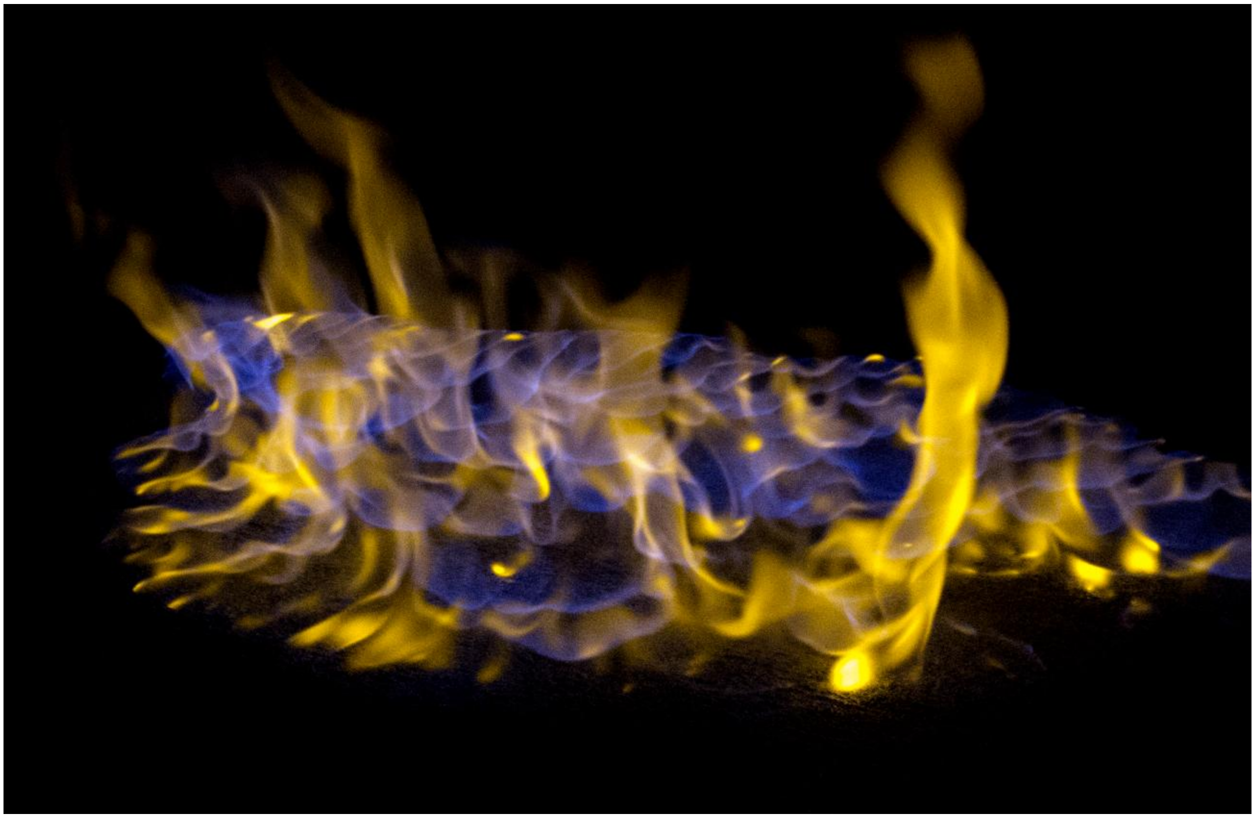
Flow Visualization

Group Image 2



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Introduction

For the Group Image #2 assignment, we decided that it would be interesting to try and capture the movement of flames of varying colors. Flames can be very beautiful and inspiriting things; both mesmerizing and destructive at the same time. The motion of the flames is even more interesting but can be hard to capture well without a top-notch camera. The picture above was taken outside on a mildly-windy night, so the flame motions were especially furious and difficult to capture in focus. We also wanted to try and experiment with flames of different colors to see what kind of visual effects we could produce. We thought about igniting a solution of boric acid and methanol, which produces an intense green flame, but decided to avoid doing so for environmental reasons. Methanol by itself produces a beautiful blue flame when light, which is what you can see in my image. Salt was added to the methanol to enhance the burning time and provide the yellow flame in the image. Although the camera focus and resolution isn't perfect, I decided to choose this image because it clearly shows the intensity of the fluid flow while the vivid contrast of the flame colors draws the audience into wonder.

Procedure

The Following materials were acquired for this experiment.

