Team First

Flow Visualization: The Art of Fluid Flow

Andre Szlendak

10/31/2015

Background: The inspiration for this image was to capture the physical fluid phenomena of combustion of rubbing alcohol. We thought it would be most striking to present this phenomena by focusing on the light emitting component of combustion As such, our light source was the combustion of the reaction contained in a 1 gallon mason jar. This project “Team First” outlines the emphasis of a team dynamic, and was done accordingly with the help of Michael Bruha. In experimenting many images and methods were pursued but this image best captures the movement of combustion gases, here highlighted with the glow of their soot emitting photons.

Image Capture: This image was captured at night, in the confines of a garage with proper ventilation. The materials involved were as follows: a one gallon glass jar with removable cap, 16 FL OZ. of 70% isopropyl alcohol (rubbing alcohol), and a pack of matches. Setting up the experiment is quite simple. First, we filled the gallon jar with enough rubbing alcohol to have a one centimeter puddle at the bottom. Next, we tightly screwed on the cap and shook the jar so the alcohol coated the edges of the jar and became mixed with the air inside. When working with combustion, it is important to be extremely safe, so wear personal protection equipment such as safety glass and gloves/oven mitts to avoid injury. Then, with the shaken up jar, we moved to a well ventilated open area in a garage and removed the jar’s cap. We placed the jar on a small stool, then dimmed the lights. With one of us controlling the camera the other struck the match and held it directly above the mouth of the jar (figure 1). This then caused the vapor exiting the mouth of the jar to ignite a spread downward through rest of the jar. The reaction is quite fast, only approximately two seconds, so timing is crucial. Multiple trials were performed in order to obtain better results.

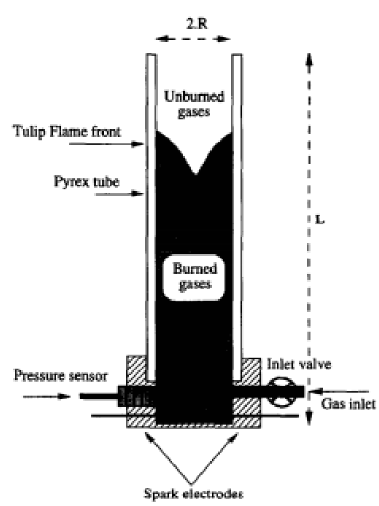

Fig. 2. Apparatus.

Figure 1: Flame Propagation (Clanet and Searby)

The result of the image technique was a bright blue flame. The blue is a result of the flame temperature of around 400 degrees Celsius. Near 400 degrees Celsius the unburnt carbon soot emits photonic energy in the blue range of the visual spectrum. That emitted light is enhanced with the lightless surroundings.

$$2C_3H_7OH_{(l)} + 9O_{2(g)} \longrightarrow 6CO_{2(g)} + 8H_2O_{(g)}$$

Equation 1 Stoichiometric reaction of isopropyl alcohol combustion (sciencefusion)

The notable physical phenomena is the flame propagating down the container away from the opening. This "tulip flame" phenomena was studied extensively by Christophe Clanet and Geoffrey Searby with the University of ST. Jerome. In similar experiments, given the high Reynolds number and turbulent flow the viscous forces are negligible relative to the inertial forces. They conclude that because of the unique geometry consistent even without closed containers it is not a boundary layer phenomena. Instead, they observe the flame propagation is a geometric function of pressure with higher gradients at the container walls which would force the flame more quickly in the axial direction of the cylindrical container. The flame propagates both up and down from the opening ignition source. It's quenched by the limited oxygen in the container as the flame moves down giving the tulip shape. The flame also combusts out from the opening fed by the outgas from the container which is just normal fueled combustion giving its steady constant flame.

$$\boldsymbol{Re = \frac{vL}{\nu} \approx 6.5E4}$$

$\boldsymbol{v} = \textbf{flame velocity } (\mathbf{1}\ [\boldsymbol{m/s}])$
L = Jar diameter (10 [cm])
$\boldsymbol{\nu = kinematic\ viscosity\ of}$ **air (1.57E-5 [m^2/s])**

Equation 2: Effective Reynolds Number

Photographic Technique: The biggest struggle to capturing this image was the timing and the lighting. The image was captured using a Canon EOS Digital Rebel. Lighting was corrected with a wide aperture (f/4.5) and maximum allowable ISO of 1600. To further capture more light the shutter speed was relatively long (1/30sec). Despite the slow shutter, there is limited motion blur helped by a solid camera mount and the quenched (slower) combustion. There was little necessary field of view as the phenomena was small relative to the distance to the camera lens, using a 27mm focal length at a distance of 1 meter. The result was a single unaltered image 4272 x 2848 pixels that was cropped to 968 x 1740 for the final image. Using image enhancing software GIMP, the image was cropped to size and the contrast enhanced to saturate the black background and emphasize the flame.

