Flubber

Anthony Johnson

Team Photo 2 Report

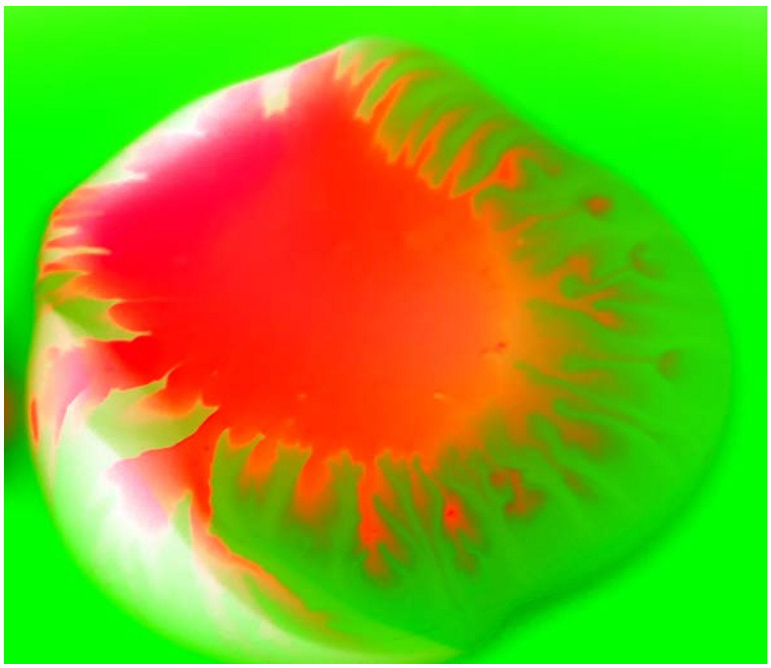

Image description:

The effects and overall appearance of a less viscous fluid flowing over another fluid with a substantially higher viscosity creates an image that not only displays good physics, but these physics and fluid dynamics produce a visual effect that is both beautiful and puzzling to the untrained eye. The intent of the cover image was to capture this effect in a way that was not only aesthetically appealing, but also was clear and detailed to demonstrate the flow characteristics present. This primary flow characteristic was that of the Saffman-Taylor instability and the resulting viscous fingering displayed by the less viscous fluid places on top to the greater viscous fluid. In order to obtain the detailed image, a team made up of myself, Aaron Coady, Jeff Byrnes, and Alyssa Berg was utilized to provide the highest quality image as well as demonstrate the fluid dynamics present in a way that would be un-achievable in a solo photographic session.

Method for capturing Phenomenon:

The method used for capturing the Saffman-Taylor instability and resulting viscous fingers was quite detailed and require several trials to obtain the clearest and most aesthetically appealing image possible. The photograph was taken in the flow visualization lab located in the ITLL. This lab was chosen not only because it had materials that were used for the photographic apparatus, but also was capable of very low lighting, which was critical for the photograph. To successfully achieve the desire image, a large, opaque acrylic plate was placed over two large black lights provided by Jeff Byrnes. An opaque plate was used because it diffused the black light so the physical light housing and assemblies could not be seen in the image, yet allowed enough black light to pass through to produce the desire effect of the black light. A pool of tide detergent approximately one inch in diameter was then placed in the plate directly over the black lights which produced a blue fluorescent glow as seen in the original image at the end of the report. A slightly larger pool of more viscous corn syrup was placed over the detergent. This provided height to the image, which aided in the 3 dimensional effect desire for the photograph. Finally, highlighter fluid was mixed with water and a few droplets were placed on top to the corn syrup and detergent mound. The highlighter fluid produces a fluorescent, tennis-ball green glow when exposed to black light. Photographs were then taken at approximately a 45-degree angle to the acrylic surface. This angle was necessary because it captured the 3 dimensional effect developed by the higher viscous fluids under the highlighter fluid droplets. This produced the original image as seen at the end of the report in which the base of the fluid mound was glowing blue with the bright green highlighter fluid demonstrating the Saffman-Taylor Instability by way of the viscous fingers developed over time. The overall size of the mound is roughly one and a half inches in diameter by half an inch tall. The photographic apparatus can be seen below.

