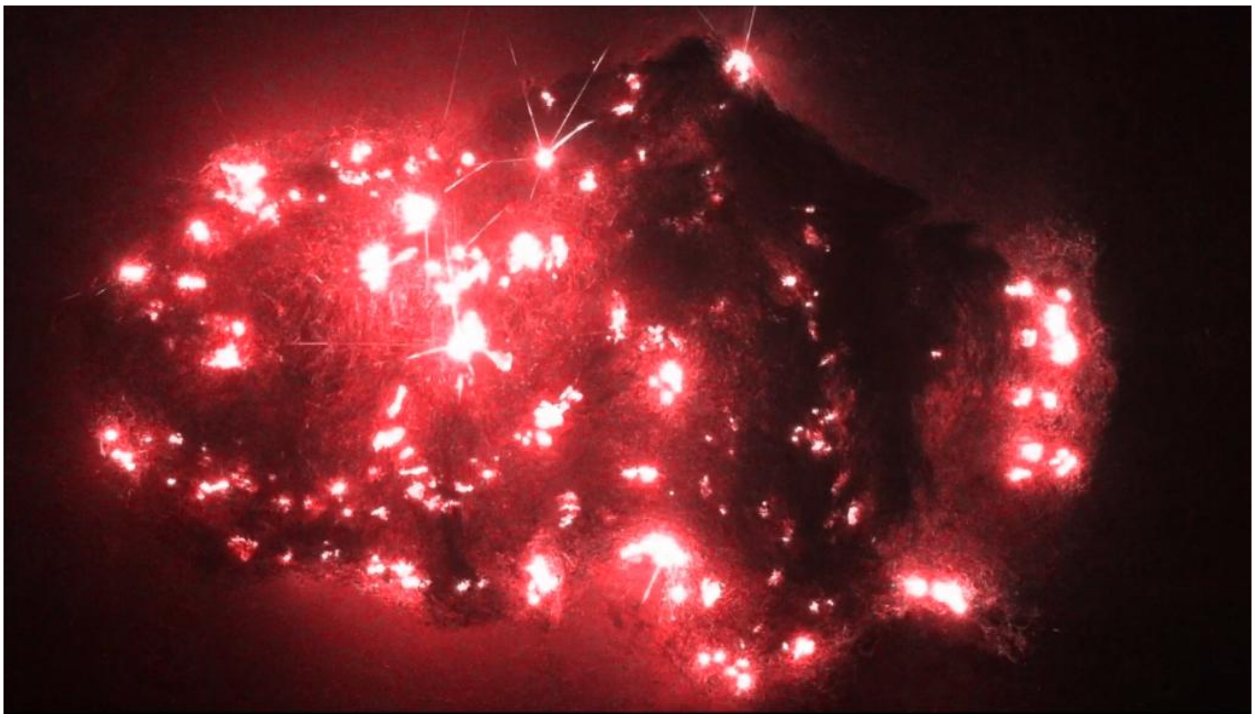
Group Project #3 – Burning Steel Wool



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MCEN 4151
Professor Hertzberg
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Purpose

The purpose for this visualization was for the “Group Project #3” assignment assigned in the Flow Visualization course given at the University of Colorado – Boulder, led by Professor Hertzberg. The goal of the “Group Project #3” assignment was to display the physics of fluid flow in both an experimental and artistic way. It was the group’s intent to display the intricate burning pattern that results from burning steel wool.

Team

For this assignment, I chose to work with a student that wasn’t in my assigned group. The team consisted of the following members:

1. Ryan Kelly
2. Greg Lundeen

Materials

For this representation, the team chose to use several materials that can be easily found at a local hardware store. This was done to allow the reader an easier way of replicating the team’s results for future endeavors. The materials were as follows:

1. Rhodes American Steel Wool Grade #0000 Super Fine Steel Wool
2. 9 Volt Battery
3. Bath Tub
4. Baking Sheet
5. Hockey Stick
6. Chair
7. iPhone 4

