December 5, 2015

Team Project 2 Report

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Flow Visualization
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Motivation

This video was created for the second team assignment in a course called Flow Visualization, taught by Dr. Jean Hertzberg at The University of Colorado, Boulder. The ultimate goal of this work was to create an aesthetically pleasing video of a dynamic fluid. A fluid is any substance that continuously deforms under shear stress [1]. Dynamic implies that the fluid is moving, as opposed to being still. The video was taken and edited by John Zeldes, and intends to show the difference between yellow candlelight flame and a pre-mixed lean blue flame. A pre-mixed flame is made with the right amount of oxygen, and fuel mixed upstream of the ignition point, where as an open flame is fuel rich and not premixed with oxygen. The flame was created using the combustion of butane gas. The complete and incomplete combustion of butane can be seen below:

butane + dioxygen → carbon dioxide + water (complete)
butane + dioxygen → carbon dioxide + water + carbon + carbon monoxide (incomplete) [2]

It was predicted that the pre-mixed flame would resemble a flame produced by a welding torch. The open flame was expected to look like a campfire, where the flames move depending on the air pressure, and are more yellow and orange than blue.

Background

Figure 1 on the following page shows the apparatus used to create the flame.

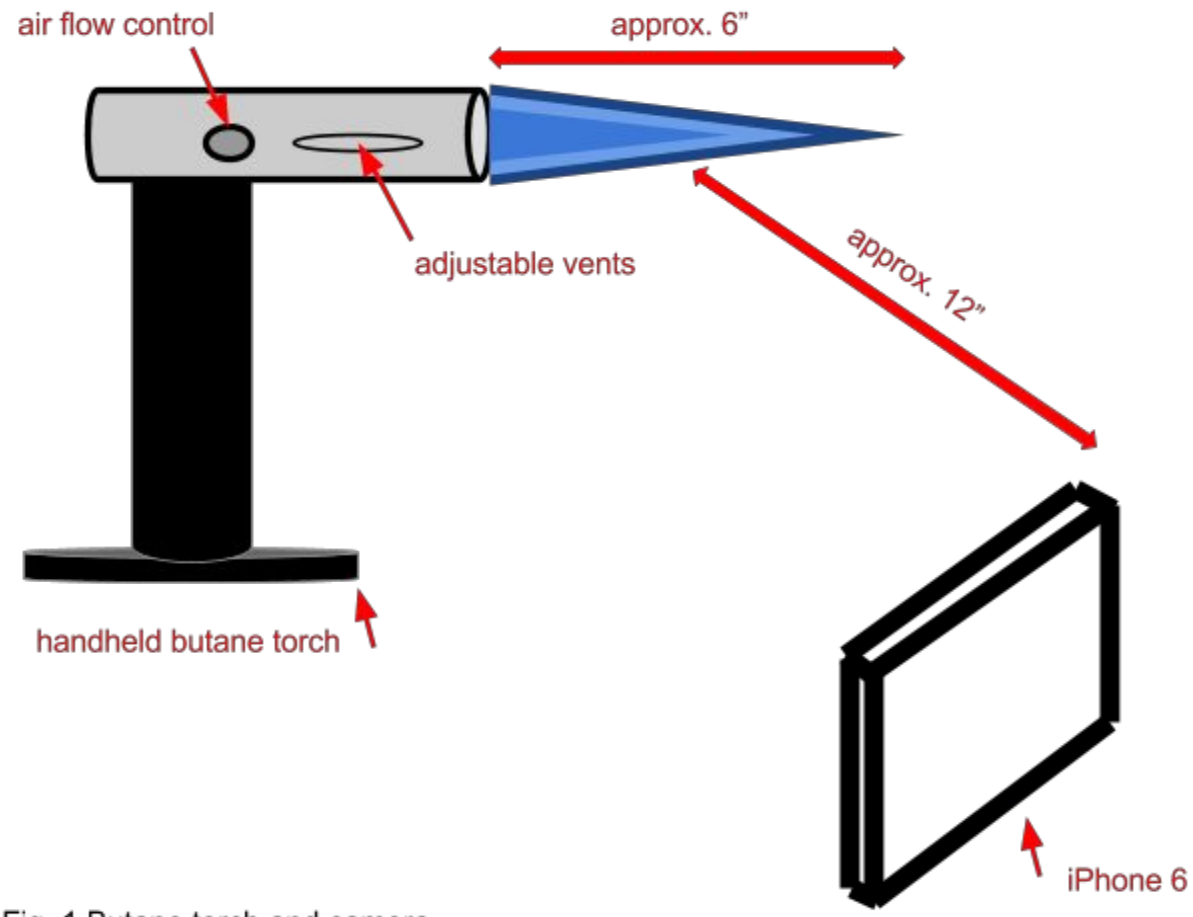

Fig. 1 Butane torch and camera

The flame was created using a small handheld butane torch used for cooking. The flame produced varied from about 3 to 6” in length, depending on if the oxygen was premixed or not. Mixing of the oxygen was controlled by adjustable vents on the side of the torch. The oxygen burned was from air in the atmosphere. An “open” setting would allow for air to pre-mix with the fuel causing a strong, laminar looking flame. The “closed” position did not allow for butane to evenly mix with the air before ignition, causing the candlelight looking flame.
The main difference between the two flames is the burning rate, which can be controlled by the rate that air and butane are brought together in the proportions necessary for the combustion reaction [3]. The balanced equation can be seen below:

$$2\ C_4H_{10\,(g)} + 13\ O_{2\,(g)} \rightarrow 8\ CO_{2\,(g)} + 10\ H_2O_{\,(g)} \quad [4]$$

The “candlelight” flame is known as a gaseous diffusion flame. Various shapes created by such a flame are known as coflow configurations. In diffusion flames, the chemical reaction takes place over a large volume, whereas in premixed flames the reaction takes place over a more narrow

volume. Heat diffusion, mass diffusion, and mechanisms of combustion reactions are factors in determining whether a flame is premixed or diffused [3].
For the most part, the flame in the video is blue. This is an indication that the reaction, the combustion of butane, is running to completion. In an instance where there is a lack of oxygen, the reaction does not run to completion always and some of the carbon forms soot. The glimpses of yellow can be explained by this soot emitting blackbody radiation [5].

SAFETY PRECAUTIONS:

