Group Project #2 – Flaming Polyethylene

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Purpose

The purpose of this image is the second group project for MCEN 5151: Flow Visualization, taught by Professor Hertzberg at the University of Colorado at Boulder in Spring 2012. The image is meant to adequately show and demonstrate a fluid flow that can be physically explained in the accompanying report. The image shows a flaming droplet of P-Tex splattering on a plate.

Team

I worked with a group consisting of the following members to acquire and analyze this image

1. Andrew Fish
2. Doug Schwichtenberg
3. Ryan Kelly
4. Nicholas Travers
5. George Seese

Materials

The image was created using all commonly used materials, save for the camera, which can be found at any snow sports store. The materials are as follows:

1. Matches
2. P-Tex ultra-high-molecular-weight polyethylene
3. Samsung SGH I777 Rear-Facing Camera

Procedure

The apparatus used to create the image is as shown in Figure 1, below.

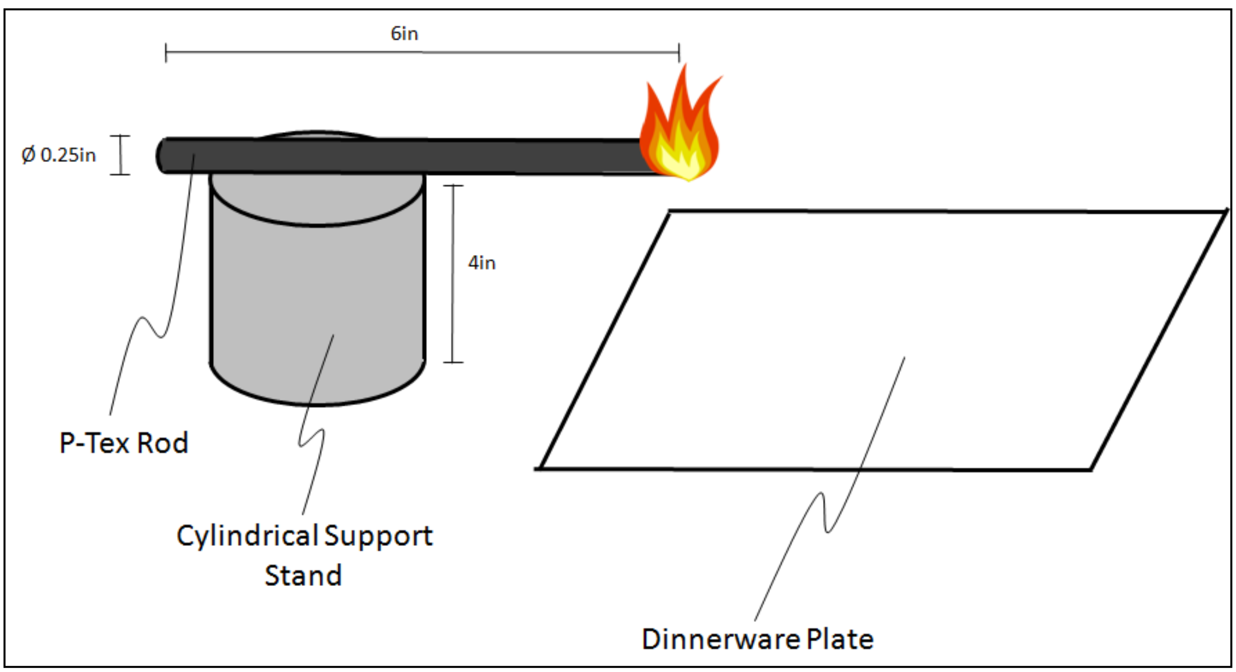

Figure 1: Experimental Setup

The apparatus for this image is very simple. It consists of three components: P-Tex, a support stand, and a dinnerware plate. The end of the P-Tex rod is on fire and drips drops of flaming plastic onto the dinnerware plate. There is no ambient light; all of the light in the image comes from the light emitted by the combustion process.

