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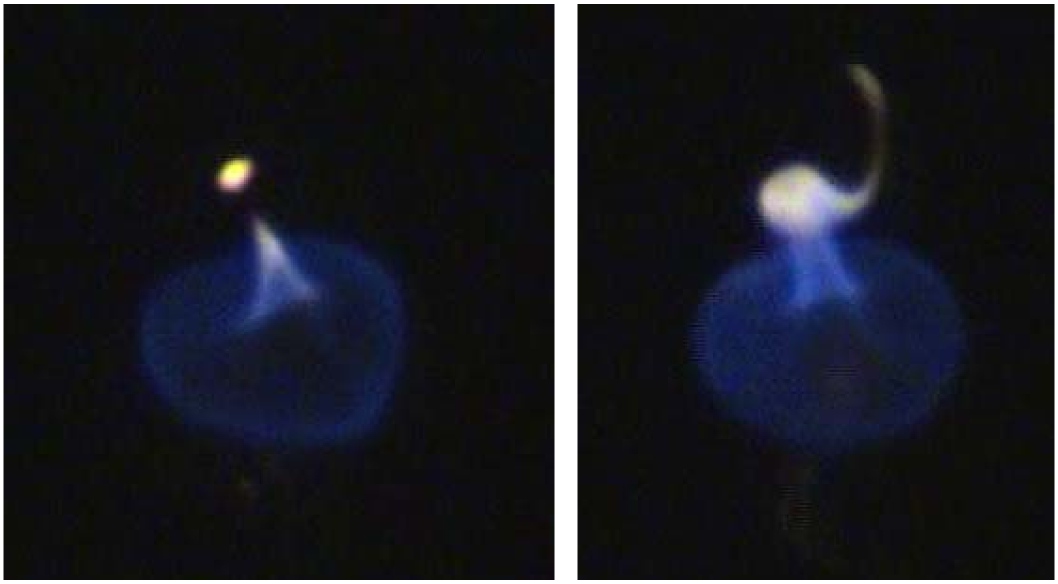
Isopropyl Alcohol Flame Propagation

The goal of this project was to capture the ignition and propagation of a small, 70% (by volume) isopropyl alcohol pool flame. The propagation rate of flames is important to understand for many reasons including fire safety and flame extinction. In addition to understanding the physics of flame propagation, the process visualized at a reduced speed can be very interesting and can produce beautiful images of the initial stages of the fire.

Isopropyl alcohol was chosen for this experiment because its flame propagates relatively slowly and produces a sufficient amount of light to be captured by a typical digital video camera (i.e. not a high speed camera).The drawback to using isopropyl alcohol is that it produces a predominately blue flame in its initial stages which does not produce as much visible light as a yellow flame, and it is therefore more difficult to capture detailed and interesting images (see figures 1 and 2 below for some examples of stills taken from the video). The concentration used for this experiment was 70 vol.% isopropyl alcohol. The other 30 vol.% of this mixture is water, as isopropyl alcohol and water are fully miscible[1]. This concentration plays a key role in the propagation speed of the flame. This is because water is a product of the combustion reaction (the other primary product being CO_2)[1][2], and the water concentration in the fuel mixture can act to slow the propagation rate, or extinguish the fire (in sufficiently large concentrations). Isopropyl alcohol can also produce relatively low temperature flames[3] despite the blue temperature, which usually indicates a high temperature flame[4]. This factor may also place more importance on the water content of the fuel mixture, as the cool flame might not produce enough energy to evaporate the water or overcome its detrimental effects to flame propagation.



Figures 1 and 2: Stills taken from video showing color of flame and difficulty to capture depth of flame.

The mixture concentration (in this case, a water and fuel mixture) is important because, according to Stephen R. Turns [5]:

> A flame will propagate only within a range of mixture strengths between the so-called lower and upper limits of flammability. The lower limit is the leanest mixture (Φ_{min}) that will allow steady flame propagation, while the upper limit (Φ_{max}) represents the richest mixture.

