Saffman-Taylor Instability

Group 3 Assignment

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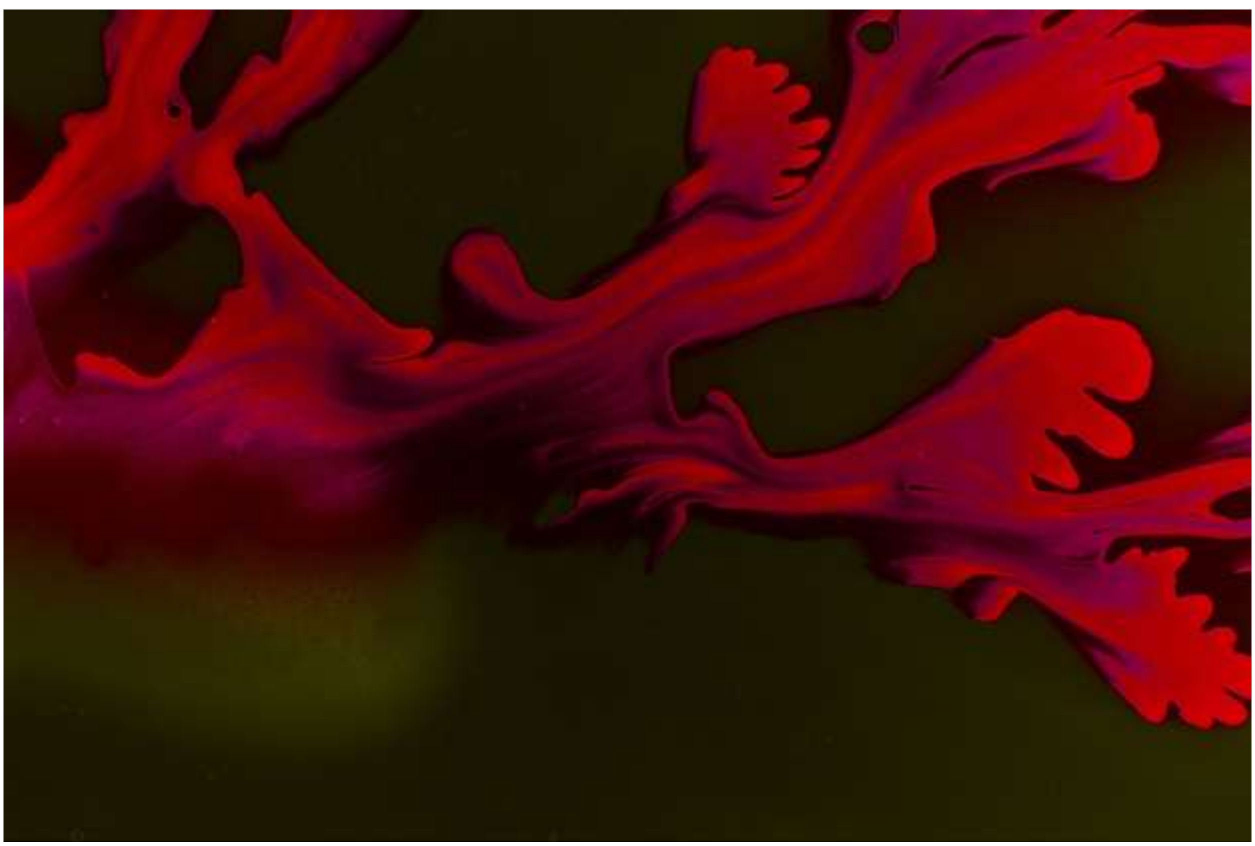
Flow Visualization

Spring 2011

5-4-11



This image was taken as part of the third group assignment for the spring 2011 Flow Visualization class at CU Boulder, and was an attempt to visualize the flow characteristics of two fluids with different viscosities in a Hele Shaw cell. The photo shows water mixed with red food dye injected into a layer of honey. The result is the beautiful example of a Saffman-Taylor instability seen in the image.

