Team Project 2: Burning Acetone: Laminar and Turbulent Flames

Dominic DiMarco

Senior Mechanical Engineering

MCEN 4151: Flow Visualization: Dr. Jean Hertzberg

April 6, 2011

Introduction

Acetone has the chemical empirical formula $(CH_3)_2CO$, a chemical which is commonly used as a commercial solvent or nail polish remover. What makes acetone interesting as a fluid, besides being a great solvent, is that it is quite flammable. Since acetone burns with minimal heat needed, it is quite easy to produce a controlled flame to watch how it interacts with environment changes. The resulting data from this project interestingly brings a realm of fluid dynamics which is very fascinating and shows how fluid dynamics encompasses more than just water and air.

Behind the Physics of the Flow

The chemical reaction that occurs with the combustion of acetone is:

$$(CH_3)_2CO + 4O_2 \rightarrow 3CO_2 + \ 3H_2O$$

Overall the chemical reaction is exothermic and allows the combustion to provide a flame which appears very "smooth" and uniform. If the process was to not produce any NO_x or CO emission, it would require that the reaction be at adiabatic flame temperature. However, because most of the conditions within an open environment do not allow for such a high temperature without proper insulation, the adiabatic flame temperature is not reached. This produces a turbulent mixture rate for the atmosphere around the flame, even if the heat exchange itself is laminar[1].

Once the acetone burns, right away the flame is visible and produces a shape which is remarkably a lot like when water comes out of a faucet. This phenomenon comes from the diffusion of heat, which creates flame propagation[2]. When this heat is diffused, the cold air around it is denser and therefore lifts the less dense hot air, lifting the soot we see as fire.

What causes the narrowing effect as you go up along the flame is a result of this buoyancy, however since heat diffuses in equal amounts throughout the flame, less heat and more importantly mass, is available at the top of the flame to be carried upward. The interesting aspect of the flame when it is laminar as well is how uniform the flame appears.

[1]Bert, Walter George. *International Symposium on The Use of Models in Fire Research*. Washington, D.C.: The Committee on Fire Research, 1959. Print.
[2]Glassman, Irvin. *Combustion*. Burlington, MA: Academic Press, 2008. Print.

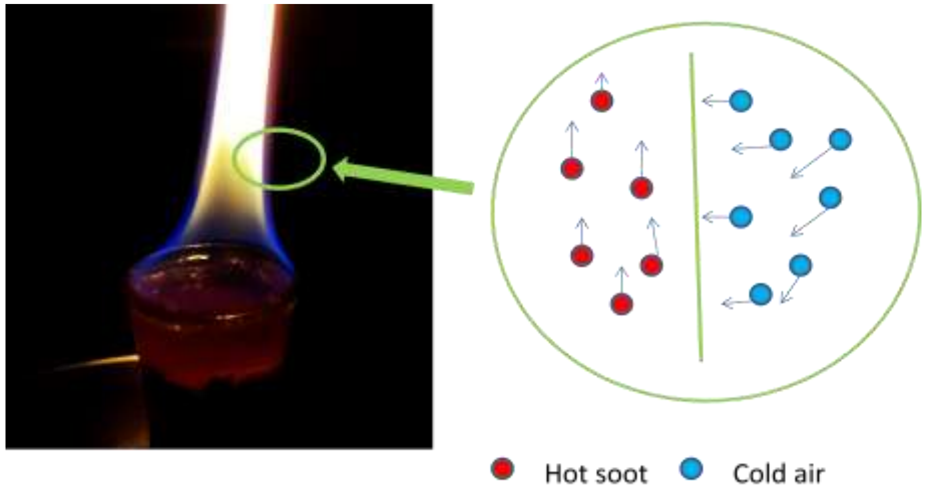

Figure 1: Free Body diagram of molecular interactions in flame.

There is a lot more physics going on here than there is room to talk about, but what can be readily shown is that buoyancy in the air plays a significant role in the shape of the flame itself.

When water is poured over the flame and displaces the acetone in the shot glass, the acetone itself is still undergoing a combustion process while the water moves the acetone over the shot glass. Because of this, the acetone burns while falling over the shot glass to produce the illusion that the shot glass itself is burning. However, under close inspection, one can see clearly that once the acetone stops spilling over, the glass is indeed not burning, but was in fact turbulent combustion around the glass. Also, when watching the video, the flame diminishes in strength because the water replaces some of the acetone in the shot glass. This makes a more dilute solution to have combustion under and therefore diminishes the flame. While the overall effect is very artistic, the combustion process is the same as when it was laminar. The main difference was in the mixture of the acetone and water to reduce the combustion and also in the conditions around the acetone with water present that caused the turbulent flame around the shot glass.