Procedure

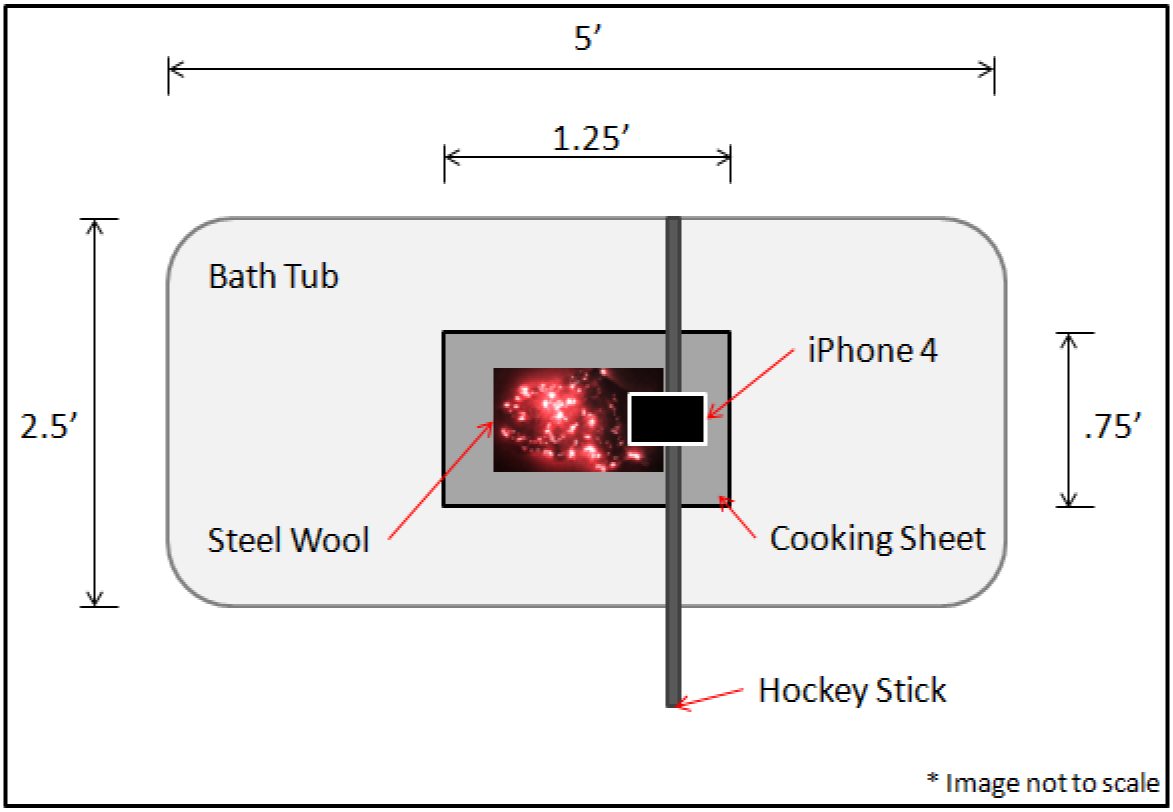

Figure 1: Experiment Setup

The full experimental setup can be seen in Figure 1 above. To setup this experiment, the team placed the baking sheet in the middle of a bath tub. The team then gathered one bundle of super fine steel wool, and "fluffed" it by spreading its fibers from each other, allowing for more oxygen to enter the bundle. After being fluffed up, the team compacted the steel wool slightly, and placed it in the middle of the baking sheet. Compacting the steel wool allowed for the entire bundle to be seen in a single still video frame. To set up a proper support to keep the iPhone 4 still during the video shoot, the team chose to lay a hockey stick across the bath tub, and rest the end of it on a chair of the same height. One team member sat on the chair, stabilizing the hockey stick, and placed the iPhone on the hockey stick with the camera pointing directly downwards at the steel wool. Once proper stabilization occurred, the other member of the team turned off all lights in the bathroom, and used a 9V battery to create a spark in the steel wool.