A Hele Shaw cell available in the ITLL was prepared with the help of Teaching Assistant Jesse Capecelatro, and was the apparatus used by the team. The cell consisted of a backlit table which supported two plates (Fig. 1).

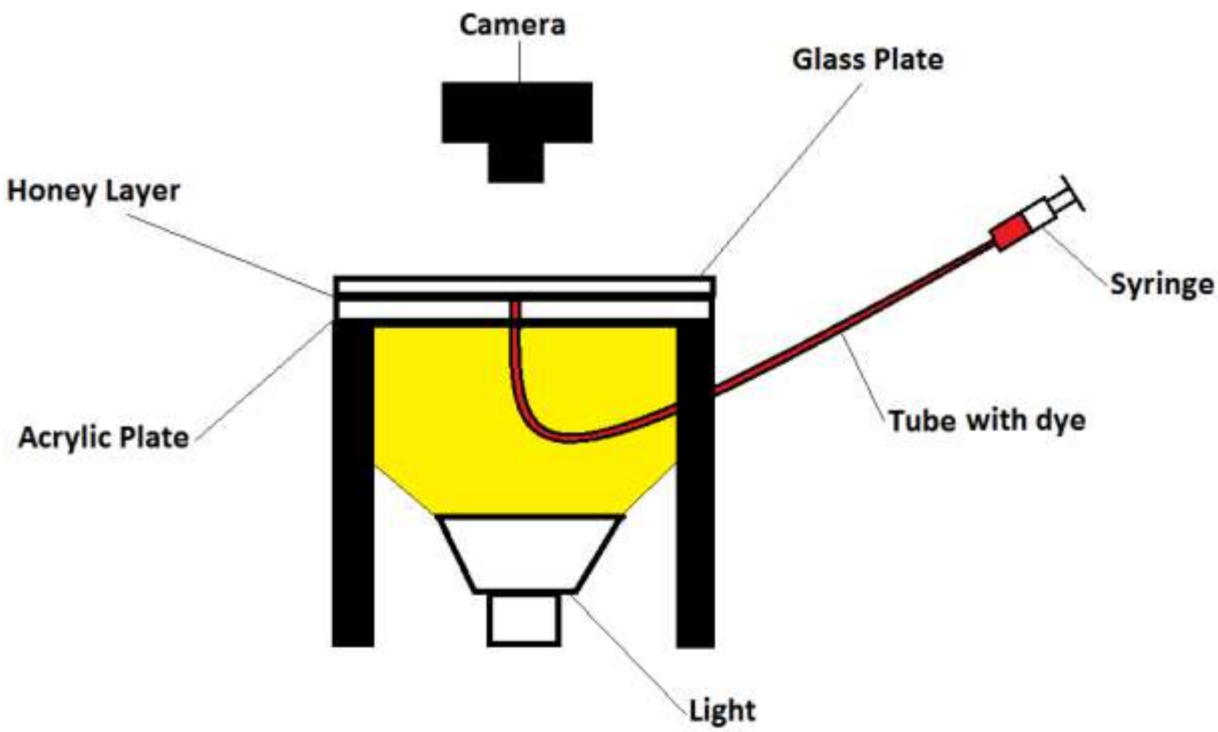


Figure 1: The configuration of the Hele Shaw cell used for the photograph

The first plate was a translucent acrylic baseplate which allowed the light from two halogen lights through. A thin layer of clover honey was poured on this plate and the clear glass plate was placed on top. A small hole drilled in the translucent plate allowed a tube attached to the tip of a syringe to inject red dye mixed with water between the two plates. Once the top plate was in place, a mixture of 40 drops of red food dye mixed with approximately 2 oz. of water was injected into the apparatus through the tube with the syringe, forcing the dye to flow through the layer of honey trapped between the two plates.