Set Up

The project was a little complicated in the sense that a great deal of safety considerations that needed to be followed for burning acetone. One of the primary concerns is the fire moving out of the pool of water surrounding the shot glass. This was easily solved by using a ceramic countertop that was far away from any outlets or cabinets. Another health consideration is that acetone is poisonous when the vapor is being breathed in for long periods of time. By having a ventilation system in use or having a cracked window nearby helps release the fumes and disperse them much more readily. If the window is open too much to the point where it affects the project itself or if the fan is too strong to cause an erratic atmospheric condition, it may hinder the project results. Lastly, when pouring the water, it is imperative that *warm* water be used when pouring over the shot glass and that not too much water is being poured over the shot glass at a time. If the shot glass is suddenly introduced to a steep temperature drop, the glass may shatter. First, the surroundings must be taken care of to remove flammable objects and should have a readily available source of warm water to put out the flame if necessary. Then, place a cooking pan full of warm water on the ceramic counter top or a similar fire retardant surface. Then, in a generous amount, add pudding inside the shot glass to allow just enough acetone to burn a controlled flame size that should not be any larger than the shot glass itself. This shot glass is then introduced to a small amount of acetone and placed inside the pan of warm water. Carefully, once the camera is at a safe distance (around a foot and a half away is good) light the acetone with a long reach lighter *with the lights still on*. After this, slowly pour small amounts of water over the flame from about a half foot height and watch the flame.

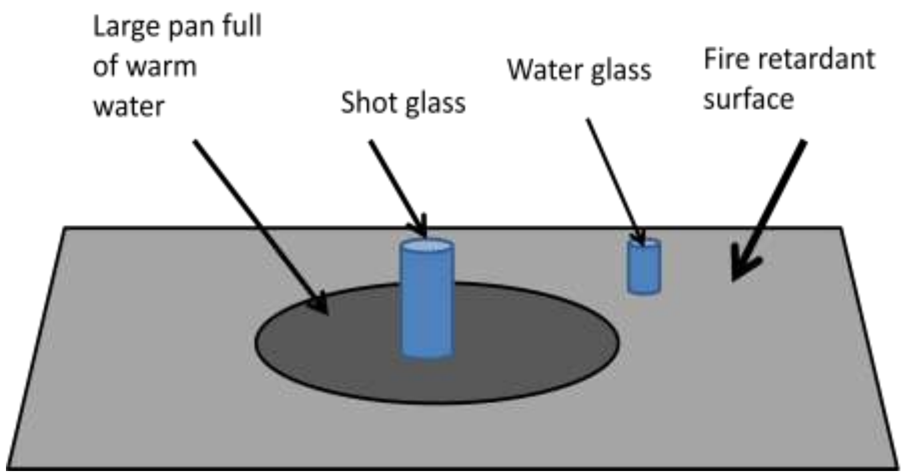

Figure 2: Set-up of shot glass with necessary materials.

The camera used to take this video was a Casio Exilim EX-H5 on March 27, 2011. The main light source was left to be the flame resulting from the project since the effect was much more dramatic when it was lit in this manner. The video was shot at a pixel count of 4000x3000 pixels which provided plenty of information for this project. The ISO was automatically adjusted while the focal length remained at 14mm. The still photo was taken with an F-stop of 4.6, an exposure time of 1/20th of a second, an ISO rating of 800, and a focal length of 14mm. The resulting maximum aperture value was 3.4, a pretty good field of depth. Also, the final still photo was reduced to a 3380x3000 pixel count. With this setup, a very clean image was able to be produced and a good focus was kept throughout the video. The fluid visualization may have been more beneficial with a high speed camera or even a regular camcorder with better ISO control, but for the given equipment the resulting visualization provided an amazing detail of acetone combustion.

Result

While acetone is commonly associated as being a highly effect solvent, the combustion properties are also just as intriguing and produce a beautiful sight when under the right conditions. What is most fascinating is the turbulent and laminar flames seen when burning in atmospheric conditions. The resulting combustion, when water displaced the acetone, showed that the flame itself was relatively low enough where the shot glass did not melt or compromise. Also, the artistic beauty which creates the illusion of a burning glass has an appeal to why humans are fascinated by things which move in fluid movements. The project answered the question of whether acetone burns at a relatively high or low temperature, along with how combustion can diminish in the presence of water. Even though these answers were met, much more about why acetone can stay on the glass and burn for a somewhat extended period of time has not been fully covered, along with answering the question of why fluid movement creates the illusion of life. Overall the project was a great success and is a great way to analyze flame physics and combustion.