<u>Group Project 2</u>

David Levine

MCEN 4228

8^{th} November 2007

Background

My emphasis on this project was to create a fire image of a green colored flame as well as examine it's interaction with a flammable liquid, such as WD40. Spraying the WD40 onto a laminar flame would cause the flame to become turbulent and capturing a green, laminar flame turning into a turbulent, yellowish-orange flame is what I wanted to capture for my final image.

To accomplish a green colored flame, it involved a lengthy trial and error period of different materials. The final flame materials used involved boric acid and methanol. The exact materials used and procedure will be discussed in the materials section. After multiple trials, I was able to obtain a green flame that last for approximately five minutes. It was now time to construct an apparatus that would allow me to control the size of the flame, introduce a combustible substance, and permit a safe method to capture a series of photographs. After taking multiple images, I decided I wanted the final image to be composed of three different images including the flame by itself, the flame with the combustible fluid before the interaction, and then the flame's reaction to the combustible substance.

After spending many hours of capturing images of flames, I finally was able to obtain a series of images that were in focus, and with a little bit of touchup from Adobe Photoshop and iPhoto, create a photo that not only demonstrates the physics and chemistry behind fire but also an artistic image.

The rest of this report will focus on the physical chemistry behind the creation of the green flame, the physical interaction between the flame and WD-40, and why a turbulent flame was produced using a flammable liquid.

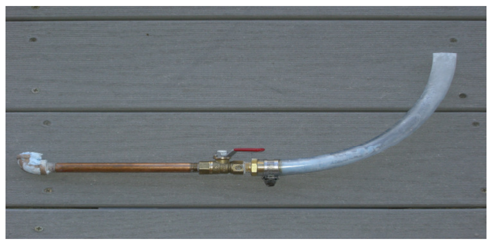
Experimental Setup & Safety Precautions

After figuring out a good mixture of the boric acid and methanol, I realized I was not going to be able to just put some on the ground, light it, and obtain a good image. I identified the following two things as imperative to obtain a well-focused image as well as a series image:

1. Pipe with valve to control the flow and ultimately the size of the flame
2. Needs to be suspended in air for a better framed image

With those two things necessary, I had to build an apparatus that would allow me to control the flow of the methanol/boric acid mixture. This fixture was built by buying brass tubing and a ball valve and this fixture is shown in Figure 1.

Figure 1

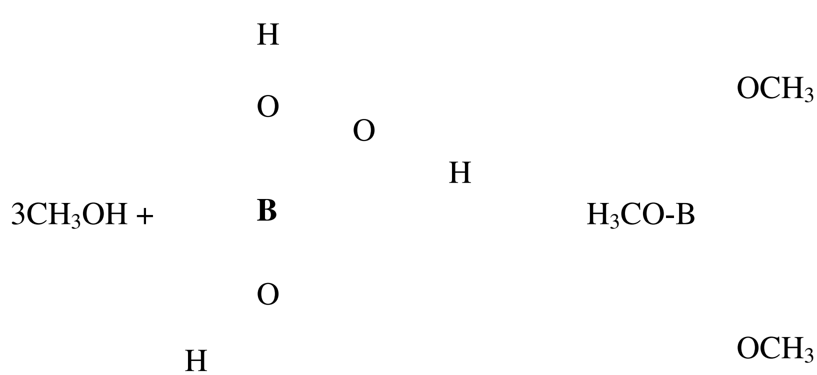


As with Group Project 1, safety was a top priority and the safety precautions taken included working on cement (garage), with no dry leaves or grass nearby, a bucket of sand, and a gallon of water.

<u>Chemistry & Physics of Fire</u>

Mixing methanol with boric acid yields the green flame shown in the final image. So what exactly is the dominating factor creating the green colored flame? The answer comes not from the methanol, but from the composition of boric acid. The combination of methanol and boric acid is shown in Figure 2.

Figure 2



A single molecule of boric acid is composed of a Boron (B) atom and three hydroxy groups (OH) and it turns out the Boron atom is the key element in producing the green colored flame. The chemistry behind the color is directly related to the atom's electron configuration. For Boron, the electron configuration is $2s^2 2p$. This means there is only one electron in the p-orbital and as a result, the electron is easily excited in the presence of a catalyst. For this project, heat acted as our catalyst and is absorbed by Boron. The heat then disrupts the bonds between the boron atom and the hydroxy groups and the electrons use this energy to jump to a higher energy level, otherwise known as an excited state. Once the energy introduced by the catalyst is consumed, they electrons relax to lower energy levels by emitting the energy as photons of light. These photons of light emit a precise quantity of energy and this energy is equal to the difference between two energy levels. This energy is also inversely proportional to the wavelength and means the greater the difference between the two energy levels, the smaller the wavelength. So whenever a green flame is seen, it is valid to say that the energy difference between the two energy levels is greater than that of a normal yellowish-orange flame.

