Get Wet: An Introduction to Flow Visualization

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Purpose

The purpose of the first image in the University of Colorado's Flow Visualization course is to introduce students to the boundless possibilities available when artistically exhibiting fluid phenomenon. Several students and I had seen some amazing photographs of the turbulent behavior of bubbles in carbonated beverages. Eager to capture similar behavior, we proceeded to epically fail in producing anything similar to our inspiration. Turbulence only occurs for a few seconds after the drink is poured and requires a fairly delicate set up and quick response, if one wishes to trace the turbulent bubble path lines. While my team members (Jason Brownstein, Eric Fauble, Ryan Coyle) and I were unable to recreate anything of quality, we learned a lot about what it will take in the future to develop experimental set ups. So spurred instead by my passion for scuba diving, I decided to instead demonstrate the concept of buoyancy. As an avid scuba diver, buoyancy is a fluid property we must be constantly aware of, or one can quickly find his or herself in a dangerous situation. While in scuba diving buoyancy is largely controlled with weight and water displacement, the same concepts can be applied to an experiment of a much smaller scale; one that can fit in my kitchen. Armed with corn syrup, cold water, alcohol, food dye, and my brand new DSLR camera, I endeavored visualize buoyancy, laminar, and turbulent flow through a homemade Rayleigh-Taylor instability.

Experimental Set-Up and Flow Observation

To demonstrate buoyancy, the set up can be quite simple. Technically only two different fluids are needed, but I used three to so as to see a dynamic change at an interface. The set up is depicted in Figure 1. The denser fluid (Karo corn syrup) is placed at the bottom of a transparent and smooth glass, and cold water sits on top. Cold water was used to slow diffusion and make the image easier to capture. I used dyed isopropyl alcohol (70%) as the injection fluid. Plain food coloring can also be used, but the alcohol makes it less dense and therefore easier for it to travel upwards through the corn syrup. The higher the alcohol content, the less dense the injection fluid will be.

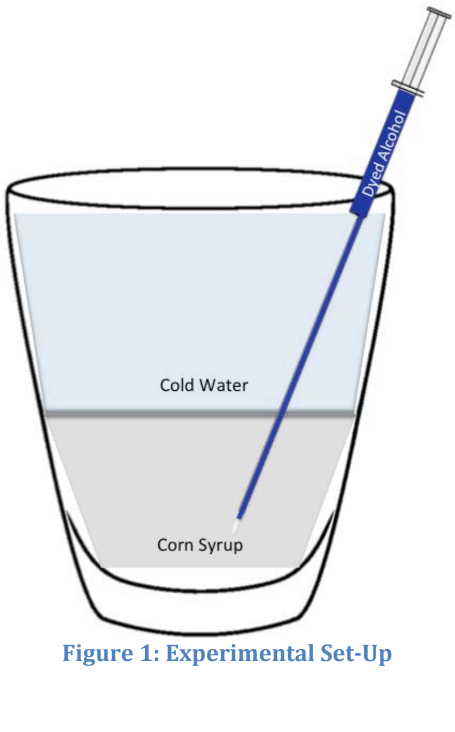

Figure 1: Experimental Set-Up

I experimented with several different colors, but blue proved to provide the clearest depiction of the phenomenon. As the dyed alcohol is manually injected into the bottom of the glass, the corn syrup, denser and heavier than the alcohol beneath it, begins to be dragged down by gravity, forcing the lighter alcohol upward. The corn syrup displaces the dyed alcohol in what is known as creeping flow, where the flow of the corn syrup downwards has a very low Reynolds number. [i] The buoyancy of the alcohol drives the corn syrup flow and is given by the equation for buoyancy in Wirth [ii].

$$b = -g\frac{\rho_{object} - \rho_{fluid}}{\rho_{fluid}}$$

Equation 1: Buoyancy (ms^{-2})

The densities of corn syrup, water, and alcohol are 86.2, 62.4, and 49.0lbs/ft^3 respectively. From Equation 1, it is clear the alcohol moves upward, with a positive "b" value in both regimes, in what is known as positive buoyancy.

Another phenomenon witnessed in this experiment is a transition from laminar to turbulent flow at the interface of the syrup and water. This can be understood with the Reynolds number in each region. The Reynolds number is a ratio of inertial forces to viscous forces in a flow, and can be written as

$$Re = \frac{VD}{\upsilon}$$

Equation 2: Reynolds number

where D is a hydraulic diameter or characteristic length, V is velocity, and υ is kinematic viscosity. As can be seen in the final project image as well as the reference images in Figure 2, the alcohol leaves behind smooth streamlines, and the mushroom cap stays fairly intact throughout its laminar journey through the corn syrup. As mentioned above, the corn syrup flowing downwards is an example of laminar "creeping flow." To compare Reynolds number in each region, velocities must be determined.

To find the velocity of the alcohol through each fluid medium, I can use pictures leading up to that which was used as my final image. The camera was set up to take 3 frames per second with a shutter speed of 1/10sec. I was able to measure the distance traveled by the alcohol from one picture to the next, (see Figure 2) as the alcohol traveled through each liquid. Pixels were correlated into inches from a pen, which was used as a reference object in other pictures.