- Follow all torch manual instructions.
- Perform this activity with proper supervision, outside, and away from flammable objects.
- Do not leave torch lit for long periods of time, as the nozzle will become very hot.
- Wear gloves, face shield, apron, or other fire retardant garments to protect against burns.

Visualization Technique

The flame was created in a completely dark room, with the only light source being the flame itself. The torch seen in this video is the BonJour Professional Cooking Torch, available at Bed Bath and Beyond for $29.99. The brand of butane in the torch is “Vector Quintuple Refined Butane Gas”. The oxygen source was ambient air at an altitude of 5500 ft, meaning the air contained slightly less oxygen than at sea level. The flame was filmed in complete darkness to maximize the contrast between the object and background. For a completely black background, the flame must be sufficiently far away from any backdrop, so that the backdrop does not become illuminated.

Photographic Technique

The field of view was approximately 7” wide, because this was slightly bigger than the flame, which is the main focus of the film. The distance from the object to the lens was about 8”. At this distance, the camera could capture the entire flame without using digital zoom. This video was filmed using the iPhone 6 in “slomo”, which shoots at 120 fps. The user has some control over the “brightness” of the iPhone video, but the exposure settings are mostly automatic. The film was edited using iMovie. The footage was not altered, just trimmed with the addition of a title and some transitions.

Conclusion

The film shows an excellent example between a diffused and premixed flame. I like how this illustrates the physics of combustion reactions, but the work is not an excellent piece of art. The diffused flame is more artistic, as it appears to be alive as it dances but the premixed flame is rather boring. The fluid physics are shown fairly well, the slow motion recording seems to assist in this. A better camera could improve resolution and clarity therefore revealing the physics

better. The intent to make an interesting video of combustion while being safe was achieved. In order to improve the film, I would get a high speed camera with better resolution and investigate the effects of using different shaped nozzles on a torch. This could make the piece more of a work of art rather than a science demonstration.

Video URL

https://vimeo.com/146552132?from=outro-local

References

[1] Munson, Bruce R., and Donald F. Young. "Introduction." *Fundamentals of Fluid Mechanics*. 6th ed. Don Fowley, 2009. 3. Print.

[2] "The Combustion of Butane." *Physics-Chemistry Class*. Web. 5 Dec. 2015. <http://www.physics-chemistry-class.com/chemistry/combustion-butane.html>.

[3] Glassman, Irvin, Richard A. Yetter, and Nick G. Glumac. Combustion. Academic press, 2014.

[4] Bettelheim, Frederick, et al. Introduction to general, organic and biochemistry. Cengage Learning, 2012.

[5] Dutch, Steven. "Why Are There Blue and Green Flames?" *Steven Dutch, Natural and Applied Sciences, University of Wisconsin - Green Bay*. Steven Dutch, 15 Apr. 2013. Web. 15 Dec. 2015. <https://www.uwgb.edu/dutchs/AstronNotes/Blue and Green Flames.html>.