Fluid Dynamics

P-Tex is a commercial name for Ultra-High-Molecular-Weight Polyethylene, which is a variant of the polyethylene thermoplastic characterized by extremely long, cross linked chains of unusually high molecular weight molecules. It is a very tough material as a result of this cross linking and also has a very low coefficient of friction, rivaling that of Polytetrafluoroethylene (Teflon)[1]. For these reasons, among others, it is commonly used as a ski & snowboard tuning tool. It is much stronger and denser than wax, so it is used to fill in deep cuts in the bases of boards and skis before the wax is put on the surface. When P-Tex is heated to near its melting temperature, which is at about 290^{o}F[1], it will combust with oxygen, thereby producing a flame. The heated portion of the P-Tex will remain on fire and continue heating up until it melts. The melted drops of the P-Tex fall, still on fire, until they hit a surface, where they are quickly cooled down and extinguished.

Fire is the emission of light particles as well as grey body radiation and superheated gas[2]. It therefore is not the fluid, but it shows exactly where the combusting fuel source (in this case melting P-Tex) is. While the fire is not the fluid in question, it is subjected to gravity. On Earth, gravity driven convection of heated gasses form flames into a teardrop shape; but in space, where there is effectively no gravity, the convection does not take place and the shape of the flame is spherical, as shown below[3].

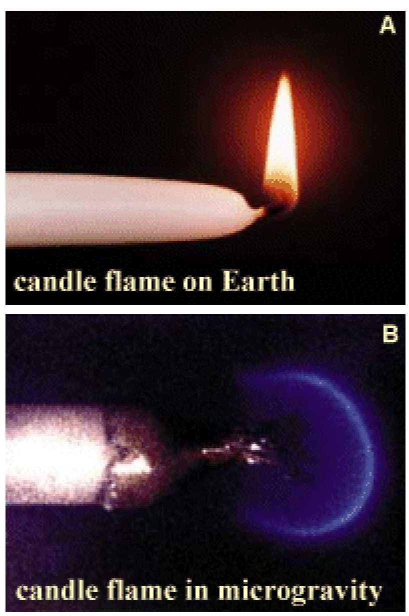

Figure 2: Flames in Microgravity[3]

This proves that gravity plays a role in the formation and location of a flame itself, therefore there the flame in the picture is indeed falling, and is a legitimate method of visualizing the flow.

The Reynolds number of the flow, intuitively will be laminar and far below 50000, can be calculated by the following formulas:

$$Re = \frac{UD}{v} = \frac{(U)(0.2in)}{0.145\frac{ft^2}{s}} \quad with \quad U^2 = 2ay$$

$$U^2 = 2ay = 2\left(386.4 \ {}^{in}/_{s^2}\right)(4in) \ \rightarrow \quad U = 56 \, {}^{in}/_{s}$$

$$Re = \frac{\left(56 \ {}^{in}/_{s}\right)(0.2in)}{0.145\frac{ft^2}{s}} = 77$$

This calculation confirms that the flow is firmly laminar, which we would expect, and is clearly shown in the smoothness of the image.

Visualization Technique

There was no external visualization technique used in acquiring this image such as dye, smoke, etc. The fluid flow can be visualized by the flame itself, as described above. There was no external light source in the image at all. The only light was provided by the flame itself.

Photographic Technique

The size of the field of view is 8in tall by 3in wide, the flame was about 12 inches from the camera lens, which was the closest that I was willing to get to the flame to preserve my camera. The lens had a focal length of 4mm with an f-stop of f/2.6. A rear facing digital camera on a Samsung SGH I777 produced a 1677x2238 final image. The camera settings were a max aperture of 2.81, a shutter speed of 1/15sec, and ISO 400. These were chosen to balance the need to absorb a lot of light because of the darkness of the background but yet have a quick enough shutter speed in order to not have too much motion blur. Post processing was performed on the image using Adobe Photoshop. The contrast was enhanced to darken the background a bit, the clone stamp tool was used to remove the support cylinder as well as a couple of objects in the background, and the image was finally cropped. The result is a simpler, less distracting picture that lets the observer focus more on what is going on with the fluid flow.

