Get Wet Report

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MCEN 5151-002 Flow Visualization
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Purpose and context

This image was taken for the first Get Wet assignment in Flow Visualization (Fall 2023, MCEN 5151) with Professor Hertzberg. The end goal for the assignment was an image that artistically demonstrated a fluid phenomenon. I photographed the interaction of honey and water in a splash impact. My initial experimentation was with honey, trying to capture buoyancy, but my images were failing to capture movment. I noticed the water-honey shear boundary when washing up after these experiments and changed my focus to capturing this phenomenon. There were a number of interesting visuals, and I selected the splash off the glass plate because of its motion.

Materials and methods (flow apparatus)

I opted to use materials readily available in my home and constructed the set up under the kitchen faucet. The setup is depicted in Figure 1. At full flow, the faucet runs at about 70 ml/s, as measured by placing a 2-cup measure under the flow for 5 seconds and was about 10 degrees Celsius as estimated by an electronic cooking thermometer. The faucet nozzle was 2 cm in diameter. Beneath the faucet, I layered a 10 x 15 cm glass pane, a sheet of printer paper, and a translucent white plastic cutting board. The glass surface was 10 cm below the faucet nozzle. An LED light source (Petzl Bindi) was secured to the bottom side of the cutting board and set to medium brightness (100 lumen [1]). The light was placed directly against the cutting board, so that the blueish LED light was diffused through the warmer white plastic. The printer paper added a second, more uniform diffusive filter for the light. The glass plate was included to prevent the water from staining the paper and keep the light bright. The honey was Kroger brand with no additives. The photo was taken after dark with no additional light sources and minimal ambient light.

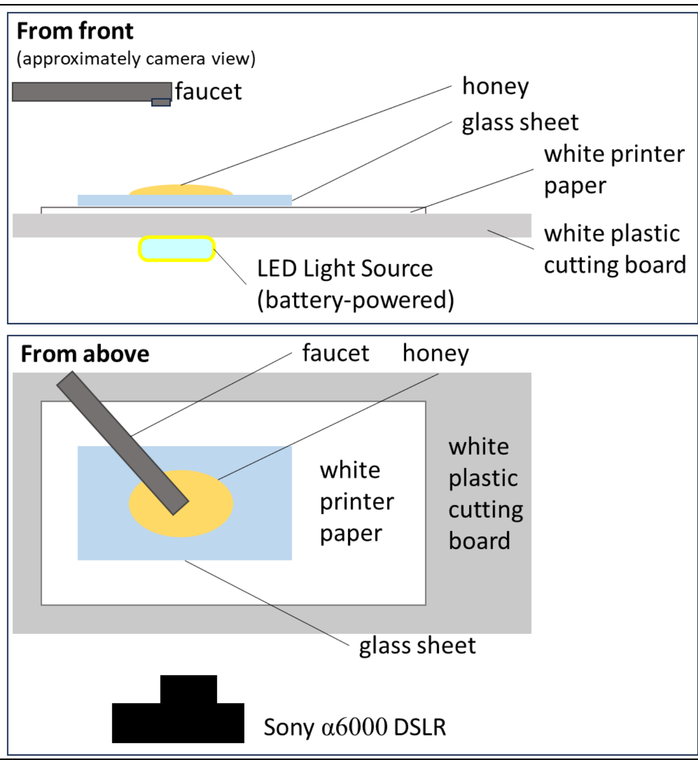


Figure 2: The experimental set up and lighting. *From the front:* the view, just below where the camera was mounted on a tripod. The camera was positioned above the cutting board level and angled down so that the light source was not visible from the side.

From above: the the front, approximately where the camera was mounted on a tripod and from above

Fluid Dynamics

The image shows the interaction between honey and water at the glass plate. The water flowing out of the faucet is turbulent $Re = \rho v L/\mu = (999.7 kg/m^3 * 0.228 m/s * 0.02m)/0.00131 kg/(m * s^2) = 3485$ and aerated (fluid parameters from [2]). The honey sitting on the glass was most likely Newtonian (some honeys, based on different pollen sources, show non-Newtonian characteristics, but as far as I can determine, the brand of honey was not sourced from those types) [3, 10]. For now, we will proceed with the assumption that honey is behaving as a Newtonian fluid. Thus, while both water and honey are Newtonian fluids, the viscosity of the fluids differ markedly. The water dynamic viscosity is 1.31 x 10E-03 Ns/m^2[4]. In contrast, the honey 18.39 Ns/m^2, a difference of three orders of magnitude [5]. Pure honey is also resistant to mixing with water, especially cool water, because natural honey has a low water content (<20% [6]) and mixing requires the water molecules to pull sucrose and glucose molecules away from one another [7]. The water impacted honey with momentum resulting from the vertical drop and the pressure from the faucet.