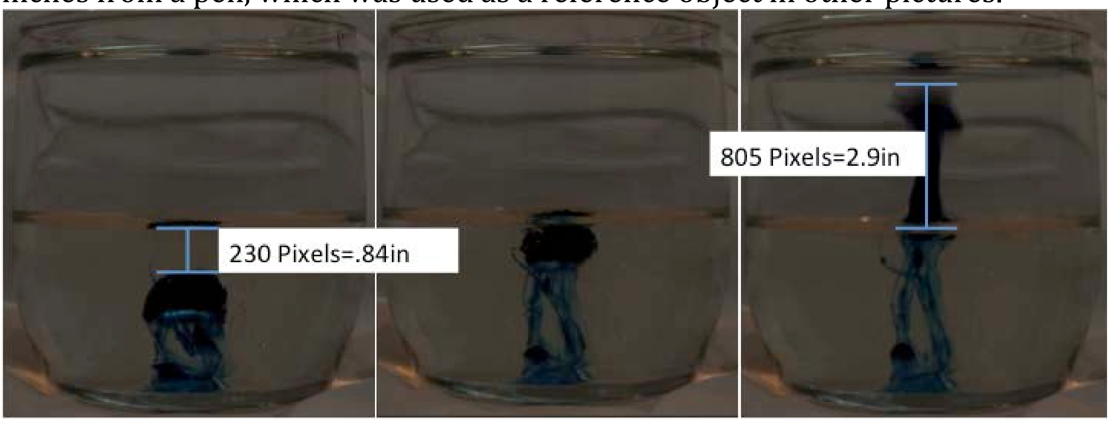

Figure 2: Method to measure velocity of alcohol

Given the burst rate, and subtracting out the shutter speed of each photo, the time between the pictures is .23 seconds. The velocity of the alcohol is then simply distance divided by time. We can put this all into Equation 3 to find the velocity through each fluid.

$$V_{syrup} = \frac{distance_{syrup}}{time} = \frac{.84in * \frac{1ft}{12in}}{.23s} = .30ft/s$$

$$V_{water} = \frac{2.9in * \frac{1ft}{12in}}{.23s} = 1.1ft/s$$

Equation 3: Velocity of alcohol through medium

From Equation 2, D is just a scaling constant dependent upon the experimental setup, but can be assumed constant throughout the corn syrup and water regions. The ratio of greatest interest is that of velocity to kinematic viscosity. Kinematic viscosities of corn syrup and water are .023 and 1.92×10^{-5} ft^2/s, respectively.[iii] Ballpark estimates for Reynolds number are 13 in the corn syrup and 57,000 in the water, where a Reynolds number of approximately 2300 is accepted as the transition from laminar to turbulent flow. This explains the laminar behavior in the bottom of the glass and the turbulent eddying and mixing in the top layer, which can be seen in the Get Wet project image.

Visualization Techniques

All necessary materials were purchased from a local grocery store. The corn syrup is Karo brand, the 70% isopropyl alcohol was a generic brand, and the food coloring was McCormick's blue. A 1/8th cup of alcohol was dyed with 8 drops of the food dye and inserted at the bottom and center of the corn syrup layer. Upon removal of the syringe, I began continuous shooting of the set up. The entire experiment took place indoors with an ambient temperature of 67°. Nearby windows had their blinds drawn, to have better control over lighting. The photo was lit constantly from above and behind the camera with flood lamps. A white paint drop cloth was used as the background. No camera flash was used.

Photographic Technique

I am very new to the art of photography, and in hindsight, I would have done things very differently, but the specs reported here are those actually used in the set-up.

Field of View	1 ft.
Distance from Object to Lens	11 in.
Lens Focal Length	18-55 mm.
Type of Camera	Canon T3 Rebel DSLR
Final Picture Size	2489 × 2541 pixels
Exposure	Aperture: 29.0 Shutter Speed: 1/10s ISO: 1600
Post-Editing	Cropping, removing of blemishes, transforming all but blue alcohol to Black and White

Table 1: Photgraphic Specs

Results

As far as demonstrating positive buoyancy and different Reynolds number flow regimes, I feel like my picture captured the phenomenon I was trying to exhibit. I was not, however, very pleased with the graininess of the photo. If I could do it all over again, I would be sure to use a stiff background, rather than a cloth, and adjust my depth of field to not be so large. As mentioned before, I am new to photography, and this was my first “professional” picture. As a learning and growing experience, I am pleased with the result. I know where I can improve, and I am excited to develop more complicated experiments.

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[i] Kundu, Pijush K., Ira M. Cohen, and Howard H. Hu. "9.11 High and Low Reynold's Number Flows." *Fluid Mechanics*. 2nd ed. San Diego: Academic, 2002. 295-96. Print.

[ii] Wirth, Achim. *A Guided Tour Through Buoyancy Driven Flows and Mixing*. *Laboratoire Des Ecoulements Géophysiques Et Industriels*. University of Grenoble, 19 Aug. 2013. Web. 9 Feb. 2014. <http://www.legi.grenoble-inp.fr/people/Achim.Wirth/lecnBDF.pdf>.

[iii] Elert, Glenn. “1.8.5 Fluids/Viscosity.“ The Physics Hypertextbook. Glenn Elert. eBook.