Honey and Taylor–Saffman

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MCEN 5151

Honey, Food Coloring and a Saffman-Taylor Instability

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Purpose:

The purpose of this photograph was to work within a group to capture a known fluid phenomenon. For this assignment we decided to capture viscous fingering using a radial Hele-Shaw cell. This viscous fingering is known as the Saffman-Taylor instability and occurs when a less viscous fluid displaces a more viscous fluid. For this attempt to capture this instability honey was used as our high viscous fluid and water dyed with food coloring as well as air acted as our low viscous fluid. Our experimental setup managed to produce some great pictures of viscous fingering as food coloring was injected in the center of the Hele-Shaw cell. However, in order to capture the picture on the title page a slightly different approach was taken that enabled air to induce fingering around the circumference of the honey.

Setup

Apparatus:

A radial Hele-Shaw cell was used in this setup, which consists of two parallel plates that could be adjusted to controls the thickness of the fluid flowing in between. Honey acted as the high viscous fluid and water dyed with food coloring as well as air were used as the less viscous fluids. The schematic below illustrates the procedure used to create the Saffman-Taylor instability.

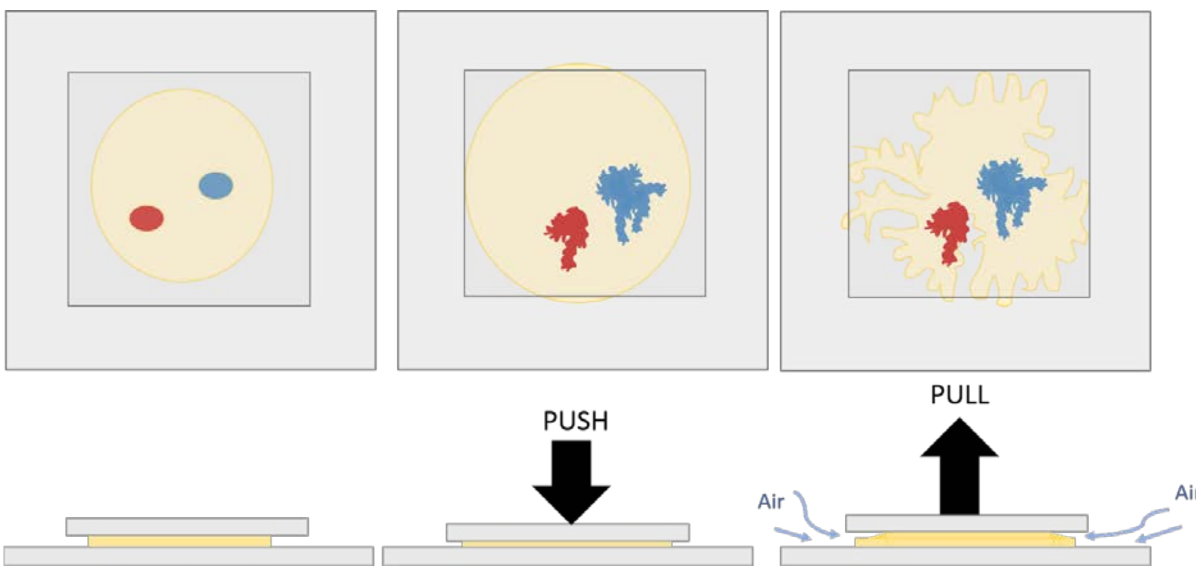

Figure 1: Setup and procedure used to create the Saffman-Taylor instability

First, honey and food coloring were placed in the Hele-Shaw cell. The top plate was then pressed downwards causing the honey and food coloring to spread out. It was observed that as the plate was being pressed down it cause the food coloring to start to finger through the honey. The top plate was then lifted. The sticky honey stuck to the top plate, thus a negative pressure was produce which forced the less viscous air into the honey resulting in fingering around the circumference.

Fluid Physics:

To achieve this photo a Hele-Shaw cell was used, which helps with the approximating Stokes flow by limiting the flow two 2-Dimensions. This is done through the use of two large parallel plates separated by a small gap.[1] The Hele-Shaw cell made it possible to view the Saffman-Taylor instability. This instability “arises when you displace a more viscous fluid by a less viscous fluid.”[2] In this experimental setup, the more viscous fluid used was honey and the less viscous fluids were dyed water and air. The kinematic viscosity of honey is 73.6cSt whereas water is 1 cSt and air is roughly 1000 times less viscous than warter.[3] This drastic difference in viscosity is the driving force behind the viscous finger. The low viscosity of water and air allows for it to flow more quickly than honey, thus long dendrites of water/air develop as it picks its way through the honey. This is related to how water picks its way through a porous medium such as sand.[4]

