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3/15/06
MCEN 5228

Fluorescent Fingers Produced using Saffman–Taylor Instability in a Hele-Shaw Cell

Introduction

The purpose of this image is to illustrate the Saffman-Taylor instability in a Hele-Shaw cell with fluorescents in order to create an image that is both interesting from a visual perspective, as well as a scientific perspective. Saffman-Taylor instability is one of the most studied flow phenomenon in fluid dynamics. Countless images and papers have been taken and written regarding this flow, and yet unique and beautiful images can be produced. One of the easiest ways to visualize the Saffman-Taylor instability is through the use of a Hele-Shaw cell. Hele-Shaw cells are useful for two reasons. First, the flow dynamics can be reduced to two dimensions making it easier to see and analyze the flow. The second reason is that the process is slow enough to easily capture a quality image that is free of blur. The image that was chosen for this study was produced using florescent alcohol and pancake syrup (figure 1).

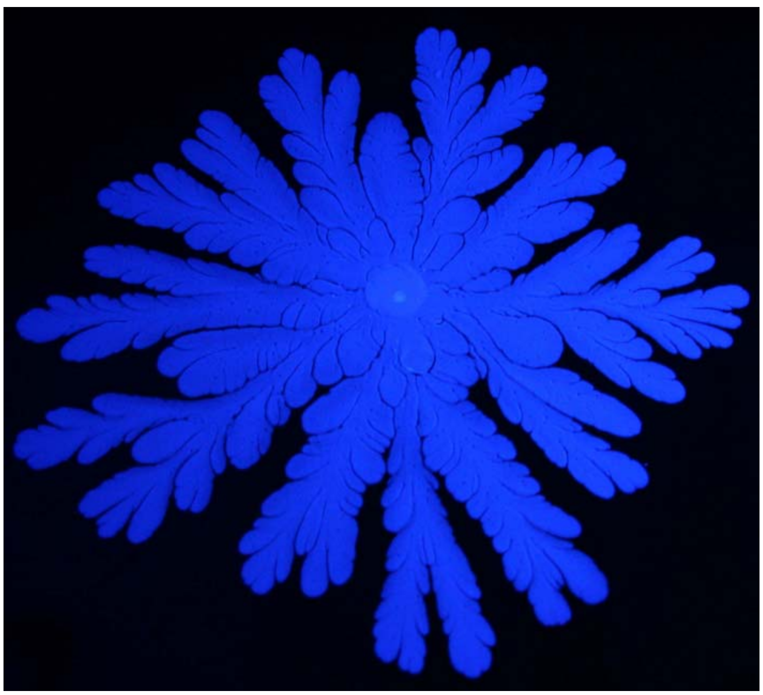


Figure 1: Image of Saffman-Taylor instability in a Hele-Shaw cell with fluorescents.

Saffman- Taylor instability is caused by the difference in the viscosities of the two liquids; this phenomenon is what gives the image its fingering effect. Fluorescents were used to eliminate distracting elements, and to enhance the visual appeal of the image.

Setup

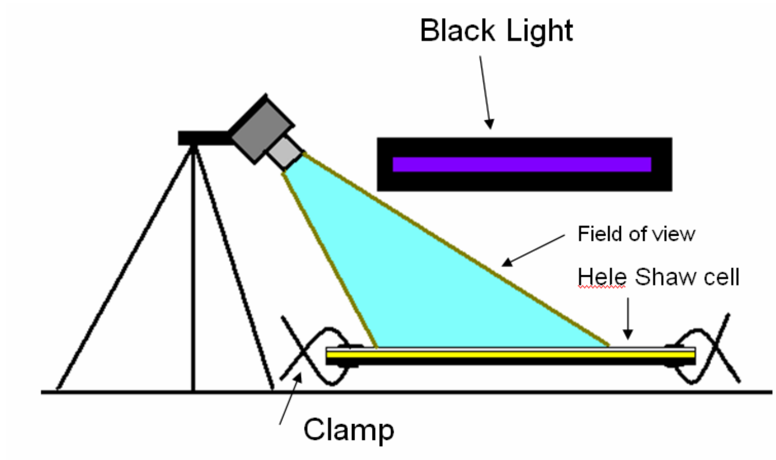
The setup for this photo is fairly simple. The equipment needed is listed below (table 1). Both corn syrup and pancake syrup were used in this experiment. Although pancake syrup consists mostly of corn syrup, it also contains additives that make it less viscous, thus creating a different flow phenomenon. This will be discussed further in the "Flow Physics" section (pg3). The final image (figure 1) was created using pancake syrup.

Table 1: Equipment needed to perform experiment.