The honey, pooled on the glass plate and largely resistant to mixing, was pressed away from the contact point from the impact of the water jet and the jet collided with the glass surface. The water jet directed at the glass surface is called an impinging jet, resulting in the spatter shown in the photograph [8]. The spatter is driven by disturbances on the surface of the jet which arise from the turbulence and aeration coming out of the faucet [8]. For impingement of a turbulent jet on a smooth surface, the amount of spattering increased with dimensionless distance l/d, for the distance from the jet nozzle to the surface l, and the diameter of the nozzle d [8]. Given the measurements of this apparatus, this distance parameter would be 5 and would result in have minimal spatter according to data in [8], though the data there was based on a range of nozzle diameters less than half of the faucet nozzle and with no aerating screen. Even so, it is likely that the large splash in the image is the result of the water jet interacting with the honey.

The water that isn't spattered is forced along the glass surface by the inertia of the water behind in the continuous flow. The honey's intramolecular forces initially resist the outward flow and shear forces of the jet. Honey's adhesive force is greater than its cohesive force [11] and so the inertia of the water first pushes back the honey, leaving a thin layer of honey against the glass around the immediate jet contact point. This honey layer deflected the water slightly and the water began to form a pocket in the layer of honey. Eventually, the shear forces from the jet flow pushed back the honey and water began to flow smoothly over it as in Figure 3.

Additionally, the appearance of the photo in Figure 1 is reminiscent of a phenomenon described in the aptly named paper "A bouncing liquid stream," published by A. Kaye in 1963 [12]. This paper described a non-Newtonian, viscoelastic fluid being poured in a thin stream into a shallow evaporating dish. The effect is characterized by the formation of a "heap" of fluid at the point where the stream meets the fluid in the dish and the generation of a small upward stream, initially parrallel with the fluid surface, but with an increasing angle that eventually merges with the heap, causing both heap and upward stream to die away before the sequence begins again [12]. While the water and honey interaction does not cycle in this manner, the initial jet impact and spatter effects do appear to generate a secondary upward water stream. In the Kaye effect, the vertical force of the liquid stream creates a dimple structure, with surface tension holding the dimple, and the jet efficiently bends to create an upward jet, with shear-thinning allowing the stream to slip around the curve of the dimple and remain intact [13]. In the Kaye effect, the stream and dimpled fluid below are the same liquid [13], but in my experiment, the honey is the liquid below the jet. Some honey has been shown to be non-Newtonian and exhibits shear-thinning [3]. And, impacted by the force of the water jet, the honey does form a dimple, directing the upward splash of the water. It is possible that shear-thinning played a role in this boundary response, however I think that the combination of honey's high surface tension and the low viscosity of water could also generate the jet in the image. The low cohesive force of the water creates a spatter of fluid.

Thus, the image presented in Figure 1, maybe a demonstration of the formation of an impingement jet as water from the faucet strikes first the honey and then the hard glass surface below. However, the behavior between those two instants, where the surface of the honey is still intact may represent the Kaye effect, though with two separate fluids.

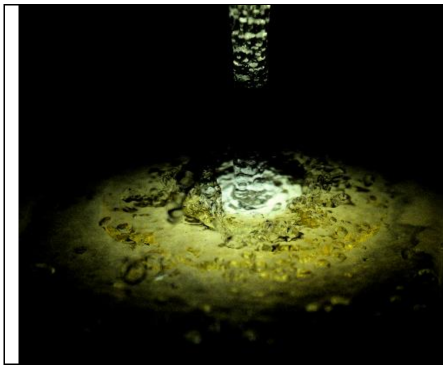


Figure 3: Water jet flowing over honey, after intial impact, the jet formed and collapsed a pocket in the honey and began to flow over the honey more smoothly.

Imaging technique

A Sony α6000 DSLR camera was used to capture a series of photos. The camera was set to an automatic action setting. The camera settings are described in Table 1.

Table 1. Camera settings

Camera settings	**Sony α6000** (ILCE-6000)
Focal length	50 mm
Aperture	f/ 2.2 (from metadata)
Exposure time	1/2000 second
ISO	3200
Pixels	6000 x 3376
Lens	**SEL50F18**
Optical Steady Shot (OSS)	Image stabilization [14]
Circular Aperture	f/ 1.8 (lens maximum aperture)

The view of the setup from the camera is shown in Figure 4 with the lens cap (⌀ 5 cm) for scale. In addition, the glass plate is 10 x 15 cm (4 x 6 in). Thus, the field of view is approximately 20 cm wide and 30 cm deep (some of that lost in the shadow beyond the white cutting board), with the camera positioned to the side and slightly above the surface of the glass. To take the image series, I pressed and held the shutter button to initiate the rapid series of short exposure photographs and turned on the water, moving the faucet fully open as quickly as possible.

