Get Wet Report: Honey Droplet on a Vertical Wire

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Flow Visualization: The Physics and Art of Fluid Flow

The get wet assignment is designed to give students the opportunity to explore scientific phenomena through creative use of photography and visualization techniques. The purpose of the associated image is to capture the slow flow of a fluid along a vertical surface as it conforms to the forces of gravity, surface tension, and fluid friction. The experiment was set-up and photographed by Hans Loewenheath.

The experimental set up contained two sources of light (a diffracted backlight and a single bulb for up-lighting), a hanging wire, honey, and a dish to capture the fallen fluid, see Figure 1. The basic flow of the fluid is laminar flow along a vertical surface. The approximate size of the honey droplet in the image is 0.5 inches in diameter.

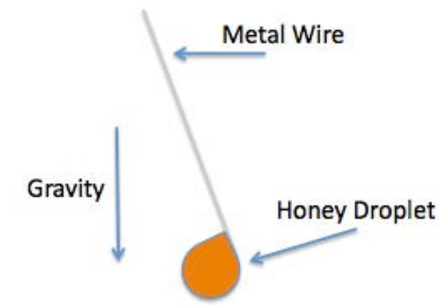

Figure 1: Schematic of the honey droplet experiment

The only internal force acting on the honey droplet in motion is gravity. Surface tension and fluid friction are external forces. Gravity is pulling the droplet towards the surface of the Earth. Surface tension (force/length) is acting to minimize the surface area of the droplet and keep its current teardrop shape[1]. Fluid friction is acting to resist the fluid's downward flow[2]. As the honey moves down the wire, the fluid is subjected to stress and strain. A newtonian fluid is one whose viscosity stays constant regardless of the stress and strain in the material[3]. Honey is said to exhibit non-newtonian characteristics, "a fluid that changes its behavior when under stress or strain[4]." As the honey is stressed and strained, the viscosity decreases and decreases the fluid friction of the honey, allowing the honey to speed up along the wire. This is known as stress thinning, or pseudoplasticity, and is also found to be true of fluids such as molasses and syrups[5]. However, the speed of the fluid observed is assumed to be constant for ease of calculations. Because the speed of the fluid is assumed to be constant, the forces are in equilibrium. If the forces are in equilibrium, then the follow equation must be true:

$$F_{gravity} = F_{friction} + l*Y_{ls}$$

Equation 1: Force balance of the honey between gravity, friction and surface tension ($l*Y_{ls}$)

Calculating the total force of the fluid friction and surface tension combination is a simple calculation once we find the force of gravity. The force of gravity is calculated using Equation 2:

$$F_{gravity} = ma = V\rho a = [1.33\pi(0.006m)^3](1360\frac{kg}{m^3})(9.8\frac{m}{s^2}) = 0.012N$$

Equation 2: Force of gravity on the honey[6]

The assumptions for this equation were that the honey is in the shape of a sphere and the radius of the sphere was about 0.25 in (or 0.006 m). The radius of the honey was selected because the diameter was assumed to be 0.5 in. The gravitational force of 0.012 N is relatively small, but equal to the sum of the frictional force and surface tension opposing the downward flow. The honey accelerated during the first few seconds of fall, and then remained at a constant velocity for the remainder of the length of the wire. The constant velocity is maintained because of the force balance between gravity, fluid friction, and surface tension.

In order to describe the general flow characteristics, often times the dimensionless value of the Reynolds number is used to compare two different fluids. Equation 3 calculates the Reynolds number of the honey.

$$Re = \frac{UD}{v} = \frac{(0.01\frac{m}{s})(0.3m)}{(73.6 * 10^{-6}\frac{m^2}{s})} = 40$$

Equation 3: Reynold's number for honey[7]

The Reynolds number calculation assumes that the honey took 30 seconds to fall the length of the 12 in wire, and that the room was at 37.5 degrees Celsius. The Reynolds number is significantly less than 2300, and is therefore in laminar flow[8]. The laminar flow region specifies that the fluid in question does not have any turbulence.

