Get Wet Image Report

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The purpose of this “Get Wet” image was to act as an introduction to creating fluid phenomenon in a controlled environment, making the flow visible, and capturing the image with the intended quality. Several fluid properties were considered but in the end the effect of Rayleigh-Taylor instability on a drop of food dye dropped into a tank of calm water was selected for flow visualization experimentation. To enhance the aesthetics of the image two individual drops of different color were paired to be dropped into the tank simultaneously. Multiple attempts were required to coordinate the camera with impact of the droplet, but eventually the perfect image was captured.

The setup of this flow visualization experiment involved a ten gallon glass fish tank, two food dye droppers of red and blue color, a high resolution camera with tripod, proper lighting, and backdrop equipment. A picture of the experimental setup is shown in figure 1, and a simplified diagram is shown in figure 2. The dye was dropped into the tank approximately a 1 cm above the water surface by the operator while simultaneously triggering the camera.

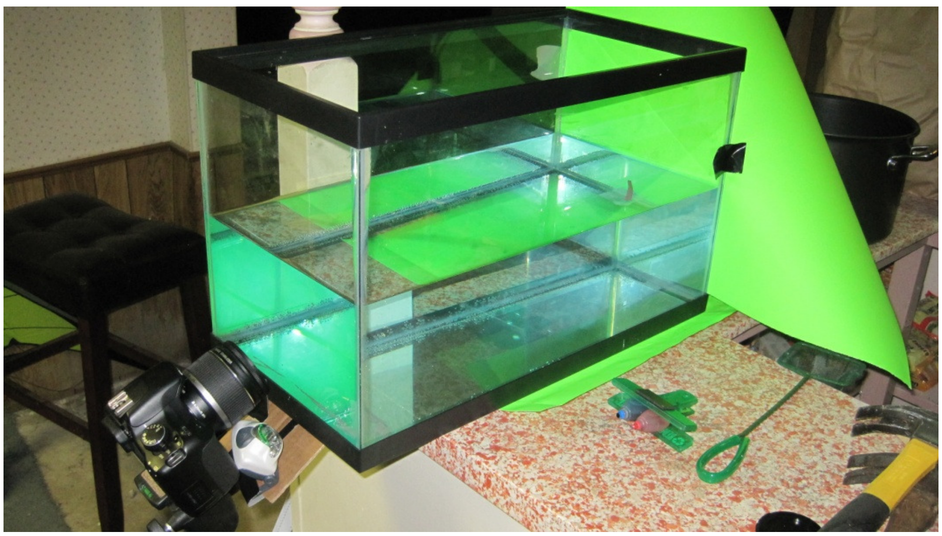

Figure 1: Experiment setup

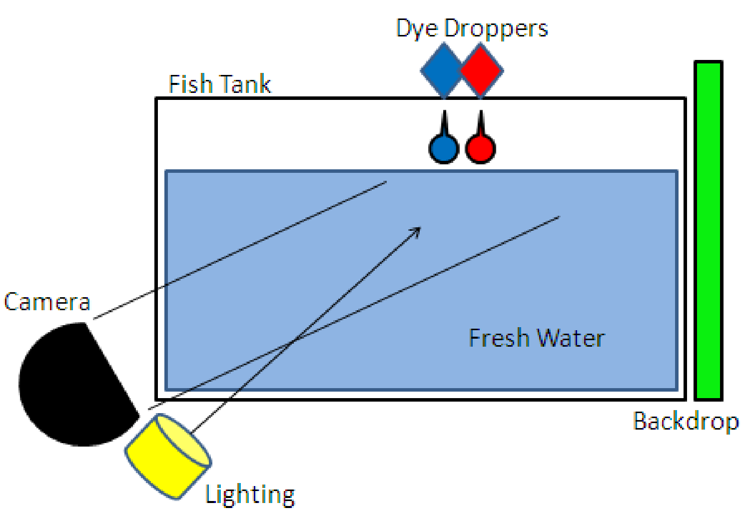

Figure 2: Setup diagram

The science behind this fluid phenomenon is defined in the properties of Rayleigh-Taylor Instability. This occurs when there when fluids of two different densities come into contact. Food dye is primarily composed of propylene glycol and water, which makes its density slightly higher than that of water. This higher density caused the dye to sink in the fluid while dispersing. The dye initially comes into contact with the water in the form of spherical drop. When the drop impacts the water surface it will do one of two things depending on its velocity and other scaling parameters. If the droplet strongly impacts the surface at high speeds it will create a cavity which quickly fills inducing a Worthington jet shot vertically upwards[1]. However, in this experiment the droplet hits at a relatively low speed and combines with the water surface to send out a small ripple along the top and a vortex ring of dye downwards into the tank[1]. When the vortex sheds the dye will finger out into new individual groups and the process will restart. This behavior is directly dependent on the Reynolds number and Weber number of the dye droplets.

