Team Second: Folding of a Stream of Oobleck

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INTRODUCTION

This report documents the image submitted for the Team Second assignment for the Flow Visualization course. The intent of the image was to capture the non-Newtonian behavior of a shear-thickening Oobleck sample as it hits a solid object. Specifically, we wanted to visualize how the fluid transitions from a stream into a rigid coil before relaxing back into a long stream. I collaborated with Ryan Cross and Jay Hall, who assisted with the creation of the Oobleck, physical setup, lighting, camera work, and ideas.

SETUP AND FLOW

The setup (Figure 1) consisted of green-dyed Oobleck poured directly from a round container onto a horizontally angled threaded steel bolt. The pour height was kept under six inches. Assuming a maximum drop height of roughly $h = 0.10$ m, we can estimate the fluid's kinematic free-fall velocity right before impact ($U = \sqrt{2gh}$) to be approximately 1.4 m/s. The background was a draped black cloth.



***Figure 1**. A diagram of the setup, being used for a different experiment.*

When the fluid hits the bolt, it slows down abruptly. Because Oobleck is highly viscous, it doesn't splash. Instead, the impact creates a compressive force that makes the stream buckle sideways. This causes it to fold and coil over the bolt [1]. At that exact moment of impact, the collision squeezes the water out from between the cornstarch particles, which leads them to compress together so the fluid temporarily acts like a solid [2].

However, since the container and bolt were both handheld and slightly moving relative to each other and the bolt was narrow, perfect coils could not form. Additionally, the fluid was poured as a flat ribbon instead of a circular cross-section. Having the width of the stream be greater than the diameter of the bolt, it folded unevenly over the edges. Therefore, the image displays messy folding. As this fluid slides off the bolt into the air, the folds maintain a solid three-dimensional shape. This is because of relaxation time, a thixotropic property meaning the fluid has a structural memory. It takes a delay for the particles to unlock and act like a liquid again.

To describe the flow at impact, we can estimate the Reynolds number. Using the calculated free-fall velocity ($U = 1.4$ m/s), an estimated ribbon width for characteristic length ($D \approx 0.015$ m), an Oobleck density ($\rho \approx 1000$ kg/m^3), and an estimated effective viscosity for the jammed state ($\mu \approx 100$ Pa · s):

$$Re = \frac{\rho U D}{\mu} = \frac{(1000 \text{ kg/m}^3)(1.4 \text{ m/s})(0.015 \text{ m})}{100 \text{ Pa} \cdot \text{s}} = 0.21$$

While typical engineering problems involve turbulent Reynolds numbers in the thousands, these kinds of viscous fluids function in creeping flow, also called Stoke's flow, where $Re \ll 1$. This explains the lack of splashing despite the impact velocity. As the tail drips downward, gravity pulls and stretches it, which causes the Oobleck to strain-harden (extensional thickening), which keeps the fluid as a continuous strip before it can break apart [3].

VISUALIZATION TECHNIQUE

Green food coloring was mixed into the Oobleck to give the fluid a bright silhouette against the black background. The flow was illuminated by a continuous LED ring light. The ring shape cast circular reflections across the fluid, which gives the surface a glossy look and traces the round shape of the coiling folds.

PHOTOGRAPHY AND PROCESSING

The original photograph (Figure 2) was captured as a JPEG using a Canon EOS Rebel T5i DSLR. The camera was placed about 0.62 meters away, giving a field of view of roughly 0.2 m by 0.15 m. The original image was 5184 x 3456 pixels, which gives a spatial resolution of about 0.038 mm per pixel, which resolves the fluid's texture. The focal length was 69.0 mm, and the aperture was set to f/5.6. This aperture was chosen to avoid blur. The shutter speed was 1/400 s, which froze the moving Oobleck. Because the fluid was moving at approximately 1.4 m/s, it only traveled about 3.5 mm during the exposure, meaning the time resolution was fast

enough to prevent major motion blur. To compensate for the fast shutter speed under continuous lighting, the ISO was raised to 1600.

