MCEN 4151 Gregory Lundeen
Prof. Jean Hertzberg 5/1/2012

Group Project #3

Flow Visualization

Burning Steel Wool

This video is the third group project for the flow visualization class at the University of Colorado at Boulder. The team strived to capture the phenomena of electricity arcing across the steel fibers of a ball of steel wool as the burning wires from the current propagated across the ball of steel wool as a demonstration of an interesting type of fluid flow. The ball of steel wool was spread apart slightly to allow more air flow within the material in a random fashion and set on fire with a nine volt battery. The resulting video from that experiment were post produced and presented. The team consisted of students Gregory Lundeen and Ryan Kelly.

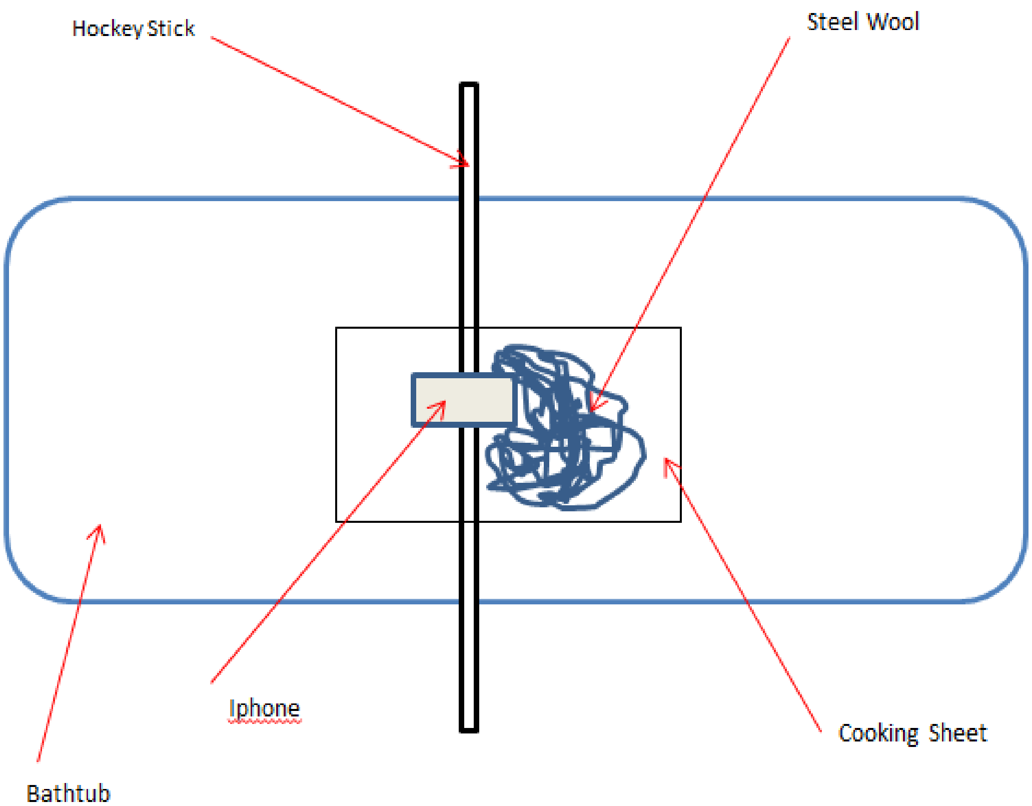

Figure 1: Experimental Setup

The overall experimental setup was relatively simple, and could be repeated in any common household. The experiment was initiated in a common bathtub. A standard baking sheet was used as a base to protect the bathtub surfaces from damage resulting from the burning and arcing of the steel wool. A hockey stick (or could be any other piece of rigid material) was placed across the top of the bathtub to give the camera a steady place to rest while filming. As seen in Figure 1, the camera was placed onto the hockey stick, above the steel wool for overhead filming of the experiment. The hockey stick was gently stabilized with a chair. The steel wool was fluffed up a bit prior to ignition to create more voids for air to occupy while the combustion took place. This aided in the oxidation of the steel wool during combustion.