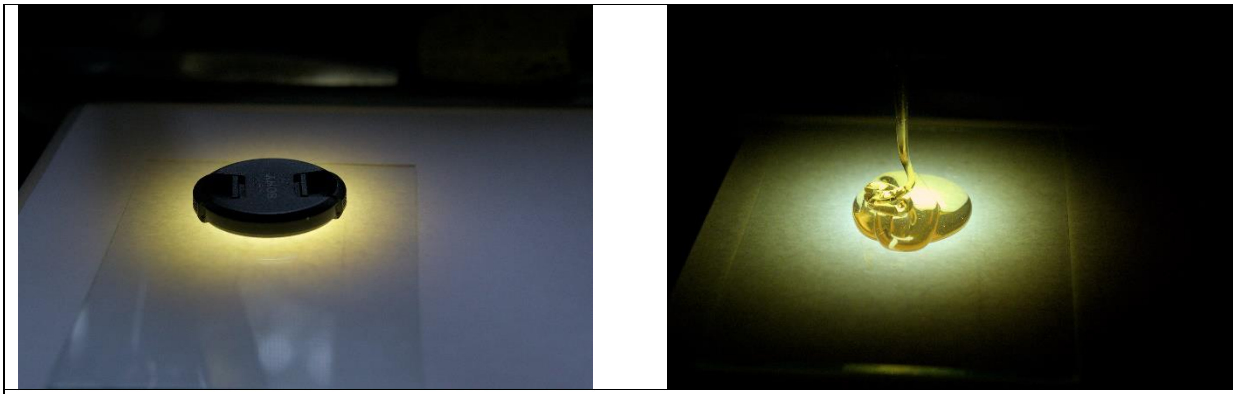
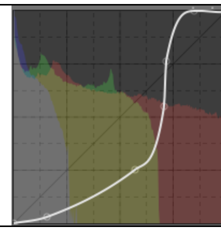


Figure 4: (Left) set up including the white cutting board, lit from below with an LED headlamp, a white piece of paper to smoothly diffuse the light filtering through the board, and the glass plate below the faucet. A lens cap is placed over the light in the place the honey will be poured. (Right) Honey coiling as it is poured onto the glass sheet in preparation. (Both photos are unedited PNG exports of the RAW files).

In post processing, I cropped the image to remove the blurry water spatter towards the camera as well as the dark area around the pulse of the LED. I then altered the color to try to recapture the warmer light feel of the honey, which was overpowered by the blue tinge of my LED light. All post-processing was done in darktable 4.4.2. The RGB curve was shifted into a tight S-shape, with emphasis on darkening colors in the middle range of brightness and highlighting the colors appearing at the furthest on the brightness spectrum. I adjusted Color Balance to reduce contrast (-18.16%), increase global chroma (+14.36%), and increase mid-tones (+28.49%). I also used Color Balance to reduce global brilliance (-31.84%) and increase mid-tones brilliance (+22.91%). Using the Filmic RGB toolset, I adjusted the black and white relative exposure so that there were more steps between middle grey and black than between middle grey and white (-7.56 EV black and +4.25 EV white). To add warmth to the colors, I used the color calibration tool to increase the red channel (+1.071). To add brightness to the photo after the color adjustments, I increased the exposure slightly (+0.520 EV).

Image reflection

I selected this image from the series because of its particular dynamism and the way that it captures and freezes something ephemeral. Though the sole light source being filtered through the honey puddle, makes the boundary between the two fluids is difficult to see, I like the way the light is central to the splash and seems to climb up the water jet with nothing else in the dark space to illuminate. While the image captures something of the fluid motion, neither the impinging jet nor the Kaye effect are clearly represented (in part because the water jet impact on high viscosity honey does not fit cleanly into either described phenomenon). I am interested in the possibility of a two fluid Kaye effect based on shear-thinning honey in this experiment and think that high speed images, as used in [13], may be helpful in identifying the flow development in the time between initial contact with the honey and contact with the glass plate. I would like to improve the lighting set up, which was limited by the pulse-width-modulated LED light. The pulsing light band meant that some images in the series did not illuminate the flow and prevented the use of a photo series or animation in this project. In further work, use of a continuous light source and a high speed camera could generate images that are more informative with respect the fluid dynamics and even more ephemeral and mysterious artistically.

	
Figure 5	
Unedited photo	Edited photo
Dimensions: 6000 x 3376	Dimensions: 2546 x 2442
	RGB Curve: 

Citations:

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