The dye traveled slowly as a laminar flow into the cell (approximately .01 m/s) through the relatively static honey. The food dye can be assumed to have the same density and dynamic viscosity as water, and at 30^{o}C are 995.7 kg/m^3 and 0.798 x 10^{-3} N*s/m^2 respectively (1). The honey has a density of 1,360 kg/m^3 (2) and a dynamic viscosity of 10 poise (1kg/m*s) at 50^{o}C and 16% moisture (3). The difference in temperature between the two fluids is estimated due to the heating of the honey by the light bulbs, which got very hot underneath the cell. Since the honey was on the acrylic plate for several minutes before the dye was injected, the honey likely reached a much higher temperature than the dye. The fingering effect seen in the image is a Saffman-Taylor instability caused by the difference in viscosities between the food dye and the honey, which causes a pressure gradient between the two fluids, driving the dye through the honey (4). The pressure from each fluid can be described with the following equation:

$$p = \frac{-\mu}{k}\cdot g\cdot\phi - \rho\cdot g\cdot y$$

Here we can see that the first term in the pressure is directly proportional to the dynamic viscosity of the fluid μ. Since the permeability k is similar for both fluids, the pressure due to the difference in viscosities of the two fluids means that the honey will have a pressure on the order of 1000 times greater than the dye within the cell. This is the driving force of the dye, as the honey puts pressure on the dye causing it to flow outward. The downward flow of the dye onto the honey is unstable, causing the fingering effect seen in the photograph (4).

The lights that were used were two 200W type t halogen lights also available in the ITLL. There was no flash used on the camera but there was a small amount of ambient light within the room. The dye was injected slowly into the honey with pauses in between injections to take photographs before more dye was injected.

During the experiment the flow changed fairly quickly. The finger-like portions of the flow would appear and be gone due to mixing within a few seconds while the dye was being injected. The camera was therefore chosen to be handheld rather than tripod mounted so that small portions of the flow could be photographed to capture detailed portions of the instability. The distance from the camera to the subject varied throughout the experiment, but for this image the distance was approximately 0.2m. The camera used to take the images was a Canon T1i Rebel 15.1 Mega-Pixel DSLR camera, with an 18mm-

55mm EL-S lens. The focal length was 55mm with an exposure time of 1/160 sec, an ISO of 100 an F-stop of F/9. The low ISO was used to help reduce noise in the image, and since the flow is nearly 2 dimensional, the depth of field was less critical so a moderate aperture value was chosen. The field of view was approximately 4cm x 3cm, and with an estimated velocity of .01 m/s, gives a movement of the fluid of about 6.25×10^{-5} m during the 1/160 sec exposure time. Thus the flow was temporally resolved.

The photo was edited using GIMP to enhance the colors and provide a more visually dynamic image. The colors were modified using the “curves” tool to change the hue and contrast of the image. Additionally, the “clone stamp” tool was used to eliminate some of the bubbles that appeared in the layer of honey.

Overall the image turned out beautifully, and the team successfully captured the Saffman-Taylor instability of the two fluids. Unfortunately, a shadow in the left side of the image caused some graininess in the image, but the key characteristics of the flow are very visible and it does not detract too much from the image.

The original image prior to editing with GIMP

Bibliography

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2. Honey. *Wikipedia.* [Online] [Cited: May 3, 2011.] http://webcache.googleusercontent.com/search?q=cache:nP2ZG7fuRlYJ:en.wikipedia.org/wiki/Honey+density+of+honey&cd=2&hl=en&ct=clnk&gl=us&source=www.google.com.

3. Technical Information for Manufacturers. *Airborne Honey.* [Online] [Cited: May 2, 2011.] http://www.airborne.co.nz/manufacturing.shtml.

4. **Mei, C.C.** Saffman-Taylor instability in porous layer-Viscous fingering. *web.mit.edu.* [Online] [Cited: May 4, 2011.] http://web.mit.edu/fluids-modules/www/porous_media/6-3SaTay.pdf.

The following are additional photographs taken using the cell, with either red or a combination of red and blue food dye injected into honey. All photos were post-processed using GIMP software.