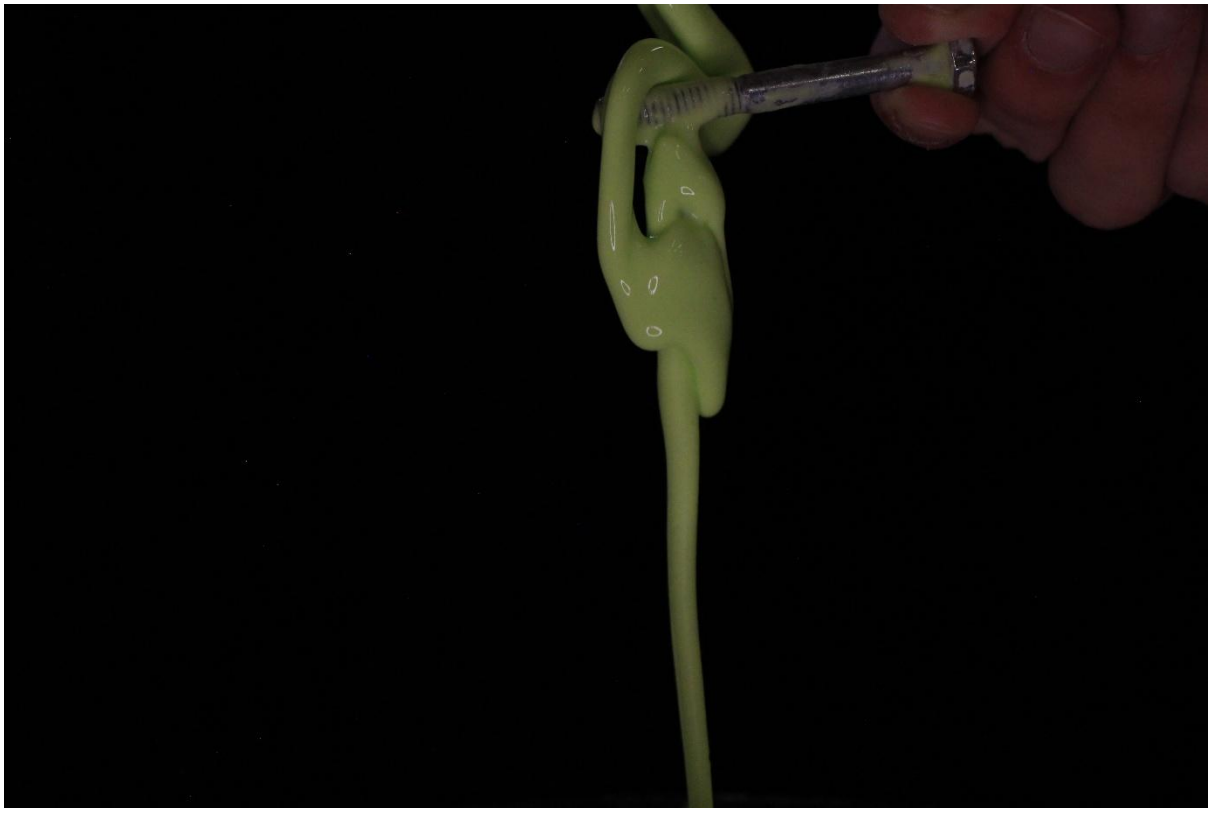


***Figure 2**. The original image. Jay Hall is holding the bolt, and the flow is centered.*

Post-processing was done in Darktable. The image was rotated and cropped to a portrait orientation of 3687 x 3456 pixels, intentionally leaving empty black space on the right side to avoid an unnaturally narrow aspect ratio. To handle grain without blurring the bolt, smoothing was applied with a mask in the contrast equalizer module. The main edit to make the colors and contrast pop was using the sigmoid module alongside a teal hue shift. Hot pixels were removed with the retouch module, and an exposure gradient was applied to the bottom so the tail fades into the darkness.

