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Group E
Flow Visualization

This image was created for the first group project in Flow Visualization at the University of Colorado. Our goal was to capture interesting surface phenomena at the interface of corn syrup and water. These self-separating liquids (corn syrup is more dense) were contained in a glass vase. Air bubbles dragging an oil droplet from the corn syrup-water interface towards the water-air surface is pictured.

We used a syringe to inject liquids (such as water, soap, dye, and olive oil) into the bottom of the vase through plastic tubing, which was wrapped in wire to increase stability. Figure 1 shows a flow diagram of liquid pumped into our glass container.

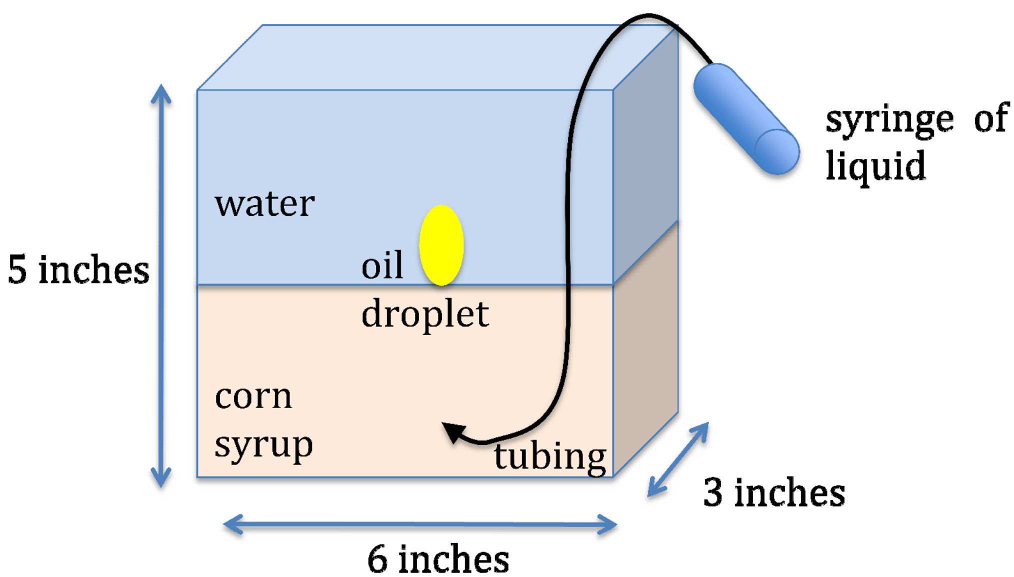

Figure 1 shows the liquid of interest being pumped into the corn syrup, water system. Approximate length scales are shown. The oil droplet's position in the image is also shown.

We can approximate a Reynolds number for the spherical droplet flowing in the syrup as well as in the water,

$$\mathrm{Re} = Dv\rho / \mu,$$

where v is the velocity of the spherical droplet, D is the diameter of the droplet, and ρ and μ are the density and viscosity, respectively, of the surrounding fluid. The droplet had a diameter of 0.3 inches when it was spherical. The diameter of the droplet sphere can be used instead of a characteristic length because while in the bulk fluid, surface tension maintains a spherical droplet shape.

However, the image is nearly static; only the top portion of the oil droplet is moving. The bottom of the droplet is attracted to the corn syrup surface while an air bubble is deforming the static droplet. This attraction is caused by the mutually higher surface tension of oil and corn syrup compared to water. Flow is caused by the deformation of the oil droplet rather than it's motion through a media. Therefore, the calculation for flow over a sphere would not be relevant to the flow visualized and a more complex analysis would determine if this was laminar flow.

Injecting one fluid into another can provide details on a fluid's physical properties. A known force (buoyancy) and measured velocity will determine the mobility of the spherical droplet[2]. Stokes' Law for flow around a sphere or the Stokes-Einstein equation for the drag force will determine the viscosity[1]. This is not a practical technique for experimentally determining the viscosity of simple fluids due the range of viscometers available, however, this approach is used in simulations of granular 'fluids' to determine the 'solid viscosity', a closure for the proportionality constant that shows up in the shear stress term in the two-fluid continuum model (Navier-Stokes-like equations) used to describe the motion of solid particles in a fluid[1].

Standard cooking olive oil was injected into standard cooking corn syrup and tap water. The difference in color was sufficient to visualize the flow. Two desk lamps were using to light the vase without a camera flash.

The picture was taken about 1 foot from the vase. The image field of view is about 6 square inches. Additional camera information is given in table 1. The image was initially 4272 x 2848 pixels and was cropped down to 700 x 793 pixels to increase the sense of scale. The decreased field of view also makes the trail of oil, which is penetrating into the corn syrup, look like a reflection. I de-noised the backdrop to make it less distracting, and sharpened the image and increased the exposure to bring attention to the oil droplet and air bubbles.

Table 1. Camera Specs

Camera type	Canon EOS Digital Rebel XSi
Focal length	214 mm
F-number	5.6
Exposure time	1/60 s

This image shows a balance of forces between the attraction of oil to the corn syrup surface and the buoyancy of air bubbles, which are held within the oil by the droplet's surface tension. I like the shine on the air bubbles and oil against the smooth background and what seems to be a reflection of the oil against the corn syrup surface. I'd like to have achieved better resolution to capture the interior of the oil and its interaction with the air, but I think the physics have been well visualized.

References:

1. Van der Hoef, M.A., Van Sint Annaland, M., Kuipers, J.A.M., Computational fluid dynamics for dense gas-solid fluidized beds: a multi-scale modeling strategy. Chemical Engineering Science 59 (2004), 5157- 5165.
2. SklogWiki.org. http://www.sklogwiki.org/SklogWiki/index.php/Mobility