At the moment in the image, the flow of the honey droplet is just about to transition away from the wire. Dropping away from the wire will essentially neglect fluid friction and allow the droplet to accelerate.

The experiment did not use any additive materials for visualization. Excellent lighting was sufficient to illuminate the honey with enough contrast from the background. Of the two lights used, one was diffracted from behind the droplet and the other was used as an upward spotlight. The diffracted light spread to illuminate the droplet and the surrounding area from behind while not appearing as a point source of light in the image. The up-lighting was used to better illuminate the droplet and wire on the side closest to the camera and to add some reflected light to the refracted image of the background. One either side of the wire, dark textbooks were placed upright in order to complicate the image reflected in the honey droplet.

The camera captured the honey droplet while extremely close to the wire and droplet of honey. The camera was so close that some residual honey was transferred onto the lens during one of the shots. This technique was chosen so that only the honey droplet and wire were in focus, while the background would be blurry and out of focus. This focused the viewer's eyes on the honey droplet. The field of view is approximately 6 inches (~150mm). The lens was about an inch from the droplet. The lens used has a focal length of 18-135mm and was mounted on the end of a 49mm extension tube. With the extension tube, the focal length was 99mm. The camera used was a DSLR (Cannon EOS 60D) with an original and final pixel dimensions of 5184 wide by 3456 high. Using Av (aperture priority), the exposure specifications were f/21, 1/64 sec, and an ISO of 400. In Photoshop, curves was used to increase contrast for all three colors, each color individually, and then noise was reduced using the JPEG artifact removal tool.

The honey droplet image reveals a beautiful teardrop shape that is often associated with a raindrop. The wire was able to give sufficient time to place slow-moving honey onto the wire and then capture a series of images of the honey moving along the wire. The physics of surface tension is shown in the shape of the droplet. The fluid friction is shown with the trail of honey that is residing on the upper parts of the wire. Gravity is portrayed by the downward flow of the fluid, indicating that the bottom of the image is in the direction of gravitational acceleration. The intent of the project was to convey a simple and commonly observed flow in an artistic setting while experimenting with a DSLR camera and Photoshop. The experiment could improve the shape memory of the wire, as multiple bends in the wire were difficult to smooth out for consistent droplet speed and distance from the camera. The topic of fluid friction as a function of distance from the wire could be explored in the future. How does the honey flow within the droplet over time? Techniques to display how the fluid flows within the droplet over time would be helpful to understand whether the droplet rolls or slides down the wire.

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[1] Wikipedia contributors. "Surface Tension." *Wikipedia, The Free Encyclopedia*. <http://en.wikipedia.org/wiki/Surface_tension>.

[2] "Fluid Friction." *TutorVista*. N.p.. Web. 10 Feb 2013. <http://physics.tutorvista.com/forces/fluid-friction.html>.

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[4] "Honey." *Science Learning*. N.p.. Web. 11 Feb 2013. <http://www.sciencelearn.org.nz/Science-Stories/Strange-Liquids/Sci-Media/Images/Honey>.

[5] Wikipedia contributors. "Non-Newtonian fluid."*Wikipedia, The Free Encyclopedia*. <http://en.wikipedia.org/wiki/Non-Newtonian_fluid>.

[6] Wikipedia contributors. "Honey." *Wikipedia, The Free Encyclopedia*. <http://en.wikipedia.org/wiki/Honey>.

[7] "Fluids - Kinematic Viscocities." *The Engineering Toolbox*. N.p.. Web. 10 Feb 2013. <http://www.engineeringtoolbox.com/kinematic-viscosity-d_397.html>.

[8] Wikipedia contributors. "Reynolds number." *Wikipedia, The Free Encyclopedia*. <http://en.wikipedia.org/wiki/Reynolds_number>.