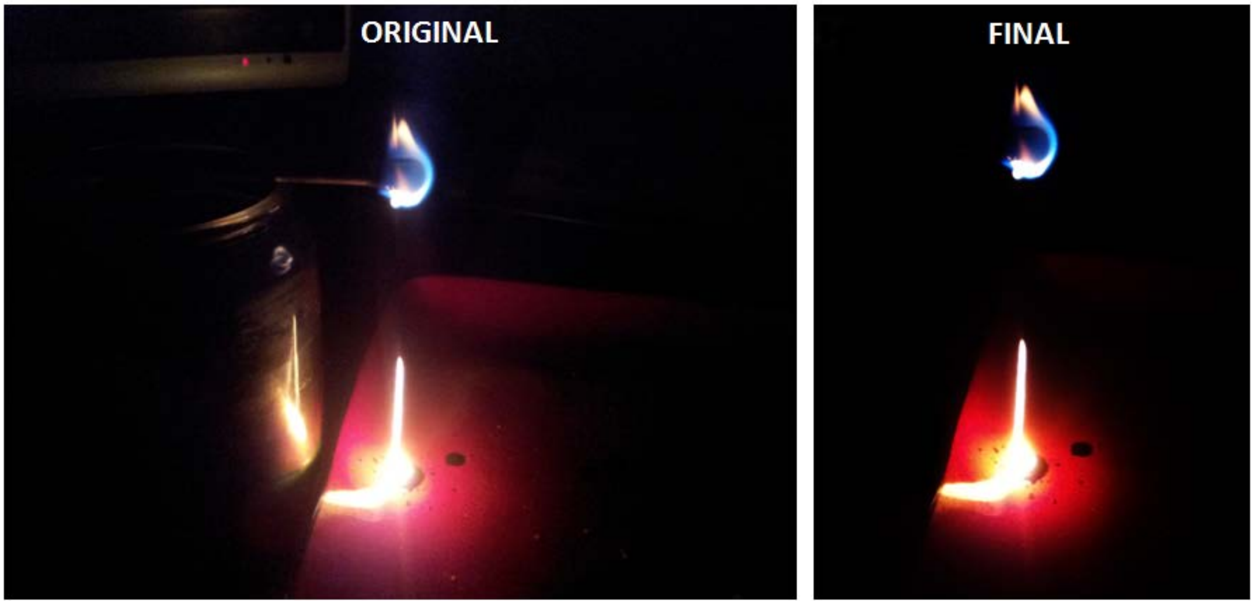

Figure 3: Before & After Post Processing

Conclusion

In the pursuit of capturing the falling flame of the P-Tex, I believe that I did a very good job. I really like how clear and simple the final image ended up. It is unfortunate that the image isn't nearly as well time resolved. With a shutter speed of 1/15sec and a droplet velocity of 56 in/s, the droplet moved nearly 4 inches while the shutter was open, which is the reason for the motion blur. Having said that, the core concept of the image is shown very well, as are the fluid dynamics. The intent of the image was fulfilled, and in the future I would like to possibly catch multiple drops falling a greater distance all in one image, with a larger camera that can capture the phenomenon with much higher temporal resolution.

References

1. Stein, H. L. (1998). Ultrahigh molecular weight polyethylenes (uhmwpe). Engineered Materials Handbook, 2, 167–171. Retrieved from http://md1.csa.com
2. "Fire." *Wikipedia*. Wikimedia Foundation, 04 Nov. 2012. Web. 16 Apr. 2012. <http://en.wikipedia.org/wiki/Fire>.
3. Rotating Spiral Edge Flames in von Karman Swirling Flows -- by V. Nayagam and F. A. Williams. Physical Review Letters -- January 17, 2000 -- Volume 84, Issue 3, pp. 479-482