There are of course a number of other factors that affect the propagation rate of a flame. These factors include, but are not limited to, energy losses due to radiation, low temperature environments, and conduction from the flame zone[5]. The ability of an environment to sustain a fire of a certain mixture can also be found by calculating Φ and comparing it with Φ_{min} and Φ_{max} for the particular fuel mixture in use. This calculation takes into consideration the environment ambient temperature and volume and assumes ideal-gas behavior. For the flame in this experiment, Φ is found to be 0.488 based on an estimated evaporated vapor volume of 0.05 m^3 around the area of the flame (see calculations in appendix). With a Φ_{min} and Φ_{max} of approximately 0.5 and 3.0 respectively[1], this environment is very near the minimum limit to support a flame. Because the environment did support a flame, it is likely that there is an error in the estimate of the vapor volume, or in the assumption of ideal-gas behavior. However, the nearness of Φ to the lower limit of flammability may also contribute to the slow propagation rate of the isopropyl alcohol flame.

All of the required equipment to perform this experiment are common household products. The flame in these images is contained in the divot on the bottom of an overturned bread pan. The dimensions of this divot in the bread pan are 3 inches by 5 inches. About 0.1 inch of isopropyl alcohol is poured into the indentation. The alcohol is ignited by a match touched to the center of the area and quickly removed. The isopropyl alcohol flame is bright enough and propagates in a slow enough manner that a Sony Handycam digital video camera can capture the flame. The video camera is held stable on a tripod and is aimed at a mirror angled toward the flame in order to keep the camera at a safe distance (~2 ft.) from the heat (see figure 3 below for schematic of photographic setup). The mirror is rested against a ladder and is restrained from sliding by a cinder block. Because fire emits light, all exterior lighting sources were removed in an attempt to capture the richest flame images possible.

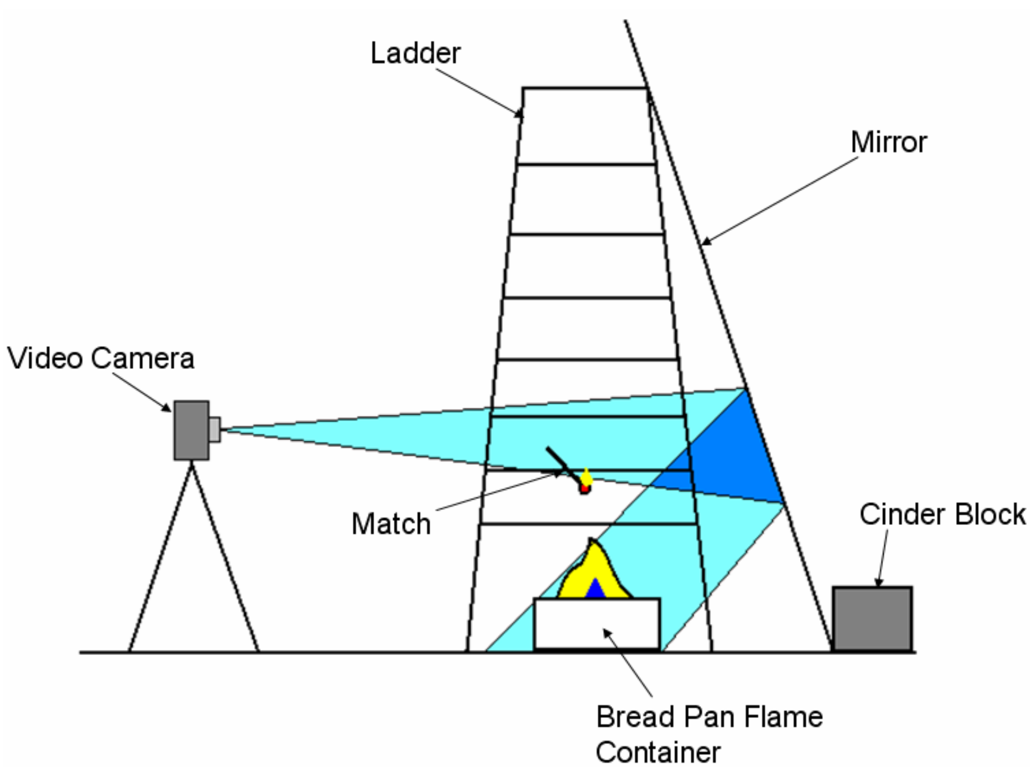


Figure 3: Schematic of setup for capturing flame propagation video.