The process that the dye droplets go through in this experiment is easily shown in figure 3. The droplet sinks below the surface and circulation around the sides begins to occur as shown in step 3. Static pressure also builds up on the bottom of the droplet which widens the droplet into a disk[1]. The flow around the edges of the disk develops the droplet into a full vortex ring which continues for a certain length downward. The vortex ring continues to expand until it loses stability and disperses outwardly. This is the action that causes the umbrella pattern and expands the dye out radially. Some of the dye reunites and begins to form new smaller vortex rings of lower energy. This is the point in the process that is seen in the image. Both droplets have impacted the surface leaving a small amount of dye there. As the droplet moved downwards in vortex ring form a trail of dye was left leading back to the source. The vortex burst into the umbrella pattern and is in the process of coalescing into new rings.

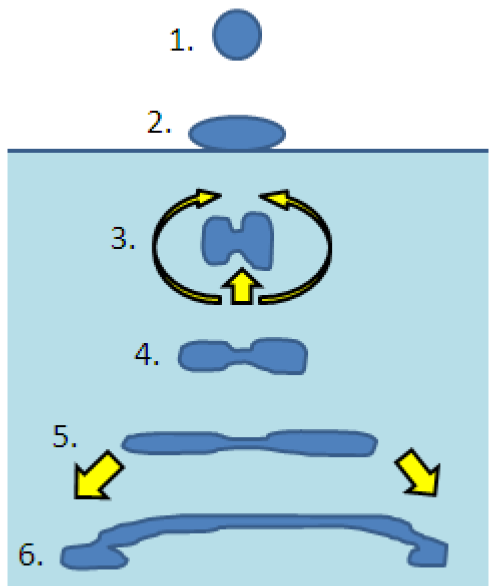

Figure 3: Vortex creation

The nature of a process such as this is directly dependent on certain scaling factors. The Reynolds number has the largest effect on the droplet when it is travelling under the surface. In this experiment the Reynolds number is defined as:

$$Re_d = \frac{u_d R}{\nu}$$

Where u_d is the velocity of the dye, R is the radius of the droplet, and ν is the kinematic viscosity of the water. The droplet was released 1 cm above the water surface, therefore 0.4429 m/s will be the representative dye velocity. The diameter of the droplet was about 1mm making the radius 0.5mm. The viscosity of the water was 1.307×10^{-6} m^2/s in the cold basement where this experiment was performed. These values calculate out to a Reynolds number of 169. The Reynolds number affects how wide the umbrella pattern will spread out and how many individual fingers will be created[2]. A numerical simulation[3] of this same fluid phenomenon shows nearly identical results as seen below in figure 4[3].

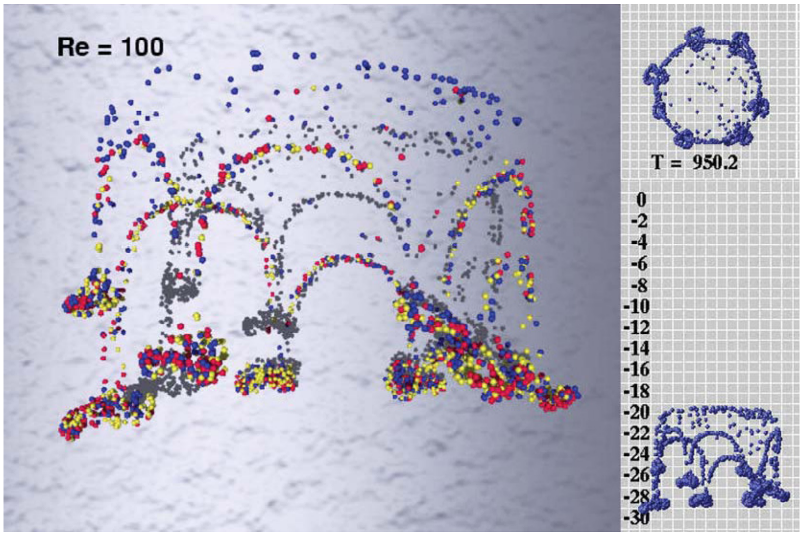

Figure 4: Simulated umbrella pattern[3]

The Weber number contributes to the effects seen when the droplet initially impacts the water. As stated earlier, a droplet will either create a downward vortex or an upward jet as determined by the Weber number. The equation for Weber number is:

$$We = u_d \sqrt{\rho \frac{D}{T}}$$

with ρ as the uniform density of the drop, D as the diameter of the drop, and T being the surface tension (approximately 0.07 dyn/m for water). An experimental study[1] found that higher Weber numbers would always create an upwards jet while lower Weber numbers would generally form a downwards vortex with the critical Weber number transition number around 8. In this experiment the Weber number was calculated to be 1.674, well below the critical value and within the range of vortex creation.

