IV 4 – Flame Ignition

https://vimeo.com/767392797

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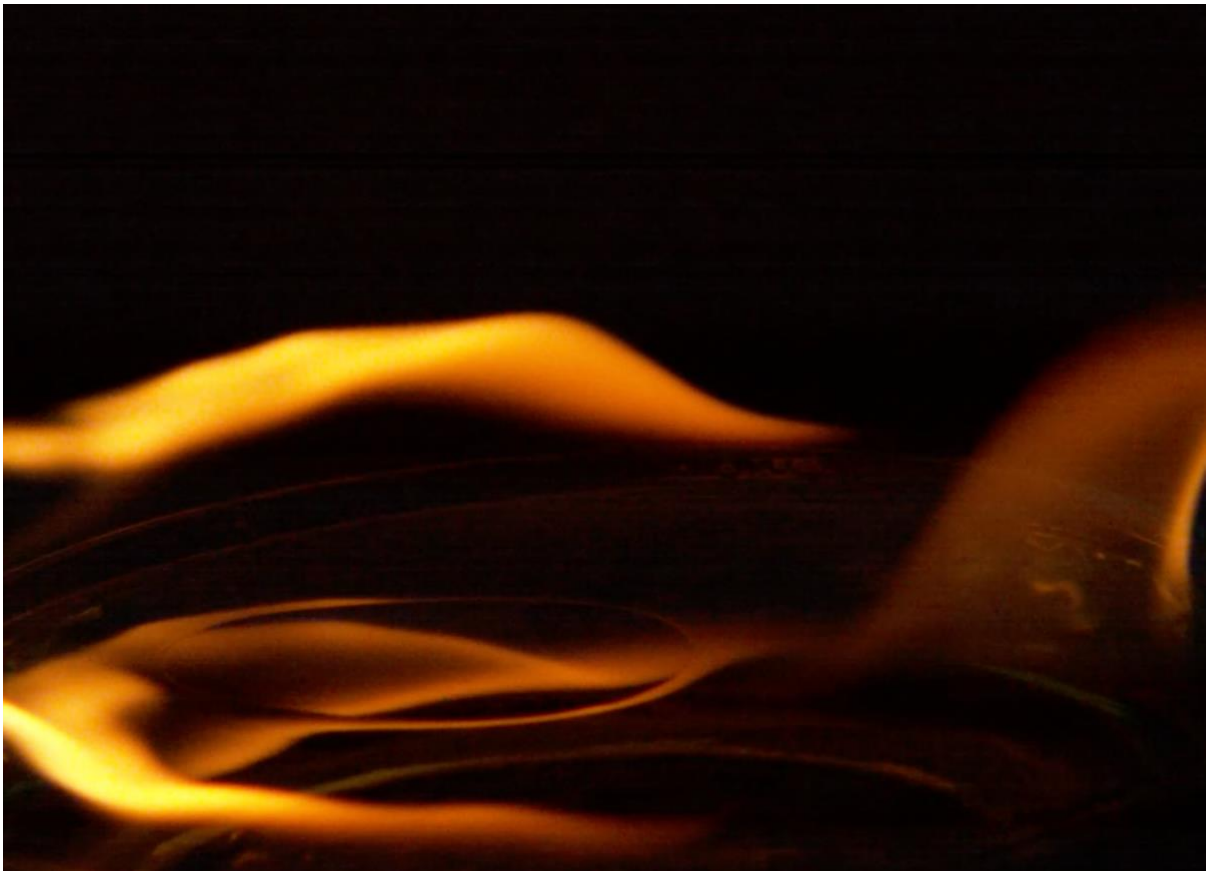

Figure 1: One frame from the video showing the initial flame ignition. This image also shows the boundary layer between the lighter fluid and the water it is floating on which will be discussed later.

Introduction:

When deciding what to capture for IV4 our team decided to use the High-speed camera again. We used this for IV3 and really enjoyed the process of capturing the video and the results when slowed down so significantly. We also wanted to try and capture some light emitting fluids such as flames. When playing with the highspeed camera the first time we really enjoyed the process and the result and wanted to do another project with it. We ended up trying to capture flame ignition and propagation. To do this we took the same Pyrex dish, filled it with slightly less water than last time and then pouring roughly half an ounce of lighter fluid over the top. Because the lighter fluid was less dense it sat on top so we could ignite it with a lighter and capture the process.

Photography techniques:

As in IV3, the camera used to capture this footage was the Phantom Miro C110 high speed camera. This was borrowed from the ITLL. The Phantom can capture up to 52445 frames per second at a resolution of 128x8 pixels. We opted to up the resolution at the expense of frame rate and settled on 915 frames per second at 1280x1024 pixels. This allowed us to see the complexities in the flame pattern and attempt to get a better view of the ignition. Unfortunately, we did not note the metadata for the video such as the ISO, aperture, exposure, or focal length. The lens used on the camera was a 50mm lens.

