Premixed Combustion of Isopropyl Alcohol

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MCEN 5151-001

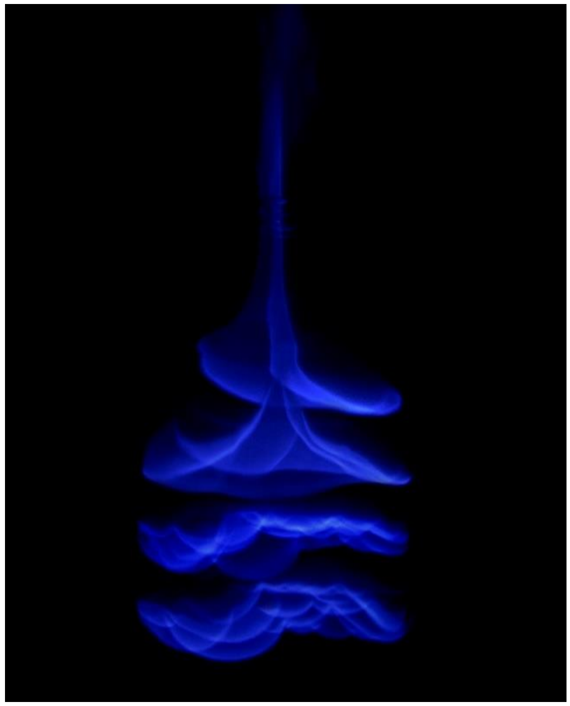

Figure 1: Final Image

INTRODUCTION

This image was produced for the first team project for the Flow Visualization class. The purpose of the image was to show the propagation of a flame within an enclosed container. I was drawn to this idea due to the color of the flame as well as the strange shapes the flame makes as it travels down the container. Originally, I planned to take a video of the flow and then slow it down in post-processing. But, when I found that I could take a series of photos that captured the flame propagation, I decided to make a composite image to show the motion of the flame. This image was taken in collaboration with Cara Medd, Michael Guenther, Michael Johnson, and Madison Emmett. Each team member had a hand in the setup of the experiment as well as image capture.

EXPERIMENT

Flow Apparatus

This experiment was carried out in the garage of one of my teammates. To ensure that the experiment was carried out in a safe environment, a large section was cleared and doors and windows were set to allow clean air to flow through the garage, in case of harmful aerosols. A fire extinguisher was on hand at all times and any team members handling the jug or the lighter were required to where hand protection. A black poster board was set up on a portion of the garage wall and the bottle was placed on top of a small (1.5ft x 2.5ft) table in front of the black background. The camera was put on a tripod and placed 2.5 feet away from the bottle on the table. All the photos were taken in portrait orientation, so the camera was tilted on its side on the tripod. The setup described is shown in Figure 2 below:

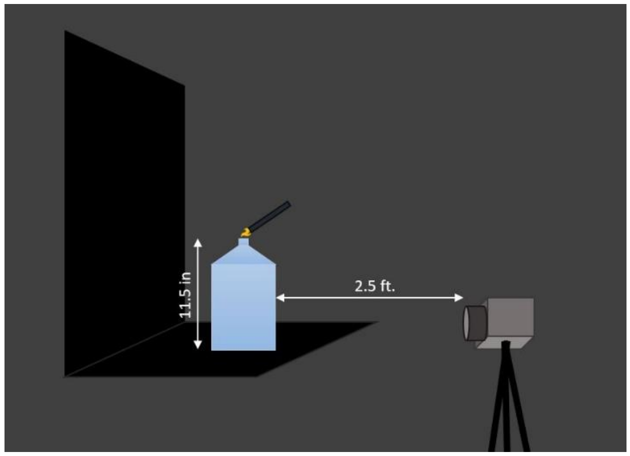

Figure 2: Experimental Setup

Materials needed for this experiment included a one-gallon glass jug[1], 91% Isopropyl Alcohol, and a lighter. The alcohol can be found at any generic grocery store and a multi-purpose lighter was used to ignite the flame. To carry out the experiment, a small amount of isopropyl alcohol was poured into the glass jug (enough to have about ½ inch of alcohol on the bottom of the jug). The cap was placed on the jug and the alcohol was swirled around to make sure the entire inside of the jug was coated in alcohol. We then brought the jug into the garage and placed it on the table. All the windows were blacked out and the lights were turned off. The top was taken off the bottle and the lighter was placed right at the opening of the jug. As soon as the lighter was triggered, the person in charge of the camera started taking photos to capture the entire reaction. Once the reaction was over, the jug was brought back outside to air out before repeating the experiment.

Flow Physics

The flow shown in Figure 1 is an example of premixed combustion of isopropyl alcohol. This combustion creates a flame that propagates down the length of the bottle and takes on the shape of the bottle. The diameter of the flame is the same as the diameter of the bottle; specifically, 6.6 inches. The speed of the flame can be estimated by a video taken of the reaction. The video of the reaction was approximately 2 seconds. Using this total time, we can calculate the speed of the flame propagation using the equation:

$$|v| = st$$

Where $|v|$ is the speed of the flame, s is the distance the flame travels (in this case, the height of the bottle), and t is the time of the reaction. Solving this equation, we find that the flame propagates at a speed of roughly 23 $\frac{in}{s}$ or .584 $\frac{m}{s}$.