Flow Dynamics

Steel wool is a bundle of strands of very fine soft steel filaments often used in finishing and repairing work to polish wood or metal objects[1]. It is also often used in emergency situations because it can still burn when wet. It is made from low-carbon steel. The steel is so low in carbon that it is closer to plain iron[1]. For this experiment, the team chose to use a super fine steel wool of Grade #0000. The team chose to use this type of steel wool after experimenting with several other grades, and concluded that the finer the steel wool is, the better the visualization and the longer it burned. Grade #0000 steel wool has an upper fiber width specification limit of 0.00889 mm[1].

When a battery is used to ignite steel wool, the process is called joule heating. Joule heating is the process by which the passage of an electric current through a conductor releases heat[2]. The electric current that passes through the steel wool travels at a high rate of speed, creating electric friction, therefore making the steel wool strands white hot. The electric current will continue to travel through the strands until all of them are oxidized and unable to burn further.

The steel wool appears like Figure 2 below before the oxidation reaction occurs.

Figure 2: Steel Wool before Oxidation[1]

The oxidation equations are as follows:

$$4Fe + 3O_2 \dashrightarrow 2Fe_2O_3 \qquad \text{(Equation 1)}^{[3]}$$
$$C + O_2 \dashrightarrow CO_2 \qquad \text{(Equation 2)}^{[4]}$$

The steel wool appears like Figure 3 below after the oxidation reaction has fully completed.

Figure 3: Steel Wool after Oxidation Reaction

As seen from Figure 3, the steel wool turns into a bluish-gray color after the oxidation reaction ceases. What's left after the oxidation is $2Fe_2O_3$, which actually weighs more than the original steel wool.

The burning pattern seen in the video shows how the electric current travels along the strands of the steel wool. Since the steel wool was "fluffed-up" to introduce more oxygen to the oxidation reaction, the strands are therefore compacted into intricate patterns in which the current travels. As seen in the video, when the 9V battery transfers energy to the steel wool, several strands ignite and go along their separate ways. It can also be seen that because many of the strands are within close quarters of one another, it is common to see a spark jump from one wire to another during the process of oxidation. This phenomenon can be viewed in the slow-motion section of the video, with one clear example at the 1:01 – 1:03 minute mark.

Figure 4: Carrier Line

Figure 5: Spark Picture

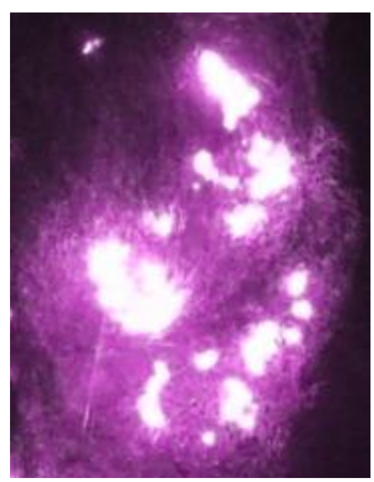

Figure 6: Forks

The spark's trajectory through the air gives a comet-like effect, often known as a "carrier line"[5] which can be viewed in Figure 4. They will also result in individual lines, as seen in the video, called "spark pictures"[5] which can be viewed in Figure 5. The sparks travelling along the steel wool strands stand out the most in the video, and are typically known as "forks" or "primary bursts"[5] which can be viewed in Figure 6. These fork formations result from the presence of carbon in the steel wool.

While the steel wool achieves its white hot state from joule heating, it is also achieved through the carbon from the steel wool combining with oxygen in the atmosphere to form carbon dioxide. This chemical reaction results in an increase of volume, and in an effort to withstand this increase, the steel wool develops an internal stress[5]. This internal stress leads to the disruption of the steel wool particles which then showcases the "fork" physics/chemistry.
After analyzing the entire video, the team was able to estimate how fast the electric current was travelling through the steel wool strands. I found a great spot in the video during the 0:58 – 0:59 second interval where a prominent spark can be viewed travelling a near straight line. I approximated that the spark travelled 1 centimeter over the time interval, which is shown in the video at half speed. Because of this, I can approximate that the sparks were travelling at roughly 2cm/sec.