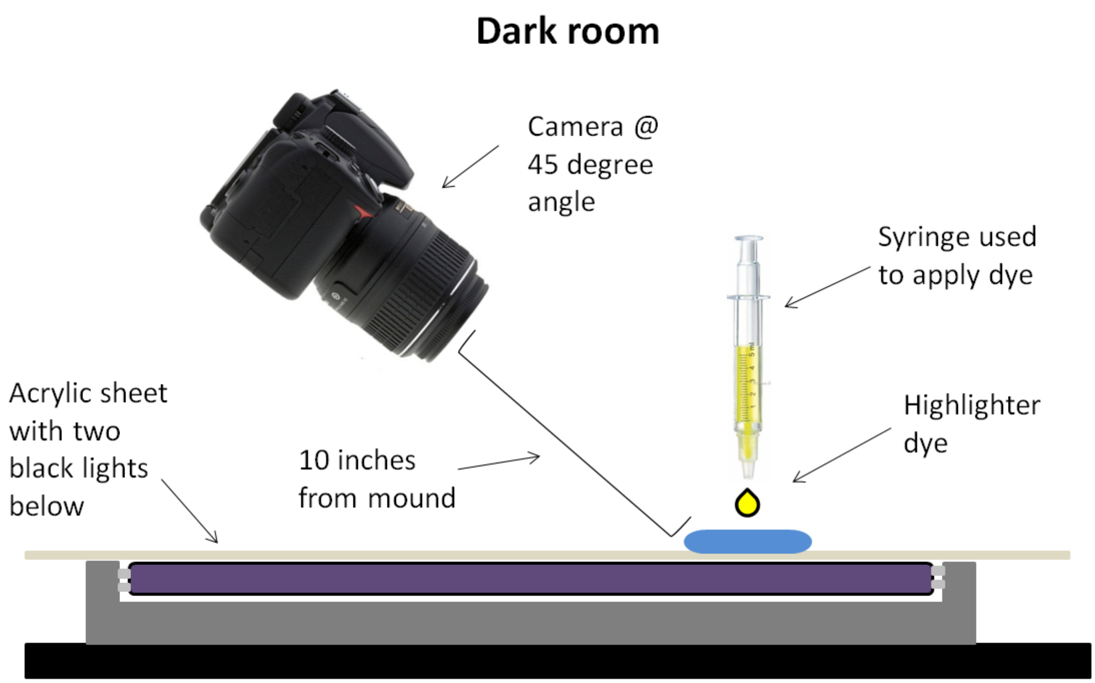

Figure 1: Photographic apparatus

Fluid dynamics and phenomenon:

The primary fluid dynamics demonstrated in the image is that of Saffman-Taylor instability and the resulting viscous fingering. Saffman-Taylor instability results when two or more fluids of different viscosities contact each other by way of either injection or by gravitational forces[2]. To form proper viscous fingers from this instability, the less viscous fluid needs to displace the greater viscous fluid. In the case of the photographic apparatus used to develop the cover image, the tide detergent and corn syrup are both more viscous than that of the highlighter dye. The force of gravity applied to the highlighter dye results in the corn syrup being slightly displaced by the dye and forming the characteristic viscous fingers. This flow is possible due to the fact that though the corn syrup is more viscous, it is actually lighter than that of the highlighter dye and therefore the heavier dye travels downward on the corn syrup and tide detergent mound[1].

In addition to the Saffman-Taylor instability, the cover image demonstrates the fluid dynamics of surface tension. This is evident in the image in the case where the fingers do not break through the surface of the mound and permeate through the higher viscosity fluids, but instead flow over the top and sides of the mound. This is due to the fact that the corn syrup and tide detergent molecules are formed tightly on the surface of their respective fluid pools and therefore do not allow the highlighter dye to pass through their tight molecular bonds[2]. These bonds create an internal pressure in the fluid mound and therefore repel the less viscous highlighter dye.

