Combustion of Nitrocellulose

Group Assignment #1 Report

MCEN 4151 – Flow Visualization

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Group 7

Introduction

For the first group assignment, my group and I had the desire to visualize an interesting combustion in slow motion. None of us had ever worked with a slow motion camera before or had ever edited video. For this first assignment we wanted to learn how each of these worked so that the possibility of their utilization would not provide an obstacle to us on future assignments. The most interesting use of a high speed camera is to gain more knowledge from something that occurs rapidly. As such, we wanted to use a combustion that was so rapid that a high speed camera would be useful. One of the first ideas we had was to use nitrocellulose, more commonly known as “flash paper.” Nitrocellulose is commonly used in magician performances and the entire combustion reaction takes place in less than a second. To the human eye, the burning of flash paper looks like a large fireball that happens almost instantaneously. To a high-speed camera, however, the reaction has some very interesting behaviors which become visible.

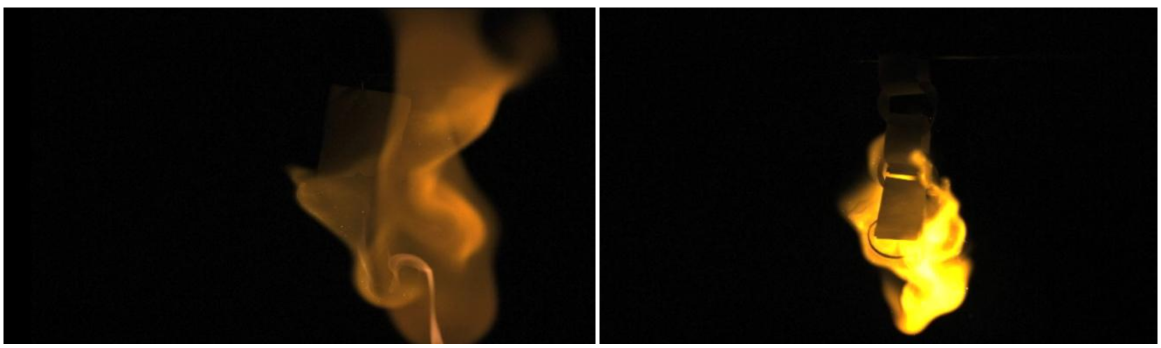

Figure 1: Screenshot of video

Nitrocellulose

Nitrocellulose is a highly flammable material developed in the 19th century and used in a variety of applications today. It is produced by nitrating cellulose through exposure to nitric acid(Nitrocellulose). It was first discovered when Christian Friedrich Schonbein spilled concentrated nitric acid on his kitchen table and cleaned it with a cotton apron(Nitrocellulose). After the apron had dried on the stove door, it exploded. Since then, the production of nitrocellulose has evolved to form a much more stable substance. The process converts cellulose into cellulose nitrate and water using nitric acid according to the formula in Figure 2 below. It can be used as a propellant, explosive and even a lacquer for finishing guitars and vehicles.

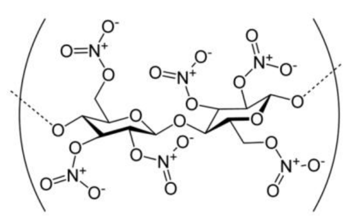

Figure 2: Chemical equation for the formation and structure of nitrocellulose (Nitrocellulose)

When the right proportions of heat, oxygen and fuel (usually hydrocarbons) are brought together, a rapid oxidation can occur known as combustion (Combustion). The reaction is an exothermic chemical reaction which produces heat and, sometime, light. Combustion is considered complete if, after oxidation, the only compounds remaining are CO_2 and water. Such a reaction is very difficult to achieve. While the reaction of nitrocellulose didn't visibly produce any solid matter, it is likely an incomplete combustion.

Combustion can also be classified by type. The high speed video taken of the combustion of nitrocellulose is very useful in identifying the type of combustion which can be classified as diffusion combustion. In a diffusion flame, the combustion takes place in a reaction zone in which the fuel gas and oxygen are transported (Bilger, 1989). This movement of fuel gas and oxygen into the reaction zone is a diffusion process, giving the type of combustion its name. The combustion does not take place directly at the location of the fuel because it is too rich. Instead the fuel undergoes pyrolysis which is a reaction in which the fuel is decomposed by convective and radiative heat feedback (Bilger, 1989). This pyrolysis can be seen in Figure 3 where the flame doesn't appear to touch the actual material. This fuel gas generation must continue or increase in order for the process to continue (Bilger, 1989).

Figure 3: Pyrolysis of nitrocellulose while falling

This diffusion of gasses, both fuel and oxygen, can be laminar or turbulent. Laminar diffusion will result in flames that are smooth and steady as seen in the oxidation of nitrocellulose. The oxidant travels towards the flame as buoyant forces cause the hot combustion products to move upward. Towards the top of the flame, the process is lean as most of the fuel has been burnt at its base. The flame "searches" for more oxidant, resulting in a turbulent diffusion flame (Bilger, 1989). This turbulent flow can also be seen using the high speed images presented.