A flammable liquid is combustible only when introduced into a high temperature zone. Since the temperature of a green flame is fueled by boric acid, it is important to note not only the heat of combustion for boric acid but also the flash point for WD40. The heat of combustion for boric acid is 336 F and the flash point for WD40 is 151 F [1]. So as the WD40 is sprayed into the green flame, the WD40 particles are rapidly heated and are exposed to temperatures well above their flash point. As a result, these particles combust and create the typical "WD40" reaction. The combustion, or exothermic, reaction occurring is shown in Figure 3.

Figure 3

OCH_3

$H_3CO\text{-}B$ $+ O_2 \xrightarrow{\text{Heat}} CO_2 + H_2O + \text{heat}$

OCH_3

So, does this reaction cause a change in fluid flow?

Flames created from a high-pressurized liquid such as WD40 can immediately transform a laminar flame into a turbulent flame because the liquid particles are being ejected at extremely high velocities. There are two reasons that the particles are being ejected at high speeds. The first is the pressure within the can and the second is the cross sectional area of the spraying nozzle. The smaller the cross sectional area and the greater the pressure, the higher velocity the particle will exit. I believe a basic Bernoulli's analysis of this could determine the exit velocity of the particles in order to validate that there is turbulent flow. Using a simplified Bernoulli's equation, shown in Equation 1 [2], where P_1 =110 psi, v_1=0, h_1=-12, P_2=14.7 psi, h_2=0, ρ=.817, an exit velocity, v_2, was calculated to be 1268 m/s.

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \qquad \textbf{Eq.1}$$

Using this exit velocity, a Reynolds number was calculated with v=1262 m/s and a kinematic viscosity of .05 g/cm*s [3]. The Reynolds number was 304368. This number lies within the transition to turbulent region and agrees with the flame becoming turbulent when the WD40 is sprayed into the green flame.

I believe the shape of the turbulent flame is determined by the flow of liquid particles as well as the concentration of liquid particles. As these liquid particles are ejected from the bottle into the green flame, they tend to fan out. Some particles go straight and some diverge at an angle and only portions of these particles are immediately interacting with the green flame. As a result, there is a general area of violent combustion. However, it is the edges of the fire that define the shape of the flame and I believe these edges are a result of the liquid particles' fanning out. In other words, as the particles fan out, the concentration of the liquid particles decrease and so does the flame.

Materials

Listed below are the materials used for the final image. To obtain a mixture of antifreeze and boric acid that would last for an extended amount of time, a 3:1 mixture of antifreeze to boric acid needed to be mixed and stirred for 1-2 minutes.

1.) Heet Antifreeze
2.) Roach Pesticide
3.) Brass tube
4.) Brass 90
5.) Brass Female Adapter
6.) 5/8" hose
7.) Ball Valve

Photographic Technique

Table 1 indicates information about the Final Image as well as the 3 individual images that create the final image. "N/A" is shown under Final image for some aspects because that property belongs to the individual images. Also, since this was a flame image, no lights were on in the garage. The only light source used was the flash in order to focus the image.

Table 1

	Final Image	Photo 1	Photo2	Photo 3
Focal Length	N/A	6.2 mm	6.2 mm	6.2 mm
Size of the Field of View	N/A	12 inches	12 inches	12 inches
Distance from Object to Lens	N/A	12 inches	12 inches	12 inches
Type of Camera				
Digital	Casio Exilim EX-Z700	EX-Z700	EX-Z700	EX-Z700
Width X Height (Original)	N/A	2304 X 3072	2304 X 3072	2304 X 3072
Width X Height (Cropped)	6913 X 2112	N/A	N/A	N/A
Exposure Specs				
Shutter Speed	N/A	1/60	1/60	1/60
Aperture	N/A	2.6	2.6	2.6
ISO	N/A	50	50	50

Adobe Photoshop

Although there was a sheet hung behind the setup, some of the photos contained small amounts of the garage door as well as other distracting elements. Using the levels command in Photoshop allowed me darken the background, discard the distracting elements, and retain a clear and visible image of the flame. In addition to using levels to darken the background, I also used levels on images 2 & 3 to bring out more of the light colors and create more of a contrast. I then used Photoshop to import the three photos onto one background to create a time series affect and then cropped the height of the entire image.

Final Thoughts

I am extremely pleased with the results of this project. After Group Project 1 and not feeling as though I had performed as well on it as I had with the Get Wet and Clouds project. I feel as though I worked ahead of the schedule and as a result, obtained a vivid flame color and created a final image that not only shows the chemistry and physics of fire, but also created an artistic image.

Similar to the Get Wet and Clouds project, I learned a significant amount about what affects the color of flames, how the color is related to the energy of the flames, and how flammable liquids combust and interact with a laminar flame.

Once again, I am very pleased with not only the final image, but also the information I have gained from doing this report.

References:

1.) http://www.wd40.com/Brands/pdfs/msds-wd40_aerosol.us.pdf
2.) http://www.science.ubc.ca/~csp/life/StudentSamples/Website2/index.html
3.) http://tsi301.com/comparison.htm