The editing was completed with iMovie and consisted of some minor color correction as well as cropping, time cropping, intro slides, and music. I cropped some of the outer frame to reduce distraction and focus the frame on the center of the ball drop better.

Unfortunately, some of the video file was corrupted when transferring from the camera to the computer. We are not sure if it was due to the lighting conditions or the transfer method but for some reason the beginnings of all the group's videos were corrupted and couldn't be edited with any software. This is unfortunate for my video because I thought some of the most interesting parts were the ignition travelling across the dish in the beginning which is no longer visible. As such I am going to analyze the pulsating flame instead of the flame propagation as there is not enough information to get a good analysis in this video.

Experimental Setup:

To capture this video, our team borrowed a Phantom Miro C110 high speed camera from the University of Colorado ITLL. This included all accessories needed to complete the setup such as a tripod, different lenses, and the software needed to run the camera. When setting up the camera we experimented with different lighting and distance setups before finalizing the one shown below.

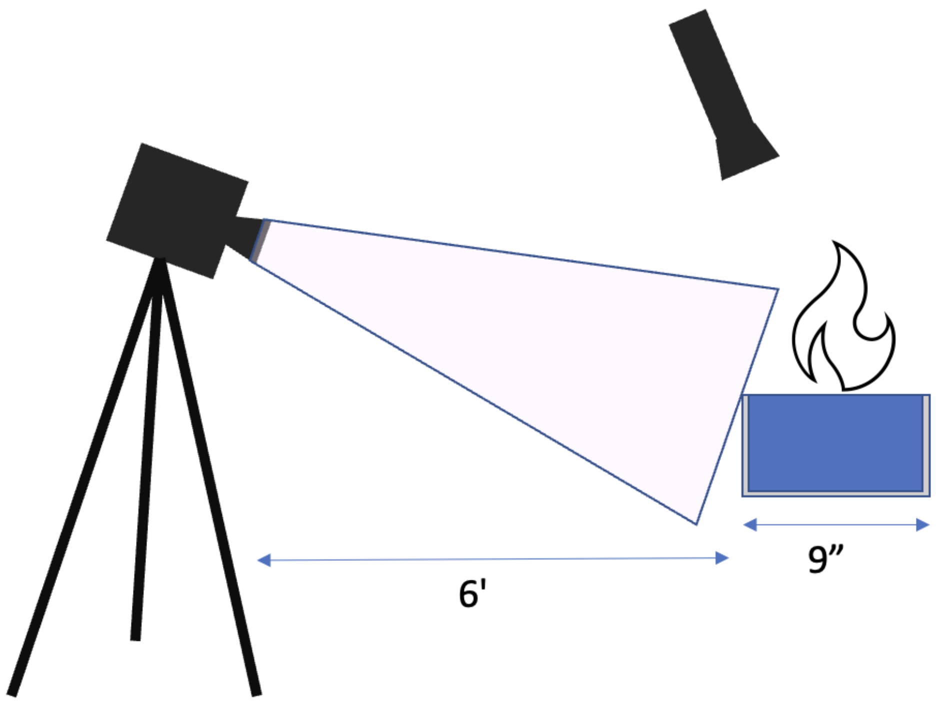

Figure 2: Experimental setup

In this setup we placed the tripod roughly 6 feet from the 9-inch Pyrex dish filled with water. We placed this over a piece of white paper to try and eliminate the background. The difficult part about this setup was setting the ISO and aperture to best capture the flame. This was an issue because before lighting the setup, the whole screen was black and then the flame provided the light. This meant that we had to try a few different times to get everything right. The software on the Miro C110 lets us select which time frame around the trigger it captures so we set it to capture roughly 0.5 seconds before the trigger and 1.5 seconds after. That way we could coordinate an ignition time and then trigger the camera at the same time and get enough of the ignition to inspect. Unfortunately, this didn't quite work because of the corruption but it still worked well. Because of the frame rate of the camera these 2 seconds of real time film become over a minute when slowed down which is why the video is so long. We completed this process roughly 5 times before selecting the most interesting and clear video.

To pour the lighter fluid over the water we used a spoon as shown below.

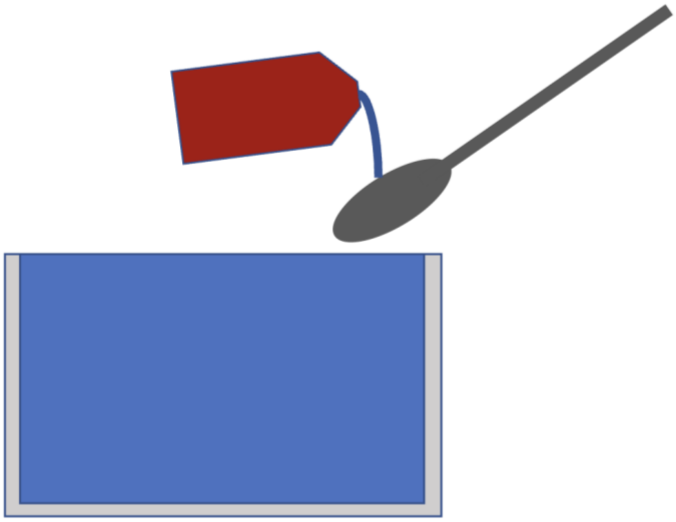

Figure 3: Pouring method

Using the spoon in this manner meant that the fluid was slowed down before hitting the surface of the water so that it wouldn't plunge into the water or mix. The nice thing about this setup was that the lighter fluid was less dense than the water and they didn't mix at all so we could just see the layer of fluid over the water. We poured enough fluid that the water was completely covered by the fluid. We did this slowly enough that it had time to disperse so we wouldn't pour too much.