1	Methanol (HEET Gas Line Antifreeze)
2	Glass for mixing
3	Table salt
4	Safety goggles
5	Safety gloves
6	Matches

Figure 1: Experiment Materials

This image was shot outside at night on a closed driveway. Methanol was poured into a small glass and varying amounts of salt was added and stirred. The mixture was then poured in a controlled size and shape onto the concrete. Once the camera was set-up and ready to go, the solution was ignited using a match, creating the beautiful blue and orange flames seen in this image. There was a slight but steady wind from the west, which generated a lot of interesting flame motion. Methanol (or Methyl Alcohol) is poisonous and any skin or eye contact should be avoided, so protective gloves and goggles should be worn at all times during this experiment. Safety was our number one priority, and it is important to always read the safety labels when dealing with hazardous chemicals.

My image was taken on March 27, 2011 using a Cannon PowerShot G12 camera. The most difficult part about taking this image was getting a decent focus on the actual flames instead of the concrete surface. We attempted to set a manual focus using a lighter and focusing on a small flame at approximately the same distance as the Methanol flames, but this still proved difficult. Once the fuel is ignited, there isn't much time to continue to manually focus until the flame dies, so often we did the best we could using auto focus instead. The other difficulty was finding an appropriate shutter speed/aperture value to capture the fire without too much motion blur. The problem is that, although this was taken at night, the total amount of available light is whatever the flame emits, which was not enough for high shutter speeds in this circumstance. The camera data for the finalized image is shown in Table 1 below.

Shutter Speed	1/80 sec
F-Stop	f/2.8
Max Aperture Value	f/2.8
ISO Speed Ratings	1600
Focal Length	6.1 mm
Pixel Resolution (Post-crop)	2153 x 1395

Table 1: Image camera data

Discussion:

The intricate and seemingly random geometry of the flames is a very complex interaction between many factors. The overall causes for the geometry seen will be discussed below

Combustion, such as a lit match, causes atmospheric oxygen to get consumed, and other gases (including carbon dioxide) to be produced. In addition, energy is liberated in the form of heat and light. The produced gases are hotter than the environment due to the generated energy, and they expand, as heated gases often do. Then, because their density is lower than the surrounding atmosphere, the heated gas rises. While it is moving up, it carries energy with it, thus the flame ends up pointing upwards. Also, because the products of combustion move upwards, they make more oxygen available to make the flame continue to burn [4]. In our case, the flame takes on various shapes because the surrounding air was not static. In fact, random gusts of wind that were estimated to be at 25 miles per hour entered the testing environment at random intervals, all of which were at lower temperatures and varying densities from the flame and surrounding ambient air. This led to the odd shapes of flame seen in the final image [4]. Given standard temperature and pressure, the Reynold's number of the incoming external air flow is roughly [1]:

$$\mathrm{Re} = \frac{\rho \mathrm{V} L}{\mu}$$

where:

V is the mean velocity of the object relative to the fluid (m/s)

L is a characteristic linear dimension, (travelled length of the fluid) (m)

μ is the dynamic viscosity of the fluid (Pa*s)

ρ is the density of the fluid (kg/m³)

$$Re = \frac{1.275\frac{kg}{m^3} * 11.18\frac{m}{s} * 5m\ (estimated)}{1.845\ x\ 10^{-6}\ Pa * s} = \mathbf{3.9\ x\ 10^6} = > Turbulent\ Flow$$

This makes sense, given the almost chaotic look of the flames' geometry. As the turbulent flow interacts with the flames, they take on the turbulent characteristics as well.

The flames themselves were ignited on a fairly static pool of methanol. An experiment with a similar set-up was performed at the Indian Institute of Technology, Madras, more tightly controlling the dimensions of the pool (or "layer"), also using methanol [2].

The temperature can be evaluated when a couple assumptions are made; if the oxidation of fuel is assumed to be irreversible and infinitely fast, thermal enthalpy and species concentrations are represented by simple linear functions of X and the reaction occurs for X = Yo,d (Yo,X+ ckYv.w) [see 3]. Temperature is obtained by inserting specific values for enthalpy, species concentrations, and specific heats [3].

When methanol is ignited, it burns with a bright blue flame to form carbon dioxide and steam, shown in the equation below[5].

$$2CH_3OH\ +\ 3O_2\ \rightarrow\ 2CO_2\ +\ 4H_2O$$

The sodium chloride, which is insoluble in alcohol, provides the bright orange color when ignited. Sodium is an alkali metal, and each alkali metal is known for burning with a different flame color. A common experiment in high school chemistry, known as a flame test, is often used to show these distinctions. In general, the alkali metals have the following flame colors: Lithium burns crimson, sodium burns yellow, potassium burns lilac, rubidium burns red-violet and cesium burns blue[6]. All of these colors are generated from different electrons changing their energy state during combustion. When the sodium burns, energy is emitted when an electron drops from the $3p^1$ orbital to the $3s^1$ orbital of a neutral sodium atom, the ion having acquired its valence electron from the combustion reactions in the flame[6].

References

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