To clearly see the fluid phenomena of interest in this experiment, food dye manufactured by Safeway was dropped into to tank. The colors red and blue were chosen because of their nice contrast to the background and their good visibility. The tank was filled with clear water to allow the camera an unobstructed view of the dye formations. The water was left to rest for five minutes after filling to ensure the water was absolutely still. The backdrop consisted of a lime-green poster board taped to the side of the tank. Lime-green was chosen since it is a color that is easily digitally modified and it provided a sharp contrast to the red and blue of the dyes. To properly light the image, a LED headlamp was mounted directly below the camera. The beam path was directed through the flow of interest then reflected off the bottom of the water surface and illuminate the backdrop. By doing this, light was added to the dye formations as well as the background. The primary flash on the camera was not used since it tended to give an unwanted reflection off the side of the tank.

The camera used to capture this image was a Canon Rebel XSi 12.2-megapixel digital camera with a standard 18mm-55mm kit lens. The dye formation in the image is only about an inch and a half long. The drops were positioned to hit the surface approximately 14 inches away from the camera lens, well beyond the macro minimum distance of 0.8 ft. The adjustable lens focal length was set at 35mm to center on the dye formation while still giving some room for error if the drop wasn't perfectly placed. The ISO was set to 400 to slightly amplify the light gathering but retain image clarity. The shutter speed was set at 1/25th of a second to allow more light to enter and provide a slight blurred motion effect to emphasize the movement of the fluid. The F-stop was set at 5.6 to as required by camera operation to attain enough light to make out the image. The original image dimensions were 4272 by 2848 pixels, but were reduced to 1248 by 1376 pixels after sharpening and cropping. Once the original image was captured on and stored on the camera, it was transferred to a computer and modified using Adobe Photoshop. The image was initially cropped to limit the view to only the flow patterns of interest. To change the originally green background to a purple, the green color channel was reduced by 100%. To further enhance the contrast between the red and blue dyes, the color curve limits were reduced to the limits of the actual color area. Image sharpening was applied, but it made little effect. The image was inverted to give a different perspective and left at a slight angle to create a more natural feel. The original is shown in figure 5.

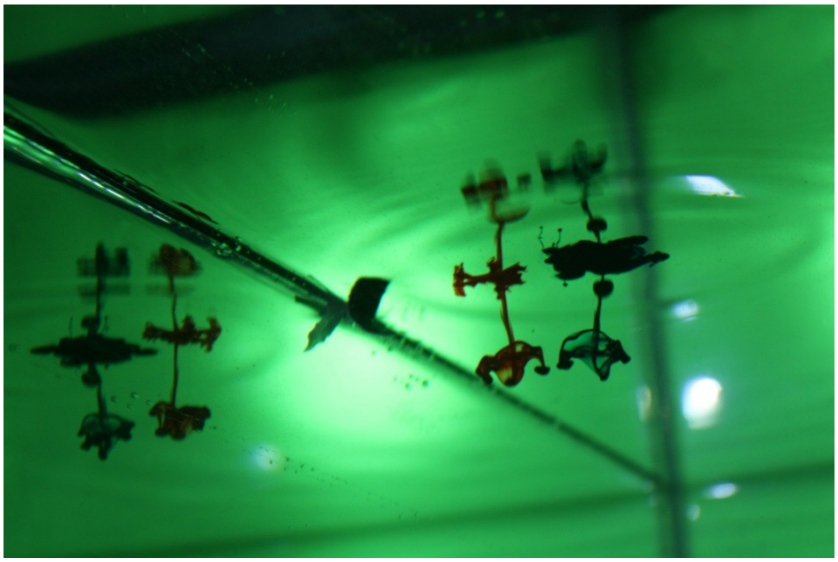

Figure 5: Original image

Though this is a common process, this image especially captures the beauty and uniformity of this fluid property. The red and blue identical flow patterns bring about a strong contrast combined with a purple background to nicely mix the two into each other. The ripple effect that slightly distorts the reflected image gives in a nice bit of asymmetry. When inverted, the two dye formations have a strong resemblance to two flowers blooming out of the ground. The fluid physics are well displayed in the umbrella instability pattern and is further proven by both droplets undergoing nearly identical processes. If done again special attention would be given to eliminate the distracting tank edge in the background of the image. The focus would also be adjusted and focal length increased to make the edges sharper and the image clearer. Seeing a third droplet of a different color could bring an added degree of interest to the image. Overall, this image exceeded expectations and is a perfect introduction to the techniques and practices that are involved with this type of flow visualization experiment.

REFERENCES:

[1]M. Hsiao, S. Lichter, and L. Quintero, “The critical Weber number for vortex and jet formation for drops impinging on a liquid pool,” Physics of Fluids 31, Vol. 12, p3560-3562 (1988).

[2]T. Bosse, L. Kleiser, C. Hartel, and E. Meiburg, “Numerical simulation of finite Reynolds number suspension drops settling under gravity,” Physics of Fluids 17, 037101 (2005).

[3]T. Bosse, L. Kleiser, J. Favre, and E. Meiburg, “Settling and breakup of suspension drops,” Physics of Fluids 17, 091107 (2005).