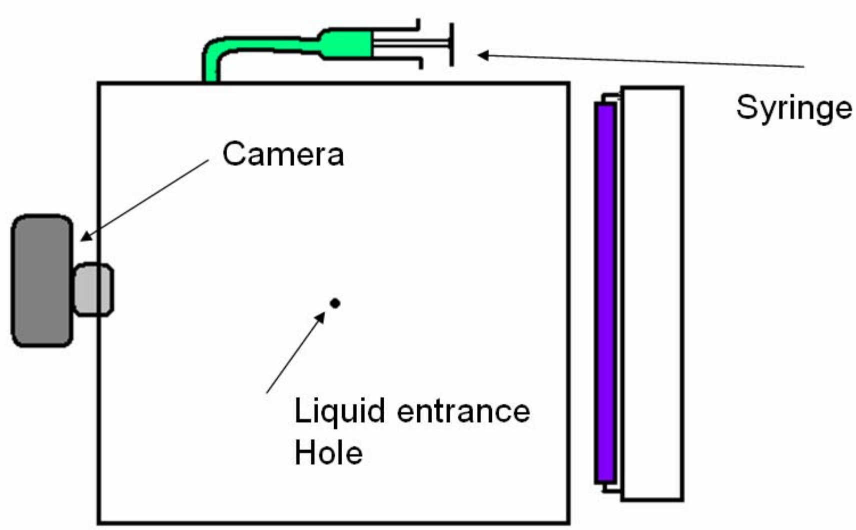
Flow equipment /testing setup	**Photographic/lighting**
Pancake syrup/Corn syrup	Camera
Liquid laundry detergent	Black light
Black plastic plate with 0.5 mm hole in the middle	Tripod
Clear plastic plate	
Syringe with tubing and 0.5mm nipple	
Table	
4 X ratchet clamps	

The first step is to mix the fluorescent laundry detergent in the isopropyl alcohol at a ratio of 1:50 detergent to alcohol respectively. The next step is to place the mixture in the syringe, which is then positioned in the hole located in the center of the black plastic plate. Next, a generous amount of syrup is placed on the black plate. The clear plastic plate is then placed over the corn syrup, being careful not to allow any bubbles to enter the corn syrup. Clips are placed on the four corners of the plates in order to squeeze the syrup into a thin layer about 0.1-0.3 mm thick. The camera is placed on a tripod about 350 mm above the plates. Ideally, the camera should be placed directly above the setup.

However in this case, due to the use of a tripod, the camera was at a slight angle. The black light was placed 250 mm above the plates, and slightly off-center (figures 2 a-b). Then alcohol (with fluorescents) is then injected between the plates causing the Saffman-Taylor instability which forms the fingers seen in figure 1. After approximately 25 ml of alcohol solution is forced into the Hele-Shaw cell, the fingers will remain for around 5 seconds; this is the time in which the photograph was taken (before the alcohol mixture reaches the edge of the plates).



a)



b)

Figure 2: a) Side view of test set up (top), b) View from above of test set up (bottom).

<u>Flow Physics</u>

The flow represented in this study is interesting; in fact, a lot of research has been done on Saffman-Taylor instability and Hele-Shaw cells. The basic principle of a Hele-Shaw cell is that two plates positioned close enough to each other turn a three dimensional problem into a two dimensional problem by eliminating the z axis from the calculation. These cells can be positioned in both a vertical and horizontal orientation.

The Saffman-Taylor instability is similar to Rayleigh-Taylor instability. The difference is that Saffman-Taylor is dynamic instability in that the interface of the two liquids is moving [1]. The most common visualization of Rayleigh-Taylor instability is where there are two fluids of different densities. When the fluid with the higher density is above the one with the lower density, due to surface tension, the higher density liquid has difficulty penetrating the lower density fluid. In most cases, the high weight of the upper fluid wins over and breaks the lower fluids surface tension causing the fluid to fall, forming the finger like structures as it does. If it falls far enough, a droplet will form from the finger. Visualization of this is usually done in a vertically oriented Hele-Shaw cell.

The Saffman-Taylor instability is the type pictured here (figure 1) where there are two fluids of different viscosities, and the lower viscosity fluid is forced though the fluid with a higher viscosity (table 2).

Table 2: Summary of fluid viscosities

	Corn Syrup [2]	Isopropyl alcohol [3]	Pancake Syrup [4]
Viscosity	24,000 cP	2.43 cP	3200 cP

The width of the fingers is controlled by the velocity of the incoming fluid and the difference in the viscosities of the two fluids. Several photos were taken of the flow before the final image was decided upon. One interesting aspect that was noticed was the difference in the fingers when corn syrup was used instead of pancake syrup (figure 3).