Despite the name steel wool is made from a very low carbon steel, almost plain iron, broached into fine filaments and bundled together to form a product for buffing, scraping, and polishing [1]. When connected to a battery, the effect on the steel wool is a process called Joule Heating [2]. Joule heating, also called ohmic heating, or resistive heating is based on Joule's first law, which states that the heat produced by a wire is proportional to the square of the current multiplied by the electrical resistance of the wire [2]. It forms the fundamental basis of electrical heating sources, but in a much simpler form is exhibited visually in steel wool combusting, as shown in the video. The sparks seen ejecting from the steel wool is during the rapid iron oxidation is due to the carbon content of the steel wool [8]. The more carbon that is contained in the steel the more the sparks will branch, therefore cast iron will branch much less than a tool steel [8]. There are actually 2 possible oxidation reactions that can occur within the steel wool during the combustion process, the first is: 2Fe0 + O2 = 2Fe0, the second is: 4Fe0 + 3O2 = 2Fe2O3 [4]. This is essentially the same oxidation that causes rust, except on a far faster timescale. Also, interestingly, the weight of the steel wool bundle after burning was actually greater than the weight of the bundle the bundle was previous to burning due to the addition of oxygen atoms to the iron when oxidizing, forming the Fe^{+2}, and Fe^{+3} Iron oxides [5, 6]. The added weight of the oxygen adds to the overall weight of the bundle, and creates the byproducts of the reaction. This reaction propagates across the individual filaments of the steel wool as it oxidizes and creates light and heat. This makes it an interesting fluid flow to examine. What is essentially happening is that the battery terminals are causing a line to line fault across the steel wool filaments [7]. This type of fault is when one conductor comes into contact with another conductor. This fault will have a higher temperature than the ignition temperature of the steel wool and therefore cause subsequent ignitions in filaments in close proximity to the initial fault because the energy imparted by the battery is higher than the specific heat capacity of steel, which is 0.452 J/g C [7]. The oxidation and heat released by the combustion progress along the filaments in a progressive and fluid manner due to the propagation of the processes across the filaments, while needing enough oxygen and surrounding the filaments to allow the reactions to continue.

In this imagery, the team chose to use an Iphone4, due to its adaptive nature, and ease of use. It was able to capture and compress the physical nature of the fluid flow well, as well as providing an easy format file to work with. The original video dimensions are 1280 pixels, by 720 pixels. A bit rate of 10,666 kbps and frame rate of 24 frames per second was employed. The final video was edited in Sony Vegas Movie Studio 6.0. The camera was approximately two feet directly vertical from the actual steel wool, and there was no extra lighting used. There were several adjustments to the original video made. For this video the overall brightness and contrast were adjusted to bring out the actual physical interaction of the electricity and the steel filaments. The color was over saturated to give a sense of a Coronal Mass Ejection similar to what happens on the sun, and the background was darkened to further accentuate the light emission of the steel wool. Lastly, a title was added as well as music from the popular seventies band, Pink Floyd.

This video from our group proved to be a successful imaging of the steel wool burning phenomenon. Thank you to my partner Ryan Kelly for his help and assistance. It was a pleasure to capture such captivating images in such a simple environment. This project can be easily repeated by anyone wishing to do so. The actual fluid flow is easily demonstrated and observed, while the setup is simple to replicate with supplies from a local hardware store. Overall, the team believes this was a successful imaging of an interesting fluid flow that is often overlooked in modern society. Hopefully, people will appreciate flows like this more often in the future.

References:

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

[2] http://en.wikipedia.org/wiki/Joule_heating

[3] http://www.popsci.com/node/9344

[4] http://uk.answers.yahoo.com/question/index?qid=20090204081610AAMmjP7

[5] http://www.elmhurst.edu/~chm/vchembook/105Achemprop.html

[6] http://answers.yahoo.com/question/index?qid=20080330084844AAgvrCC

[7] "The Physics of Heat Transfer from Electrical Faults", O'Conner, Michael J. (http://oconnorengineering.net/)

[8] http://shopswarf.orconhosting.net.nz/spark.html