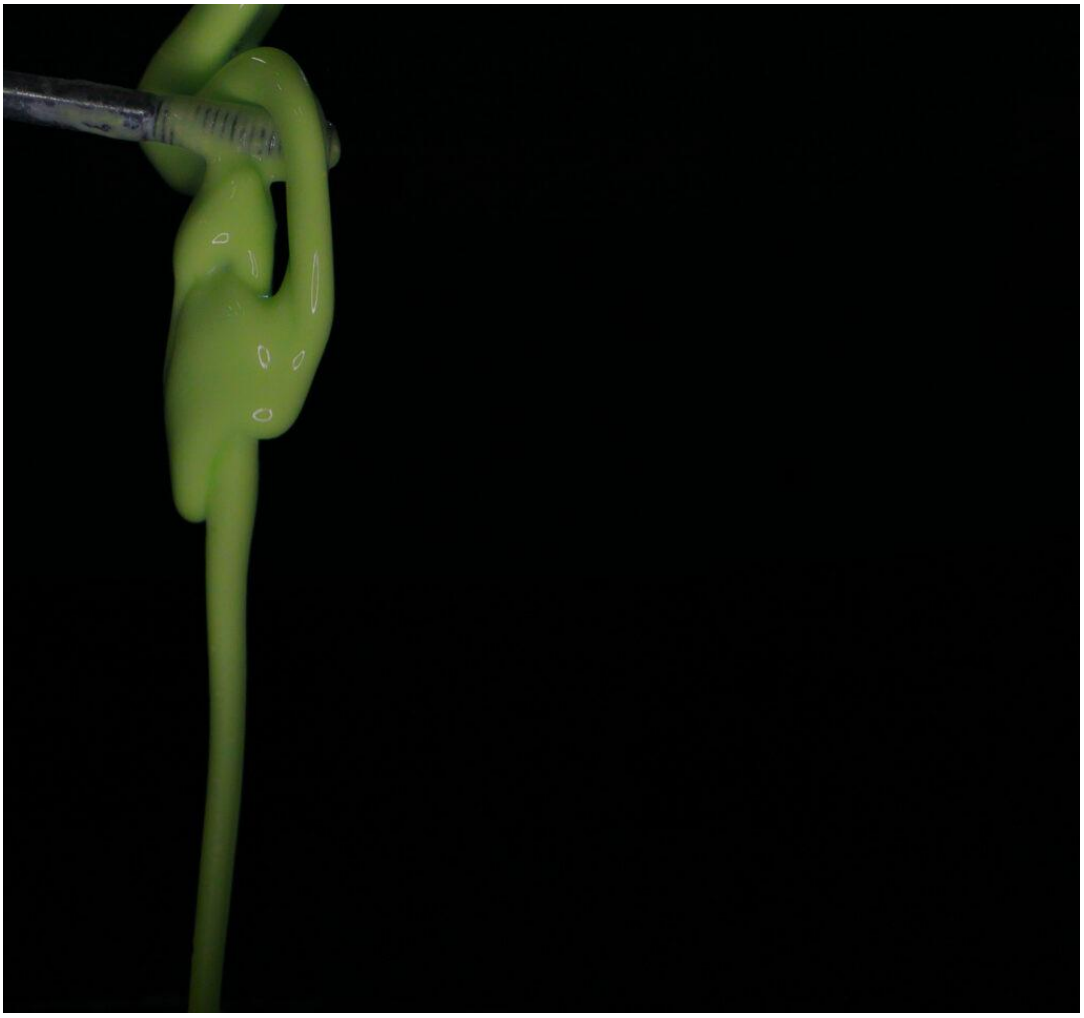


***Figure 3**. The final edited image after photo edits in Darktable. The hand is cropped out and the image is flipped.*

DISCUSSION

The final image (Figure 3) does reveal the buckling and strain hardening of a shear-thickening fluid. I really like how the highlights from the ring light trace the physical folds of the coil perfectly. However, the hand holding the bolt was a distracting element in the original photo, which forced the narrow crop. The intent of capturing liquid rope coiling was fulfilled, and fluid physics are shown clearly. One limitation of the process was shooting in JPEG, which restricted the dynamic range available for editing, but the processing successfully managed the noise and contrast. A question I have is how the folding would change if the drop height was increased. To improve this setup and develop the idea further, I would mount the bolt to a stand so it doesn't move, and pour the fluid through a circular funnel to get a round stream instead of a flat ribbon, to hopefully see a more obvious coiling pattern.

REFERENCES

[1] Ribe, N. M., Habibi, M., & Bonn, D. (2012). Liquid rope coiling. *Annual Review of Fluid Mechanics*, 44, 249-266.

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[3] Bischoff White, E. E., Chellamuthu, M., & Rothstein, J. P. (2010). Extensional rheology of a shear-thickening cornstarch and water suspension. *Rheologica Acta*, 49(2), 119-129.