The visualization technique used in this experiment was capturing the propagation of a small isopropyl alcohol pool flame using a digital video camera and reducing the play speed in order the capture the intricacies of the process. No lighting was used as the subject itself emits the only necessary light, and any other light sources would degrade the sharpness of the image of the flame. In fact, as little exterior light as possible was used in an attempt to capture the depth and colors of the flame. Because the quality of the video camera is not comparable to that of a digital camera, the video does appear somewhat grainy, but achieves its goal of capturing the propagation of a flame. The spatial resolution based on the field of view and the pixilation of the image (see below) is around 0.02 in/pixel. Based on an estimated flow speed of 3 ft/s and a shutter speed (frames per second) of 1/730 sec, the flame will blur across 3 pixels in the photograph. This blur can be seen in the pictures taken from the video (figures 1 and 2), however it is not significant and would be difficult to eliminate as not enough light would enter the lens with a faster shutter speed (and the video camera automatically selected the speed).

Photographic Technique:

- Size of the field of view: 8 in x 8 in = 16 in^2
- Distance from object to lens: 36 in
- Lens focal length: 8.0 mm
- Type of camera: Sony Handycam Digital Video Camera – 0.68 Mpixel (320x240 pixels)
- Exposure Specs: Aperture – f/3.4, Shutter speed (frames per second) – 1/730 sec, Focus – Auto focus
- Photoshop/Movie Maker processing: Trimming of beginning and end of video to capture only the pertinent and visually appealing portion.

This video reveals the ignition and slow propagation of a small isopropyl alcohol pool flame. There is a great deal of physics involved in this process, some of which is discussed previously, and much more which was not touched upon. I like that the reduced speed image shows some of the interesting movement of the flame as it propagates and I especially like that the ignition of the flame by the match is clearly and strikingly captured. I don’t like that the images are relatively grainy and that the flame produce by the isopropyl alcohol is predominately blue, as a yellow flame is much more interesting. I like some of the stills taken from the video and wish that they could have been captured by a higher resolution digital camera rather than the grainy images produce by the video camera. I would have liked to try to capture some higher quality images with a digital or film camera. Overall I am pleased with the images and am pleased to have captured the intent of the experiment.

Calculations

$$P_F = \frac{m_F \left(R_u / MW_F\right) T}{V_{vapor}}$$

$$m_F = vol \cdot \rho$$

$$vol = 3in \times 5in \times 0.1in = 1.5in^3 = 24.58cm^3$$

$$\rho = 0.78 \frac{g}{cm^3}$$

$$m_F = 24.58cm^3 \cdot 0.78 \frac{g}{cm^3} = 1.92e - 3kg$$

$$MW_F = 60.1$$

$$V_{vapor} = 0.05m^3$$

$$T = 293K$$

$$R_u = 8315 \frac{J}{kmol - K}$$

$$P_F = \frac{1.92e - 3(8315 / 60.1)(293)}{0.05} = 1556.6Pa$$

$$x_F = \frac{P_F}{P} = \frac{1556.6}{101325} = 0.01536$$

$$x_{air} = 1 - x_F = 0.98464$$

$$(Air / Fuel) = \frac{x_{air} MW_{air}}{x_F MW_F} = \frac{0.99895(28.85)}{0.00105(60.1)} = 30.77$$

$$\Phi = \frac{15}{30.77} = 0.488$$

References

[1] http://en.wikipedia.org/wiki/Isopropyl_alcohol

[2] http://www.osha.gov/SLTC/healthguidelines/isopropylalcohol/recognition.html

[3] Griffiths JF. Reduced kinetic-models and their application to practical combustion systems. Progress in Energy and Combustion Science 21 (1): 25-107 1995.

[4] http://en.wikipedia.org/wiki/Flammable

[5] "An Introduction to Combustion," Stephen R. Turns, McGraw-Hill, Boston 2000, pg. 287-290.