This was all performed outdoors and after lighting we had multiple team members with water and a fire extinguisher. If at any point the flame got too large we would immediately put it out as safely was paramount to this experiment.

Flow physics:

In this video you can see that after the flame is lit it starts to pulse. As the flame grows it moves upward due to a switch from diffusion or non-premixed combustion to premixed combustion. Diffusion or non-premixed combustion is when the oxidizer and fuel are separate before combustion. Premixed is obviously the opposite where the oxidizer is mixed with fuel before combustion. It can be seen in this video that the premixed flame is the lower, wider part of the flame pulse. As it grows, the fuel air mixture moves upwards due to rising hot air it creates. As it rises, it switches to diffusion combustion as the oxidizer (air) burns off and leaves some remaining fuel. This fuel then combusts with the air above the flame but due to smaller amount of fuel it cannot burn for as long. This is when the oxidizer and the fuel mix at the base of the flame, preparing for the next pulse of premixed combustion. This process cycles as the pulse raises, turns to diffusion combustion, runs out of fuel, and then restarts with premixed combustion at the bottom. This process is something that has been researched extensively. (Manhou Li, 2017)

In this research, Li discovered that a higher flame temperature leads to a higher pulse frequency. This makes sense logically as higher temps will provide a higher acceleration upward due to the temperature and therefore buoyancy difference between the flame and the outside air. This is evident in the video as the pulsing doesn't occur until a high enough temperature has been reached. When analyzing this video, the flame pulses at roughly 4.44Hz.

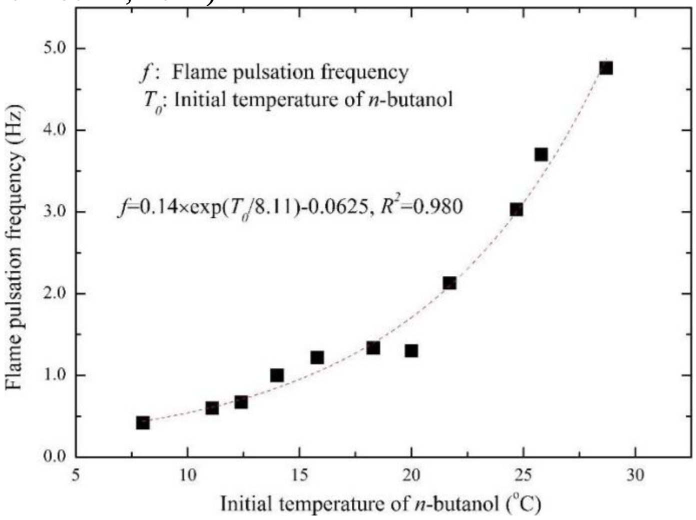

Figure 2: Temperature vs pulse rate

(Manhou Li, 2017)

Video time (s)	Real time (normalized) (s)	Time difference (s)	Average Time Difference
13	0		0.225
19	0.15	0.15	
28	0.375	0.225	
36	0.575	0.2	
46	0.825	0.25	
57	1.1	0.275	
67	1.35	0.25	

Figure 3: Flame pulses vs time extracted from my footage

These data are extracted by noting the time in the video when the pulse reaches its maximum point. This is obviously relatively subjective, but it should give a reasonable average. The normalized real time was calculated by knowing that we filmed at 1200 frames per second and the video is played at 30 fps back so each 40 seconds of film is one second of real time. From the average time difference we can calculate the frequency of 4.44hz.

he analysis of pulse frequency was done by watching the video and recording the time when the pulse left the screen. The location of the pulse leaving the screen is not significant in itself, but serves as a consistent point to reference. The time was indexed off the first pulse and then converted to real time, knowing that the video was filmed at 1,200 frames per second, 40 times faster than it was played back at. The time between pulses is calculated and the frequency can be determined.

Conclusion:

I really enjoy watching this video and wondering a little bit more about the more complicated mechanics of the fluid movement. For example, it would be interesting to study the initial flame propagation and the speed of it had it not been corrupted. This is something that I would like to study deeper given more time and energy. Experimenting with the highspeed camera was really interesting and taught me a lot about shutter speed and lighting as we had to add a lot more light to the setup than I thought we would just to be able to see anything. Before lighting the flame the screen was black in open daylight which was crazy to see. Even though this was the second time we used it, I would like to do more with the highspeed camera in the future.

Bibliography

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