Helical Coiling

Get Wet Report

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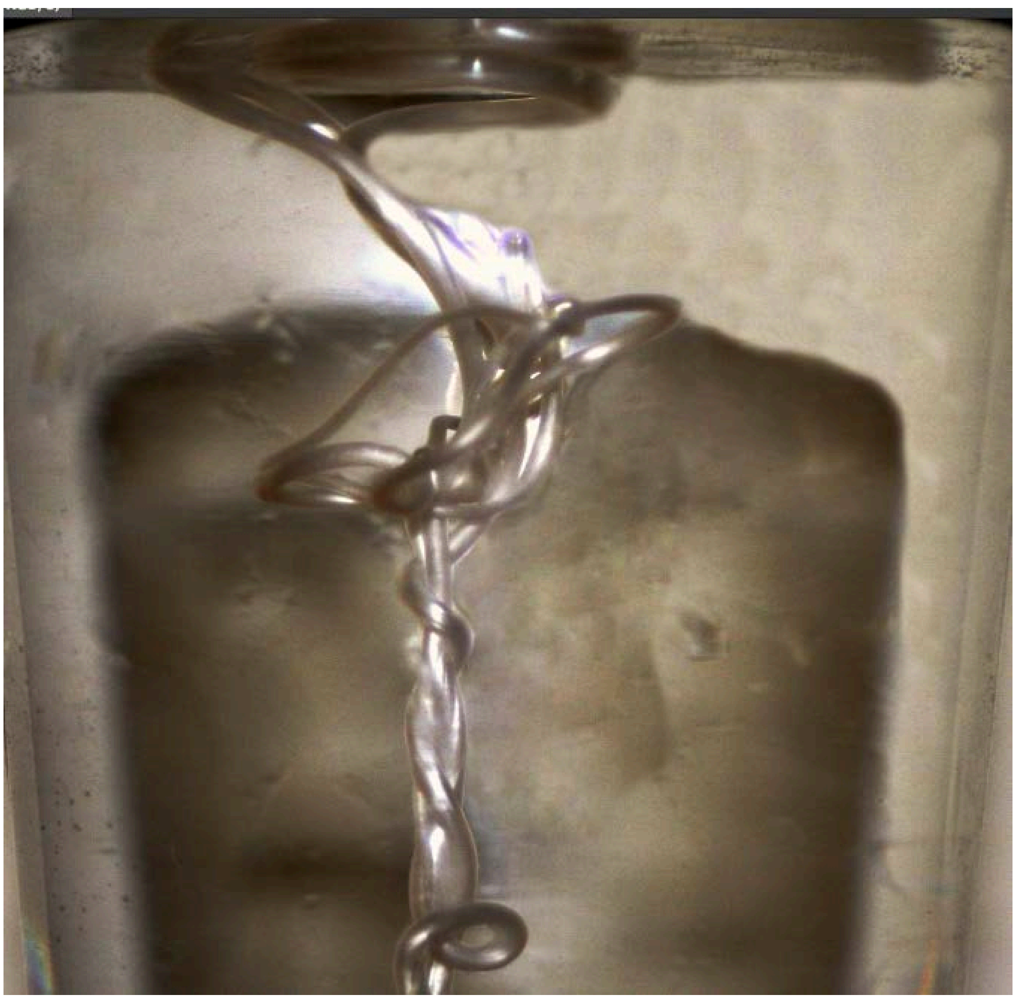

Introduction

The image shown on the previous page is my submission to the Get Wet assignment. After many photographs and much experimentation with lighting, focus, photography technique, editing and trial and error, this was the final submission that demonstrated the aesthetics as well as the unique properties of the fluids in the image. I had become fascinated with the phenomena know as "rope coiling instability" that occurs in viscous non-Newtonian fluids under particular conditions. Initially I wanted to recreate a paper that documented the four regimes of rope coiling instabilities: viscous, inertial, gravitational and inertia-gravitational. This proved to yield a rather dull image [1]. To achieve a more aesthetically pleasing image, I created the rope coiling in very cold water to slow the effect, control the shape and in turn dramatize the effect of the coil as it fell. I tried ambient tap water the first set of pictures and resolved to use cold (5^{o} C) water since it was more viscous and had a higher surface tension it allowed the coils to develop more slowly and completely.

