake. The handheld camera in the first shot, which I initially disliked, actually ended up enhancing the aesthetic as it evoked moving through and exploring the alien ocean. After settling on this aesthetic, I chose music to go with it that was suitably mysterious and alien. Overall, I am very happy with the way this video turned out, especially considering a large part of the aesthetic arose by accident.

References

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