Team Project III: Report

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Introduction

For the last flow visualization photography project, team project III, we wanted to show the physics and artistic characteristics of the Saffman-Taylor instability. Our objective was to use the Hele-Shaw cell to place a fluid in between two parallel plates and then inject a fluid with a lower viscosity into another fluid. My intent was to capture the fingering effect that occurs from the Saffman-Taylor instability using fluids with different colors to help reveal the boundaries between them and add artistic effect. I chose this specific image from the collection acquired from the experiment, because it had a good variety of color, it was mostly in focus, and the diffusion between the fluids was minimal which suggests that it was taken while the low viscosity fluid was being injected or shortly after.

Setup

The Hele-Shaw cell was set on a stand and composed of a bottom translucent acrylic plate with a small hole in the center and a top transparent glass plate and is shown in Figure 1. The setup was lighted from underneath by three 500W halogen lamps to remove the need for top lighting or a flash that when used created a lot of glare. Three lamps were used to minimize shadows caused by the protective grills attached to the lamps.

Figure 1: Hele-Shaw cell used in the setup of this image

Honey was used as the heavily viscous fluid and placed on the bottom plate and the top plate was installed and used to compress the honey into a thin circular layer. The less viscous fluid was water dyed with food coloring and it was placed in a syringe that was attached with an adapter to fit into the hole of the bottom plate. As I injected the dyed water in between the plates my other teammates took pictures and applied pressure to the top plate to help the fingering pattern from the Saffman-Taylor instability spread out evenly.

Background

When a low viscosity fluid is injected to displace a more viscous one, an unstable interface forms [1]. This instability is known as the Saffman-Taylor instability and it creates patterns known as viscous fingering [2]. The instability and shapes formed are dependent on factors such as: fluid viscosities, injection rate, and distance between the parallel plates. In the radial configuration, created by this Hele-Shaw cell, the pattern of viscous fingers is created by successive tip-splitting [2].

When the low viscosity fluid is being injected into the high viscosity fluid it is adding liquid volume in between the plates. Since the gap between the plates is constant, the fluids must spread out to take up a larger area in between the plates. If the two fluids were of the same viscosity or the high viscosity fluid was injected into the lower viscosity fluid, both fluids would spread out evenly. The injected fluid would create a circular pattern inside the other fluid because the interface between the two fluids would be stable. When a low viscosity fluid is injected into a high viscosity fluid an unstable interface forms, dominated by surface tension effects, and the high viscosity outer fluid cannot spread at the same rate as the lower viscosity inner fluid causing the injected fluid to spread out by the path of least resistance. The mechanism of the instability is kinematic: the perturbation to the interface causes pressure gradient variations to develop along the interface which in turn lead to velocity variations [3].

Visualization Technique

This image was taken in an indoor environment with an ambient air temperature around 70°F. We started by turning on the three 500W halogen lights underneath the Hele-Shaw cell, which produced a lot of heat which contributed to warming the bottom plate. Honey was poured on the bottom acrylic plate and the top gas plate was installed. Next, the syringe was filled with water and about 2% red food dye then injected slowly through the small hole in the bottom plate. As the fluid was being injected, one team member was applying pressure along the sides of the top glass to cause the viscous fingering to spread out evenly from the center hole and another member was taking pictures. After we had injected all the red water, we filled up the syringe again with water and dyed it blue. The blue water was injected slowly while the other team members applied pressure to the top plate and took pictures. This picture was taken perpendicular to the plates of the Hele-Shaw cell at about a distance of 18” from the object to the lens.

Photographic Technique

My main goal for this photo was to get an image which most accurately depicted the Saffman-Taylor instability in the Hele-Shaw cell, with no distracting elements, and in-focus. The image was shot using a Canon EOS Rebel T1i 15.1MP camera. By knowing the scale of the viscous fingering shown in the image (approximately 12”) and distance to the camera lens (about 18”) the field of view is calculated to be 37°. The shutter speed was set to 1/125 of a second at an ISO of 100; this seemed to provide the best combination to help bring out the flow pattern in the dyed water being injected. The camera was at a focal length of 18mm and an aperture stop of 7.0. The original image was 4752x3168 pixels and is shown in Figure 2.

Figure 2: Original unedited image

I chose this image because it had watermarks and bubbles that could easily be removed, was almost entirely in focus, and had very little diffusion between the honey and the dyed water. This image is kind of dull, so to help if stick out I changed the hue which caused the pink background to change into to blue, the red dyed water to go to light blue, and the blue dyed water to turn black. I also used the curve option in Photoshop to help darken the image and help define the boundary lines. The last part of editing that was performed was using the stamp tool to remove watermarks and bubbles which did not aid in showing the fluid physics. The final edited image remained the same size (4752x3168 pixels) and is shown in Figure 3.

Figure 3: Final edited image

Conclusion

The main scientific phenomenon this image reveals is the unstable interface between a low viscosity fluid (dyed water) being injected into a more viscous fluid (honey) known as the Saffman-Taylor instability and the viscous fingering that results. I really like the range of contrast of this image and they way flow pattern fits into the frame of the image, but I wish the original image would have been zoomed out so that I would have more area to work with. The image shows the physics really well and is particularly noticeable in the structuring and splitting of the viscous fingers. The thicker paths extend further away from the injection site because it was the path of least resistance. If I could redo this image, I would try injecting more colors of dyed water or fluids with florescent or magnetic properties.

References

[1] Kondic, Lou. (2002). Saffman-taylor instability. Retrieved from http://m.njit.edu/~kondic/capstone/2002/a/capstone.html

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[3] Harvard University. Instability. [Online] [Cited: 05 03, 2011.] http://www.seas.harvard.edu/brenner/taylor/handouts/saffman_taylor/node3.html.