The speed of the flame propagation can be used to find the Reynold's number of the flow, which is calculated by the following equation[2]:

$$Re = \frac{vD}{\vartheta}$$

Where v is the flame propagation speed, D is the hydraulic diameter, and ϑ is the kinematic viscosity. For the purposes of this calculation, we are assuming the bottle to be cylindrical shaped and the kinematic viscosity[4] to be that of air at room temperature, $1.52 \times 10^{-5}\ \frac{m^2}{s}$. Performing this calculation, the Reynold's number of the flow is about $Re = 6.44 \times 10^3$. This high Reynold's number means the flow within the bottle is turbulent, and inertial forces are large relative to viscous forces. The viscous forces cannot prevent the random and rapid fluctuations of the fluid[2]. These turbulent instabilities could explain the cellular flame shapes seen in Figure 1.

The combustion of isopropyl alcohol in the glass jug can be modeled by the following balanced chemical equation[3]:

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$$

This equation shows that the premixed alcohol and oxygen within the bottle is converted to carbon dioxide and water vapor in complete combustion. This reaction was observed in the experiment. When the bottle was brought back outside to be re-coated in alcohol, water had condensed in the bottle and needed to be poured out before the next experiment. Complete combustion means that no soot was produced in the reaction. This was also observed during the experiment. The flame stayed a solid blue color throughout the reaction. If any red flame appeared, that would mean excess alcohol was combusted in limited oxygen, producing soot particles, which burn red.

IMAGE CAPTURE

The final image was created by composing four photos together to make one cohesive composite showing the flame propagation at different times within the bottle. The original photos in chronological order are shown below in Figure 3:

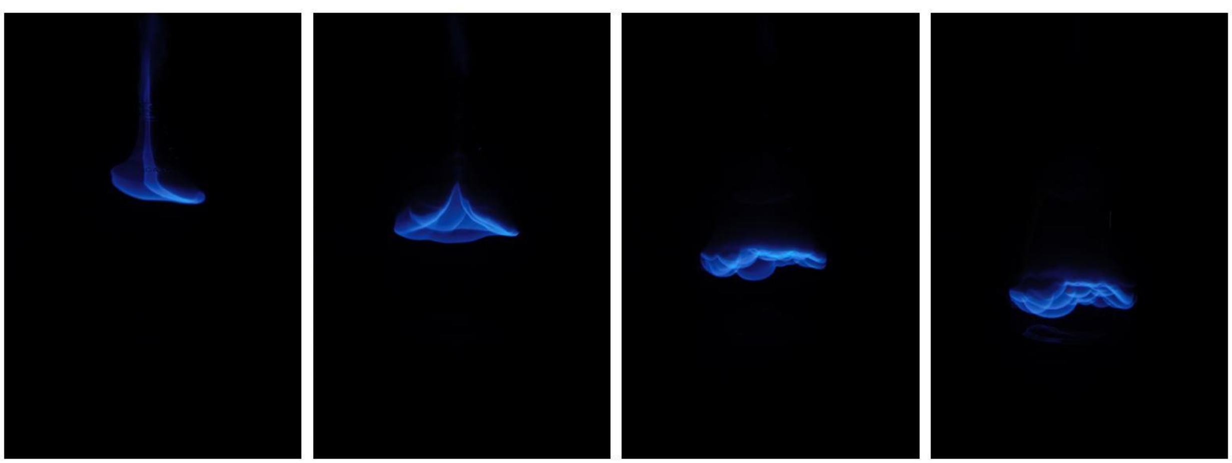

Figure 3: Original Photos

These photos were taken using a Canon EOS 5D Mark II camera with a 28-75 mm, 1:2.8 lens. The shutter speed was 1/80 second, the f-number was f/2.8, and the ISO speed was ISO-1000. As stated in the Flow Apparatus section, the camera was placed 2.5 feet away from the glass jug. The field of view of the original images is 6.6 inches from the left side of the flame to the right side. The height varies but, on average, the height of the blue flame is about 1/8th of the height of the bottle, so about 1.44 inches. The dimensions of the original images were 3744 x 5616 pixels and the dimensions of the final image were 3285 x 4082 pixels. The major edit to the original images was the composition of each into one photograph. This was done using the select and mask tool in Photoshop. Once the composition was made, minor contrast and color edits were made to bring out the blue color and the details in the cellular flame shapes. Finally, the image was cropped slightly to zoom in on the bottle.

I decided to make the final image a composition because I wanted to show the full reaction rather than one small piece. I liked how the flow at the beginning ran up the small neck of the bottle and then expanded out to fill the bottle in a disk-like shape. I also thought it would be interesting to show how the flame takes on the shape of the bottle, and I think the composite image does a nice job of showing that.

CONCLUSION

This image turned out just how I imagined it would. I like the deep blue color in the flame as well as the small, lighter highlights in the cellular flames. The composition of the four images into one really enhances the depiction of the flow of the flame through the bottle. Using the select and mask tool was difficult and in using it, some details were lost and some things inevitably overlapped. I would like to improve my photoshop skills and maybe find a more efficient way of composing these images. I think it would be interesting to try and get some soot particles within the bottle so that some red coloring is introduced into the image, making for a more dynamic color scheme. Otherwise, there is nothing I would want to change about my final image, I am very happy with it.

REFERENCES

1.) *1 Gallon Glass*. (2018). Retrieved from New Wave Enviro: http://www.newwaveenviro.com/products/1-gallon-glass/

2.) 14-2 Laminar and Turbulent Flows. (n.d.). In Y. A. Cengal, J. M. Cimbala, & R. H. Turner, *Fundamentals of Thermal-Fluid Sciences* .

3.) *Combustion of Alcohols (combustion of alkanols) Chemistry Tutorial*. (n.d.). Retrieved from AUS-e-TUTE: http://www.ausetute.com.au/combustol.html

4.) *The Engineering Toolbox*. (n.d.). Retrieved from https://www.engineeringtoolbox.com/air-absolute-kinematic-viscosity-d_601.html