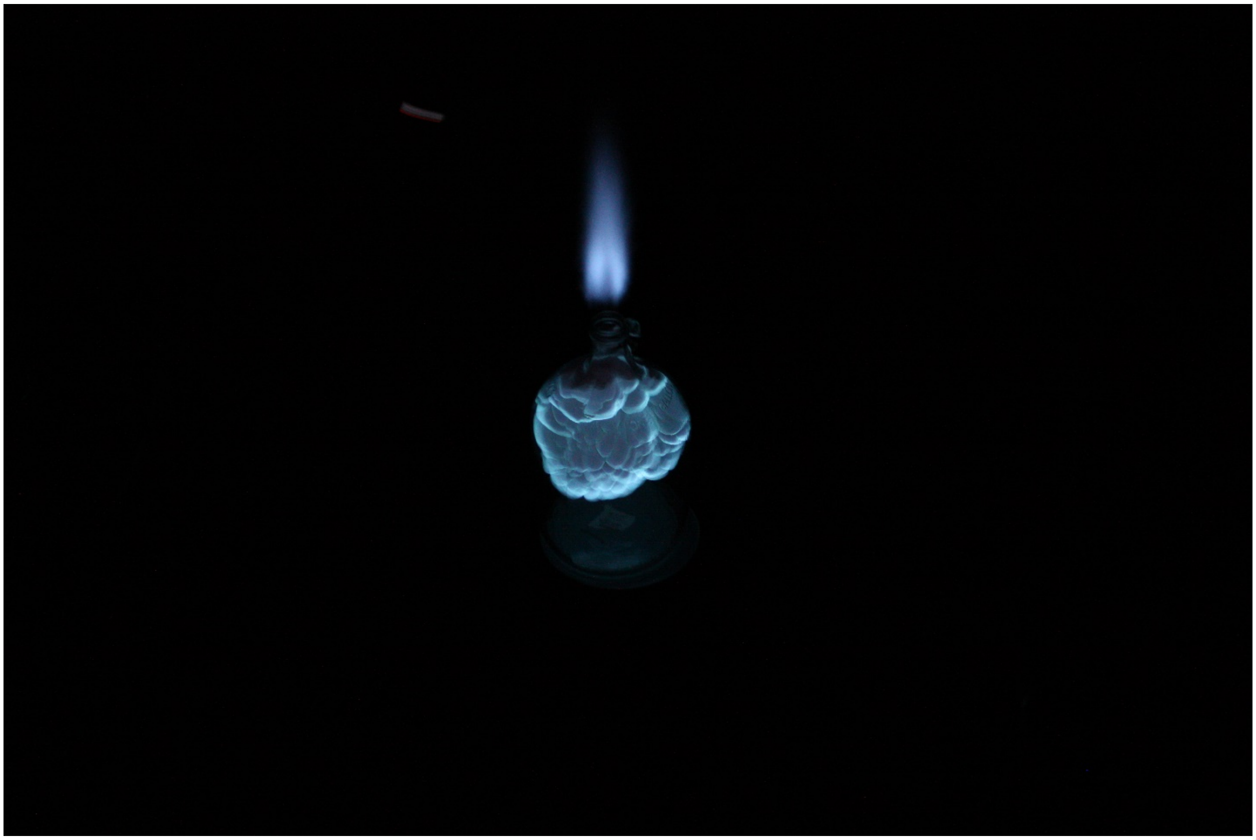

Image 2: Original Image

Takeaways: The image is a great demonstration of flame propagation. In the case here both the combustion and “tulip flame” propagation phenomena are apparent. The tulip flame propagation makes sense and is evident here with varying tulip pedals expanding at different rates relative to the center axis of the container. Likewise the combustion is literally the highlighted phenomenon with its striking blue glow.

References:

Clanet, Chistophe, and Geoffrey Searby. "Group 7." *Sciencefusion* -. University of St. Jerome, 1996. Web. 30 Oct. 2015.

"Dry Air Properties." *Dry Air Properties*. The Engineering Toolbox, 2009. Web. 17 Nov. 2015.

Lee, Hae, and Ji Lee. "Group 7." *Sciencefusion*. Wikispaces, 2015. Web. 30 Oct. 2015.

Stonecypher, Lamar. "Use Reynolds Number for Pipe Flow to Find Whether It Is Laminar Flow or Turbulent Flow." *Brighthub Engineering*. N.p., 2010. Web. 30 Oct. 2015.