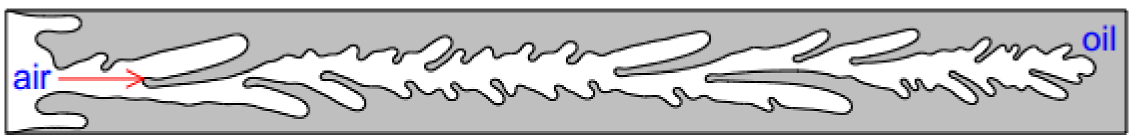

Figure 2: Schematic of viscous fingering in oil from air

Viscous finger can have a great effect on the flow rates of fluids, which is of great concern with regards to the flow of petroleum from oil reservoirs. This viscous fingering occurs because less viscous water or air are pumped into wells to assist with driving the oil out. The resulting flow rate can be describe by Darcy’s Law.[4] However, it was Saffman and Taylor that developed the model that characterized the extent of fingering that would occur. They discovered that the width and type of finger formed was dependent on the wavelength, λ, of the two fluids used in the experiment.[5] This relation can then form an equation, seen below, that describes the local curvature of the finger. When this equation is compared to an experimental results it is clear that this model does a pretty good job.

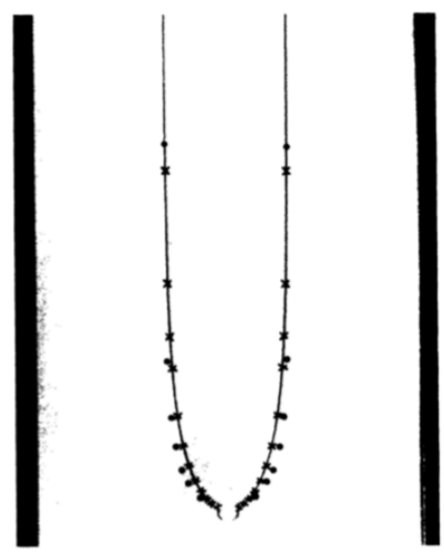

Figure 3: Experimental results compared with numerical model[5]

$$x = \frac{\lambda}{\pi} * \ln\left(\frac{1}{2 * \left(cos\left(\frac{\pi y}{\lambda}\right)\right)}\right)$$

Photographic Technique:

Camera Settings:

This photo was captured using a Nikon DMC-G5 with an 18-55mm focal length lens. The focus was set to the plane of the Hele-Shaw cell which was roughly 2 ft away. The camera was shooting with a shutter speed of 1/50, an aperture of f/3.5, and an ISO of 800. In order to reduce some of the glare from the glass surface of the Hele-Shaw cell the camera was zoomed in until the field of view was roughly 8’’x8’’. In order to properly light the setup two work lights were used as well as a white piece of foam core to create a soft white back drop.

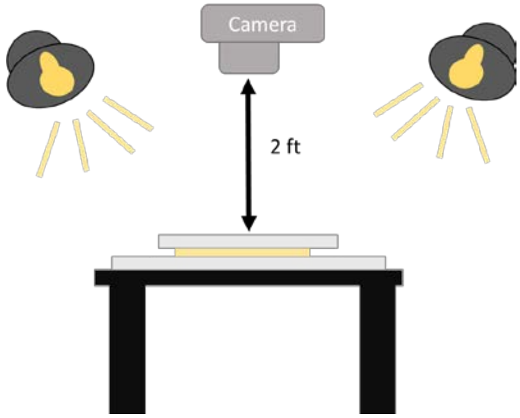

Figure 4: Camera setup

Post Processing:

Figure 5: Original photo (left) and edited photo (right)

The figures above show the original and final versions of the photograph after undergoing some post processing. The post processing included cropping the picture to remove a hand the edges of the glass sheet, as well as fiddling with “curves” in Adobe Photoshop by simply creating a parabolic line in order to amply to contrast in the brighter areas. Lastly, the sharpness and overall contrast was increased roughly +10.

Reflection:

I am very happy with the way this photo turned out. I find it to be very aesthetically appealing in terms of color and contrast. I also enjoy that you are able to observe the dramatic thin fingered features produce by air fingering into the viscous honey compared to the stubby subtle fingers that were a product of the dyed water fingering into the honey.

Bibliography

[1] "Hele-Shaw Flow." *Wikipedia*. Wikimedia Foundation, 30 Mar. 2014. Web. 07 May 2014. <http://en.wikipedia.org/wiki/Hele-Shaw_flow>

[2] Kondic, Dr. "Department of Mathematical Sciences • NJIT." *Department of Mathematical Sciences • NJIT*. N.p., n.d. Web. 07 May 2014 <http://m.njit.edu/~kondic/capstone/2014/saffman-taylor.pdf>

[3] "Liquids - Kinematic Viscosities." *Liquids - Kinematic Viscosities*. N.p., n.d. Web. 06 May 2014. <http://www.engineeringtoolbox.com/kinematic-viscosity-d_397.html>

[4] Chapter 3, *Interfacial Instabilities: The Saffman-Taylor instability*. Web. 06 May 2014. <http://www.maths.manchester.ac.uk/~ajuel/MATH45132/Chapter3.pdf>

[5] Couder, Y., N. Gerard, and M. Rabaud. “Narrow fingers in the Saffman-Taylor instability.” *Physical Review A* 34.6 (1986):5175