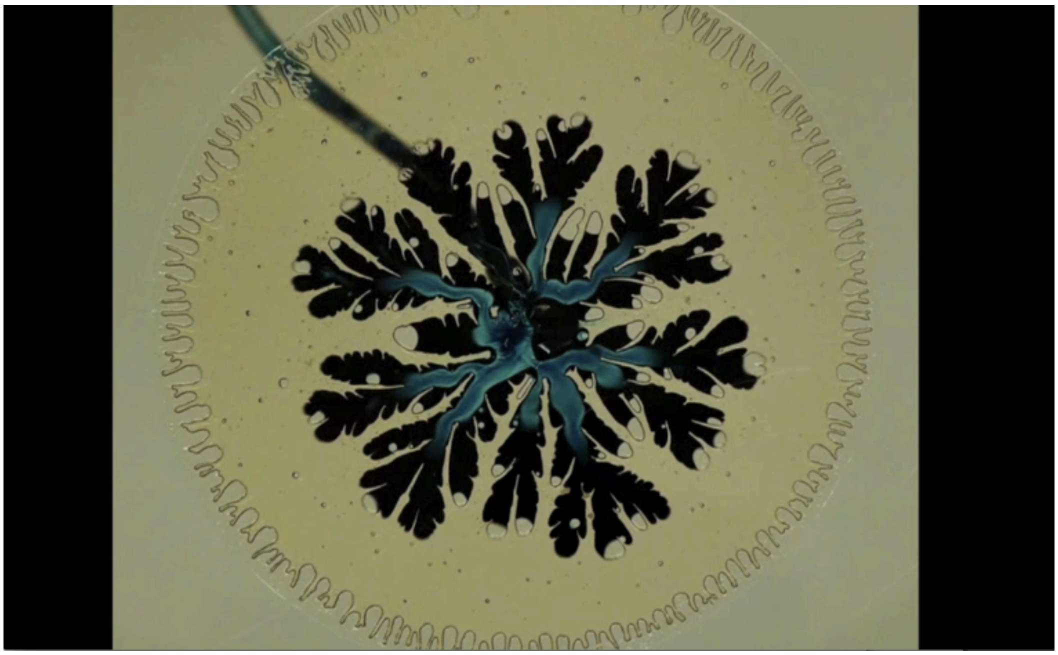
Hele-Shaw Cell Experiment

Group Image #1



https://vimeo.com/88291698

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MCEN 4151: Flow Visualization
Professor Jean Hertzburg

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I. Introduction

This video was created as the first team assignment for the course Flow Visualization. Our groups target was to capture the viscous fingering effect caused by the Saffman-Taylor instability. We were able to produce this effect using a Hele-Shaw cell apparatus that was created by a past Flow Visualization group. The Saffman-Taylor instability that we wished to capture is created when one fluid is injected into a more viscous and dense fluid. Although lighting and reflections proved to complicate capturing the flow, I am very pleased with the results.

II. Experimental Setup

As mentioned above, a Hele-Shaw cell created by a previous Flow Visualization was used to capture the Saffman-Taylor instability exhibited in my video. A Hele-Shaw cell in its most basic form consists of two flat, parallel surfaces separated by a very small gap. The bottom half of the Hele-Shaw cell used in this project was made of an acrylic sheet with a small hole in the center. This hole was connected to a syringe, which was used to inject the less viscous fluid. The upper plate consisted of a glass panel. Since glass is less prone to scratching than acrylic, this helps ensure a clear image when shot from above. A figure of the apparatus is shown in Figure 1 below.

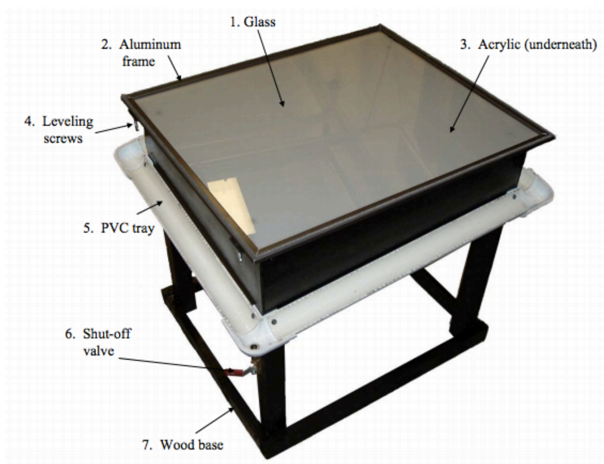

Figure 1: Hele-Shaw Cell Apparatus [1]

After the syringe was primed with water dyed blue with food coloring, honey was poured onto the bottom panel. When the top sheet of glass was set on the honey, it formed a circle around the injection hole with uniform thickness. The water was then injected into the center of the honey circle, resulting in the desired Saffman-Taylor instability.

The camera was positioned directly above the center of the Hele-Shaw cell. Two small tables were placed on the sides of the apparatus, providing a base to set a tripod on.

III. Fluid Dynamics

The Saffman-Taylor instability displayed in my video is created when a fluid is acted upon by a significantly less viscous fluid. [2] For our Hele-Shaw cell, the driving force for this process is a high pressure on the injected fluid provided by the compression of the syringe. A large difference in viscosities is required to produce this type of flow to avoid simply mixing the two fluids. After some experimentation, we discovered that injecting the dyed water at a slow, consistent pace produced many large, radially symmetric "fingers," which were found to be the most aesthetically pleasing. When the dye was injected too fast, one large finger would be created, forming a path of least resistance to break through the honey perimeter. Applying the honey evenly around the injection hole was also found to aid in producing very symmetric and even fingering.