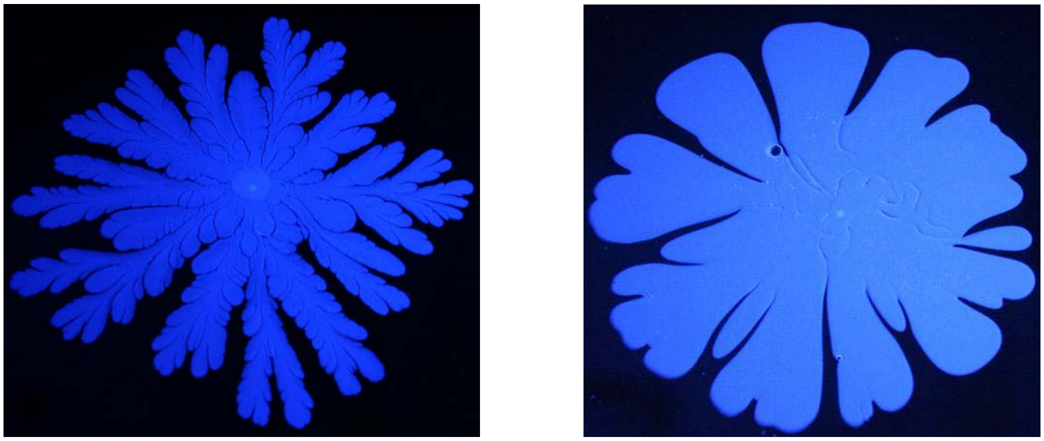


Figure 3: Photo using pancake syrup (left), and corn syrup (right).

The difference in the two images above was caused by the lower viscosity of the pancake syrup. The lower viscosity affected the flow in two ways. First, the pressure gradient is lower which allows the fluid to flow at a higher velocity [1], and second, the width of the fingers is smaller and the main fingers breakup into sub-fingers. We see from table 2 that the pancake syrup and corn syrup have significantly different viscosities. This leads to very different flow characteristics which we see in figure 3. For more information on the analysis of Saffman-Taylor instability, see references [1], [5], and [6].

Visualization Technique

The visualization technique that was used in this experiment was a mixture of florescent laundry detergent with alcohol that is forced into a Hele-Shaw cell in order to visualize the Saffman-Taylor instability. The reason that the florescent laundry detergent was used is because in an otherwise black environment, the florescent alcohol produces a bright glow which makes it easy to see the details of the finger formations (which might be missed using other techniques). The Hele-Shaw cell was chosen because changes in the different in viscosities of the two fluids will produce unique and interesting images. The lights in the room were turned out so as to allow the florescent alcohol to be as bright as possible. During the experiment, it was discovered that the faster the fluid entered the cell, the better the results. With this in mind, the fluid was forced into the Hele-Shaw cell as quickly as possible. There was only enough time for one or two photos, so the experiment was run about a dozen times before the desired image was captured.

Photographic technique

The basic photographic technique that was used for this image is listed below (table 3). In addition to these, Photoshop was used to remove a few bubbles, crop and sharpen the image. The bubbles that were removed made it into the image because they were stuck in the syringe and the tubing leading to the Hele-Shaw cell, and therefore got forced into the image along with the alcohol mixture. The space resolution for this photo was found to be 0.121 mm/pixel. Although the fingers are moving, they are only moving at around 5 mm/sec, causing them to blur across 8 pixels. There is some blur in the bottom and left portion of the image, this blur is due to a different reason. The reason is that the camera was not placed directly above the plate. It was instead located off to the side and at an angle to the plate (figure 2a). The camera focused on the far side of the plate causing some blurriness on the near side. The lighting technique that was used was to eliminate all other lighting sources with the exception of the black light. No flash was used. It was found in the process of experimenting that an average black light is not enough to provide enough fluorescence. Instead, a more powerful black is necessary.

Table 3: Information regarding the photographic technique used for this photo

Photographic technique	**Value used**
Image height	300 mm
Image width	300 mm
Field of View	90000 mm^2
Distance from object to lens	403 mm
Lens focal length	5.5 mm
Type of camera	Canon EOS DIGITAL REBEL XT (8.0 Mpixs)
-Aperture	f/5.6
-Shutter speed	1/5
-Film speed	ISO 1600

Conclusion

The purpose of this image is to illustrate the Saffman-Taylor instability in a Hele-Shaw cell using fluorescents. The combination of these creates an image that is attractive from both a scientific and artistic perceptive. Overall, I was very pleased with the results of this experiment. My only complaint is the small amount of blurring, however, the image looks very clean, interesting, and beautiful.

References

[1] "Fluid Dynamics for Physicists" by T.E. Faber, Cambridge University Press, Cambridge 1995, pg 297-301.

[2] http://www.cargillfoods.com/pdfs/sweeteners.pdf/ca209.pdf

[3] http://www.overclockers.com/articles609/index02.asp

[4] http://www.hydramotion.com/Units_of_viscosity.html

[5] Saffman PG and Taylor GI, “The penetration of a fluid into a porous medium or Hele-Shaw cell containing a more viscous liquid,’’ Proc. R. Soc. London, Ser. A **245**, 312-1958.

[6] Fast P, Shelley MJ. Moore’s law and the Saffman-Taylor instability. Journal of Computational Physics 212 (2006): 1-5.