Video Technique

For this experiment, the team chose to use my Apple iPhone 4 digital video camera as it proved to be the best camera for capturing the intricate physics. The length of the original video is 1:34, with a frame width of 1280 pixels, a frame height of 720 pixels, a bit rate of 10,666 kbps, a frame rate of 24 frames/sec, and was shot at 720p high definition resolution. The length of the final video is 1:55, with a frame width of 1440 pixels, a frame height of 1080 pixels, a bit rate of 24,192 kbps, a frame rate of 29 frames/sec, and was improved to 1080p high definition resolution. I used the Windows Live Movie Maker[6] program to edit this video. Editing consisted of me importing the raw video into the program, selectively cutting the video into sections to display the electric current physics at different speeds, and using the hue visual effect to cycle through the entire color spectrum for each of the speeds. I had the video run initially in real time, then chose to slow down the video to half speed at the 0:26 mark, followed by 2x speed at the 1:04 mark, and back to real-time at the 1:23 mark. To finalize the video, I added a title, director slide, and credits slide. I used the song "Dream Player" by Dan-O at danosongs.com[7].

Conclusion

It was the team's objective of the "Group Project #3" assignment to display the intricate electrical current visualization created from burning steel wool. The team believes we were successful in displaying the basic physics and chemistry themes of the video in an artistic yet scientific way. The team created a video that is appealing to the eye, creating interest and intent to know more on the reader's part. In the future, I would like to perform this experiment with intent of utilizing a better recording device to capture even further detail.

Original Look of Video

References

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3. “Why does burning steel wool increase its weight?” *Yahoo Answers UK & Ireland.* http://uk.answers.yahoo.com/question/index?qid=20090204081610AAMmjP7. Accessed on 5/1/2012
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6. “Windows Live Essentials: Movie Maker.” *Microsoft Windows.* http://windows.microsoft.com/en-US/windows-live/movie-maker-get-started. Accessed on 4/23/2012
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Image Assessment Form

Flow Visualization

Spring 2010

Name(s): Ryan Kelly

Assignment: Group 3 Date: 5/1/2012

Scale: +, ! = excellent √ = meets expectations; good. ~ = Ok, could be better. X = needs work. NA = not applicable

Art	Your assessment	Comments
Intent was realized	!	
Effective	!	
Impact	!	
Interesting	!	
Beautiful	!	
Dramatic	!	
Feel/texture	!	
No distracting elements	!	
Framing/cropping enhances image	!	

Flow	Your assessment	Comments
Clearly illustrates phenomena	!	
Flow is understandable	!	
Physics revealed	!	
Details visible	!	
Flow is reproducible	!	
Flow is controlled	!	
Creative flow or technique	!	
Publishable quality	!	

Photographic technique	Your assessment	Comments
Exposure: highlights detailed	!	
Exposure: shadows detailed	!	
Full contrast range	!	
Focus	!	
Depth of field	!	
Time resolved	!	
Spatially resolved	!	
Clean, no spots	!	

Report		Your assessment	Comments
Describes intent	Artistic	!	

	Scientific	!	
Describes fluid phenomena		!	
Estimates appropriate scales	Reynolds number etc.	!	
Calculation of time resolution etc.	How far did flow move during exposure?	!	
References:	Web level	!	
	Refereed journal level	√	
Clearly written		!	
Information is organized		!	
Good spelling and grammar		!	
Professional language (publishable)		√	
Provides information needed for reproducing flow	Fluid data, flow rates	!	
	geometry	!	
	timing	!	
Provides information needed for reproducing vis technique	Method	!	
	dilution	!	
	injection speed	!	
	settings	!	
lighting type	(strobe/tungsten, watts, number)	!	
	light position, distance	!	
Provides information for reproducing image	Camera type and model	!	
	Camera-subject distance	!	
	Field of view	!	
	Focal length	!	
	aperture	!	
	shutter speed	!	
	film type and speed or ISO setting	!	
	# pixels (width X ht)	!	
	Photoshop techniques	!	
	Print details		
	"before" Photoshop image	!	