As mentioned, we attempted to prime the syringe so the dyed water would be the only fluid introduced into the honey, but there were still air gaps in the tube of the syringe. Although we tried to avoid this, it ended up having a very cool effect visually. As seen in the video, air is the first fluid to be injected, hence the clear tips of the fingers. After a volume of the dyed water had been injected, there was another air patch. This is seen in the video when the light blue color rushes through the fingers. The reason this air bubble shows as light blue instead of clear is that a small film of dyed water is still clinging to the bottom of the glass surface by surface tension. This was an unintended effect that ended up having beautiful consequences.

IV. Camera, Lighting, & Post-processing

This video was shot using a Panasonic Lumix G5 Mirrorless Micro Four Thirds digital camera equipped with a Pentax Macro 1:4 lens. The 1920x1080 pixel video was captured from about one and a half feet away from the top surface of the Hele-Shaw cell, and was then cropped to create a more square frame that covers an area of about 8x8 inches. The aperture range of the lens is f/4-f/30, and the video was shot at f/5.6. This was chosen to maximize the sharpness of the image and to reduce the amount of light hitting the cameras sensor. The video was captured at 60 fps, however I also chose to play the video at one tenth speed, or 6 fps to reveal more detail in the flow.

Lighting to capture this video was provided by two fluorescent ceiling lights. We placed the Hele-Shaw cell device directly underneath these lights to get even distribution of light. Two team members held a white sheet directly under the lights to diffuse and soften the light. This also greatly reduced reflection in the images.

There were a few altercations made to the raw footage using Adobe After Effects. I increased the contrast by making the dark colors darker and the light colors lighter with the "curves" tool. This was mainly to highlight the perimeter of the honey, as there was already significant contrast between the dyed water and the honey. The "time stretch" tool was used to alter the playback speed.

V. Conclusions

This video succeeds in clearly displays the Saffman-Taylor instability using a Hele-Shaw cell. The expected fingering effect seen reveals stunning beauty through the interaction between fluids of different viscosities. I feel that the slowed down video also succeeds in revealing further detail in the flow. If I were to repeat this experiment, I would try playing around with ways to cut the dye feeding tube out of the frame, or try removing it in post-processing. It would also be interesting to further experiment with fluids of different viscosities and observe how the fingering effects vary.

VI. References

(1) Image credit: http://www.colorado.edu/MCEN/flowvis/course/SaffmanUser.pdf
(2) "Interfacial Instabilities: The Saffman-Taylor Instability." *The University of Manchester*. March 16, 2014. Web. <http://www.maths.manchester.ac.uk/~ajuel/MATH45132/Chapter3.pdf>

VII. Acknowledgements

I would like to acknowledge my team members Eric Fauble, Scott Hodges, and Zac Rice for their help in making this video possible. I would also like to acknowledge my friend Michaelee Mahan for allowing me to use his music in this video (https://soundcloud.com/michaeleemahan).

Image Assessment Form
Flow Visualization
Spring 2013

Name(s): Alex Unger

Assignment: Date:

Scale: +, ! = excellent √ = meets expectations; good. ~ = Ok, could be better. X = needs work. NA = not applicable

Art	Your assessment	Comments
Intent was realized	+	
Effective	+	
Impact	√	
Interesting	√	
Beautiful	+	
Dramatic	√	
Feel/texture	~	
No distracting elements	~	
Framing/cropping enhances image	√	

Flow	Your assessment	Comments
Clearly illustrates phenomena	+	
Flow is understandable	+	
Physics revealed	√	
Details visible	√	
Flow is reproducible	+	
Flow is controlled	+	
Creative flow or technique	~	
Publishable quality	√	

Photographic/video technique	Your assessment	Comments
Exposure: highlights detailed	~	
Exposure: shadows detailed	~	
Full contrast range	+	
Focus	√	
Depth of field	+	
Time resolved	+	
Spatially resolved	√	
Photoshop/ post-processing enhances intent	√	
Photoshop/ post-processing does not decrease important information	+	

Report		Your assessment	Comments
Collaborators acknowledged		+	
Describes intent	Artistic	+	
	Scientific	+	
Describes fluid phenomena		√	
Estimates appropriate scales	Reynolds number etc.	X	
Calculation of time resolution etc.	How far did flow move during exposure?	~	
References:	Web level	+	
	Refereed journal level	~	
Clearly written		√	
Information is organized		+	
Good spelling and grammar		+	
Professional language (publishable)		√	
Provides information needed for reproducing flow	Fluid data, flow rates	~	
	geometry	√	
	timing	√	
Provides information needed for reproducing vis technique	Method	+	
	dilution	~	
	injection speed	~	
	settings	+	
lighting type	(strobe/tungsten, watts, number)	√	
	light position, distance	√	
Provides information for reproducing image	Camera type and model	+	
	Camera-subject distance	+	
	Field of view	~	
	Focal length	~	
	aperture	√	
	shutter speed	N/A	
	Frame rate, playback rate	+	
	ISO setting	N/A	
	# pixels (width X ht)	+	
	Photoshop and post-processing techniques	+	
	"before" Photoshop image	N/A	