Visualization Technique

In order to better understand the rapid combustion described previously, a high-speed video of the process was highly desired. Fortunately, Vision Research (a subsidiary of Ametek Co.) performed a demonstration of the PHANTOM V710 high-speed camera and we were given the opportunity to collect our images with their help. The two salesmen that performed the demonstration were Mark Doerfler and Chris Kerr, and they expertly assisted in the capturing of our images. We took the images inside an unlit room in the Durning Lab. We used lights to focus the image, and then turned them off during the process. Within a single run, Mark Doerfler was able to set the aperture to allow for excellent exposure and clear images.

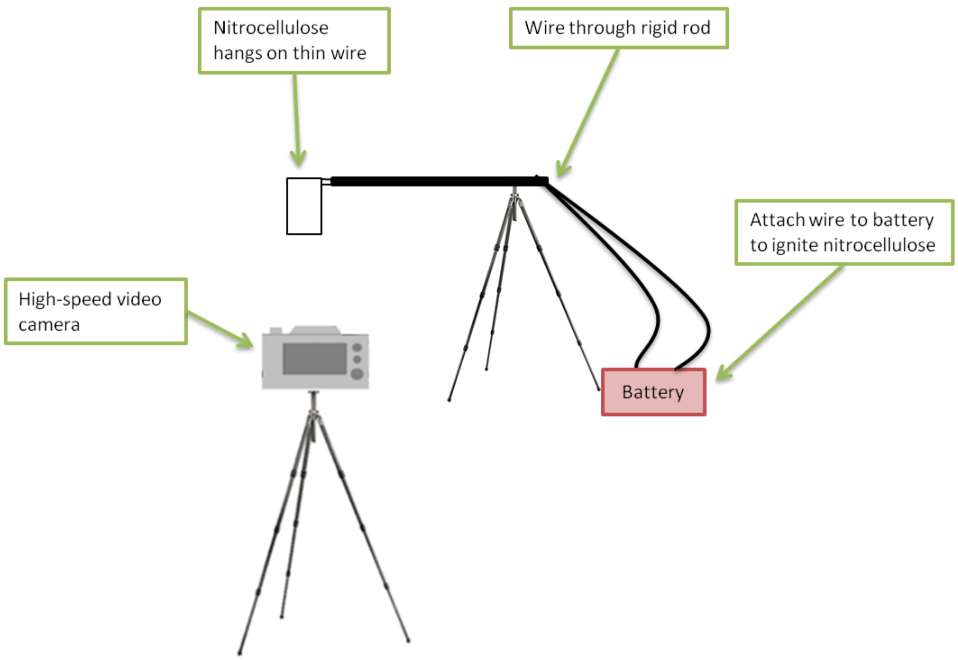

Figure 4: Image capture set-up

As seen in Figure 4, the nitrocellulose was set up on an ignition apparatus built by my team. Our desire was to use a battery to heat a wire as a source of initial combustion of the nitrocellulose. We wanted to see the flash paper ignite without the presence of an external flame as well as have the safety of distance between the person and combustion process. However, the flash paper was also hanging from where it was ignited (by the thin, hot wire) and would fall out of frame. We therefore lit the flash paper from the bottom which resulted in some interesting reactions between the two flame sources such as the vortex seen in Figure 1.

- Field of view: 12X8 inch
- Distance from object to lens: 4 feet
- Camera: PHANTOM V710, color, 8GB memory, 12-bit
- Image dimensions:each original – 1280x800 pixels, final – 1280x800 pixels
- Exposure specifications: 5,000 fps
- Post-processing: image splicing, play back speed adjustment, reverse playback

Conclusion

Using the high-speed camera effectively showed the combustion of nitrocellulose which is a rapid chemical reaction. At 5,000 frames per second, the approximately 0.5 second reaction can be seen as slow as 3 minutes at 15 frames per second. It's truly amazing to see how much happens in such a short time and how much the human eye cannot see. The high speed capture of such a rapid combustion allowed us to better understand the physics involved in the reaction. It was a great experience learning the techniques for video capturing and editing during this assignment and my intentions were met in that regard as well as capturing the image.

In addition to video capturing and a bit of editing I would like to learn more about video editing and include audio into this assignment. It would add a lot to the video and make it that much more pleasant and interesting to watch. I would also like to learn more about CODEC's and how they are used. The guest lecture concerning this topic was very informative and beneficial, yet it only made me realize how much more there is to learn. This assignment has given me the motivation to learn more about this highly useful and interesting topic.

References

Bilger, R. (1989). Turbulent Diffusion Flames. *Annual Revieow of Fluid Mechanics , 21*, 101-135.

Combustion. (n.d.). Retrieved March 17, 2011, from Wikipedia, the Free Encyclopedia: http://en.wikipedia.org/wiki/Combustion

Nitrocellulose. (n.d.). Retrieved March 17, 2011, from Wikipedia, the Free Encyclopedia: http://en.wikipedia.org/wiki/Nitrocellulose