Given the fact the highlighter dye is flowing over the mound of corn syrup and tide detergent, the Reynolds number can be determined to provide insight into the behavior of the dye flowing over the mound. The dye has similar characteristics to that of fresh water given it is water based and therefore water density will be used. The equation used to determine the Reynolds number is:

$$Re = \frac{\rho V L}{\mu}$$

- μ = highlighter dye viscosity @ 20 ˚C[3] = 4 $\times 10^{-3}$ N s/m^2
- ρ = highlighter dye density @ 20 ˚C = 1008 Kg/m^3
- L = characteristic length = .0032 m (.125 in)
- V = mean velocity ~ .002 m/s

The resulting Reynolds number is 1.62 which is much less than the critical value of 5×10^5 where laminar flow translates into unstable turbulence. This indicates that the flow is laminar and that the chaotic nature of the highlighter dye flowing over the surface of the corn syrup and tide detergent mound is due primarily to the forces and physics of the Saffman-Taylor instability as well as the surface tension of the more viscous mound.

Photographic technique:

The photographic technique used to capture the image demonstrating the Saffman-Taylor instability and viscous fingering was limited given the low lighting necessary for the black light effects to be visible and as vibrant as possible. The camera used to obtain the image belonged to Alyssa Berg. This camera was selected because through test photographs, it provided the greatest detail and adjustability to obtain the clearest and sharpest image possible given the low light conditions. The camera was a Sony Alpha 230 using a standard 55mm lens. The ISO, shutter speed, and exposure that provided the best results were an ISO of 400 a shutter speed of 1/20 and f5.6. The long shutter speed was utilized to capture the most light possible to brighten the image and therefore a lower ISO could be used to reduce any graininess or blurring that is often present in low light photographs. The field of view size for the image prior to cropping was roughly four inches wide by three inches tall with the camera placed ten inches away from the mound on the acrylic plate. As previously mentions, the camera was placed at approximately a 45-degree angle to the horizontal plane of the plate. This enables the side of the mound to be captured as well as the top surface.

The post processing performed on the original image was quite extensive in an attempt to heighten the flow visualization as well as make the image as artistic and aesthetically appealing as possible. All post processing was performed using the Gimp software. The image was initially cropped in a manner that resulted in the fluid phenomenon filling over half of the frame. The original pixel dimensions were 3872 by 2592 pixels and the final image pixel dimensions were 2448 by 2112 pixels. As evident when comparing the cover image with that of the original, you can see that nearly the entire frame is filled with the focus of the image in the post-processed image. Also evident in this comparison is that the coloration had been altered drastically. This alteration was completed by utilizing the inversion tool as well as the addition of layers to produce greater shadowing and detail of the fluid flow in the image. The initial layer of the original cropped image was first duplicated 3 times in the layers toolbox. The top layer in the toolbox was inverted and left at normal mode. The two layers below were then set to addition mode in which they are added to the original image in an overlay setting. This provided shadowing which darkened the bright reflection created in the inverted image. The bottom layer was then set to overlay to provide overall shadowing and highlighting of the inverted image by way of applying purple and dark blues from the original coloration to the bright green areas of the inverted image as well as provide green to the bright red and orange of the highlighter dye on the mound. Once the image reached the desired effects and artistic quality, it was saved in Gimp to a format (.tif) that was not subject to data or detail loss. This post processing resulted in the image having a greater level of detail as well as increased the visualization of the Saffman-Taylor instability and viscous fingering.