Technique

The method of photography is shown to the right in Figure 1. The flow was captured by pouring shampoo into a clear glass filled to its brim with cold water. The backdrop was created using a whiteboard to reflect the light evenly and minimize textures in the background from distracting from the image. The image was taken in relative darkness with the implementation of the flash. I tried to take the picture initially with backlighting and no flash, but what I found was that the flash brought out the silver, streaky texture of the shampoo. It began to look more and more like quicksilver (mercury), and this is what I wanted to capture. The technique I employed to achieve the helical coiling effect was varying the flow rate of the shampoo and constantly guiding the stream in a circular path on the water's surface.

The glass was placed about 8 inches away from the lens of the camera and a fork was used to establish the manual focus, this actually proved to be quite challenging. The glass was another 12 inches from the whiteboard background and the camera remained stationary about 4 inches from the surface of the table. Other specifications are:

- Field of view: 4x4 inches
- Camera: Cannon Rebel XT Digital
- Lens: Cannon 55mm Macroscopic Lens
- Image size: original – 3456x2304 pixels Edited – 1020x1040 pixels
- Exposure Settings: Macro mode with flash using ISO-800, F/-4.5
- Exposure Time – 1/80 second
- Editing- Cropping and color contrast adjustments were done in Photoshop CS6
    - Note: The original image can be viewed in Appendix A.

Analysis

It is clear in the image that the shampoo is denser than the cold water, thus it fell quickly through the water. I had to experiment with various water temperatures, flow rates, entrance velocities and degrees of vorticity. I found that the coldest water allowed for better helical formation for a few reasons. The cold water had a higher surface tension, 7.49E-2 Pa at 5 C versus 7.12E-2 Pa at 30 C for the warm water [2]. This allowed the thinner shampoo streams to form on the surface of the cold water more easily. Also, the cold water had a dynamic viscosity about double that of the warm water 1.519E-3 Pa*s at 5 C versus .798E-3 Pa*s at 30 C for the warm water [3]. Thus the cold water slowed the descent of the shampoo due to gravity, this increased viscosity allowed for more detailed pictures and a slower descent meant a cleaner focus could be achieved.

The shampoo's viscosity is over 2000 times that of the cold water, 3000 E-3 Pa*s versus 1.5193 Pa*s at 30 C for the cold water [4]. The highly elevated viscosity in the shampoo means that its flow was laminar throughout.

$$Re = \frac{\rho v L}{\mu} = \frac{1006\ \frac{kg}{m^\wedge 3} * 0.1\frac{m}{s} *\ .02m}{3\ Pa * s} = .67$$

Any Reynolds Number less than 5E5 is considered laminar and thus this flow is well within the laminar regime. This means that unless the surface tension on the shampoo was broken, via violent shaking, it was impossible for the shampoo to diffuse into the water. This lack of diffusivity between the fluid boundary of the shampoo and the water allowed the unique coils to form. I would allow a thin stream to form a pattern on the surface of the cold water and then use a thick stream of shampoo to break the tension and document the descent, all the while inducing vorticity in the water. The result was that the thinner streams had time to combine and would bundle and descend at one whilst the thicker streams would fall more quickly and would combine but would rather coil around one another.

Conclusion

This image proved to be a quite challenging demonstration of differences in viscosity, momentum and surface tension. The shampoo proved to yield a unique texture when exposed to the flash, despite the some instances of glare off the glass I elected to keep using it in the photography process. The image effectively demonstrates how the rope coiling effect of the non-Newtonian shampoo can form helical strands when vorticity is induced in the surrounding water. I really had hoped to include more physics of rope coiling instabilities; however, most studies documented free-falling rope coiling and because the coiling was not natural in my experiment it was not applicable to these studies. Nonetheless, the resulting image was very aesthetically pleasing and demonstrates the physics discussed.

Citations

1) Ribe, N.M. "Multiple Coesxisting States of Liquid Rope Coiling." *Cambridge University Press*. (2006): n. page. Print.
2) "Surface Tension of Water in contact with Air." *Engineering Toolbox*. N.p.. Web. 11 Feb 2013. <http://www.engineeringtoolbox.com/water-surface-tension-d_597.html>.
3) . "Water - Dynamic and Kinematic Viscosity." *Engineering Toolbox*. N.p.. Web. 11 Feb 2013. <http://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html>.
4) . "Viscosity Chart." . N.p.. Web. 12 Feb 2013. <http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0CE4QFjAB&url=http://pumplocker.com/images/lit/WEI1/FLUX-HIGH-VISCOSITY-B0000-VISC-CHART-1.PDF&ei=b7kaUc3qKIvlyAGYxIBg&usg=AFQjCNEfEbk0kK-GPmCrHuL_u8T7bdiYyQ&bvm=bv.42261806,d.aWc>.

Appendix A

Original Image