Conclusions:

Overall I feel this image captures the fluid phenomenon of the Saffman-Taylor instability quite well with clear and evident viscous fingering resulting from this instability. One aspect I really find appealing is how the different viscosities of the corn syrup, detergent and the highlighter fluid result in a 3 dimensional mound in which the viscous fingers grow and once they reach the side you can see how the drop at the edge of the mound results in increased instability. One characteristic of the photograph that I would like to improve would be to have brighter black lights to provide even greater contrast to the highlighter fluid and the blue detergent. In addition this would provide a brighter environment to take the picture in and increase the definition and clarity of the image. Given the limitations in lighting this image clearly demonstrates the phenomenon's present and the fluid flows. If this image was attempted again, I would like to obtain brighter black lights as well as purchase various fluids that have greater fluorescent properties under a black light. In addition, it would be intriguing to see how the highlighter fluid would behave if instead of being placed on top of the mound, it was injected below the mound. This would potentially provide further insight into the Saffman-Taylor instability and how viscosity can greatly affect fluid dynamics.

Bibliography:

[1]Mora, S., (2009). Saffman-Taylor instability for generalized Newtonian Fluids. *Physical Review*, E 80, 016308. Obtained: April 1, 2012

[2]"Saffman-Taylor Instability." *Wikipedia*. Wikimedia Foundation, 02 May 2011. Web. 01 Apr. 2012. <http://en.wikipedia.org/wiki/Saffman-Taylor_instability>.

[3]"Ink Information." *Pigment Highlighter Ink, Dye Highlighter Ink, White Board Ink, Permanent Marker Ink, Permanent Cd Marker Ink, Permanent Pop Marker Ink Manufacturer & Service Provider From China*. Web. 01 Apr. 2012. <http://www.hellotrade.com/nnw-ink/product1.html>

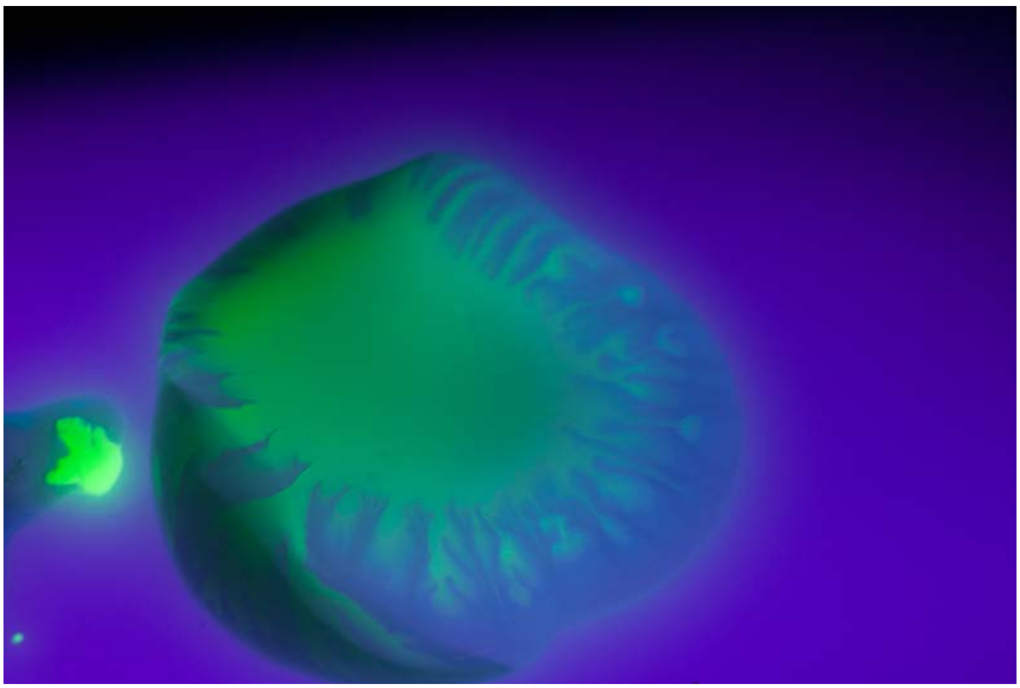

Figure 2: Original Image