# Second Team Image Assignment

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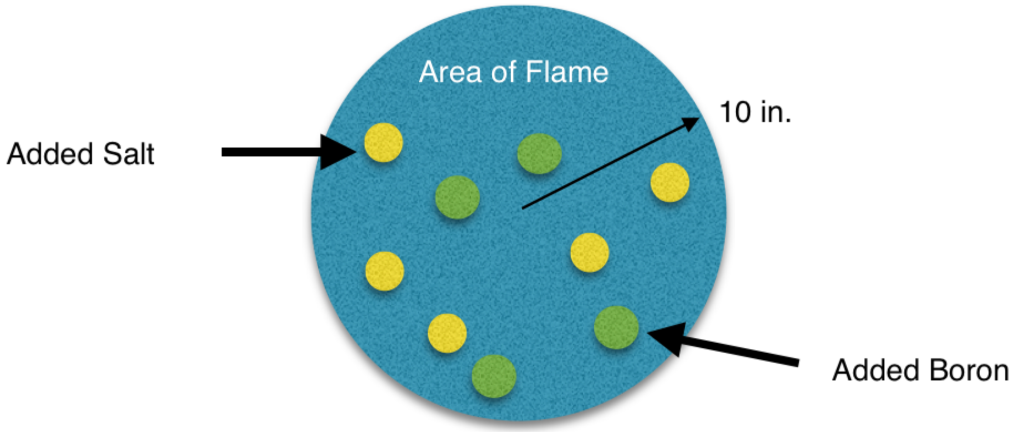
Flow Visualization - Professor Jean Hertzberg
11/18/2016

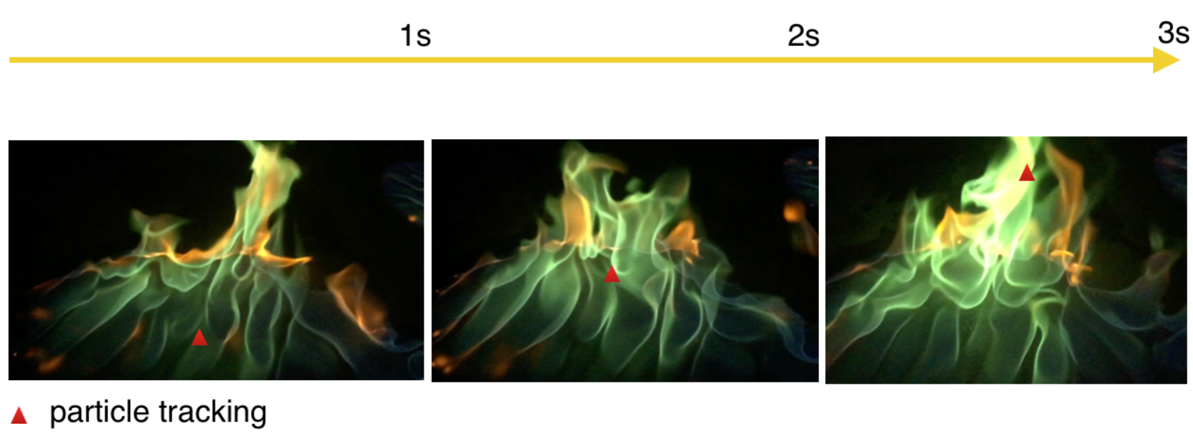
The image above is a screen capture from a slow motion (60 fps) video of fire. The fire was exposed to chemicals including boron and sodium chloride. The boron is responsible for the chemical reaction that yields the green color seen in the image. The orange represents the burning of sodium chloride (table salt) that was sprinkled onto the fire.  The flow patterns seen here create a variety of parabolic shaped flames that slowly diffuse in the ambient air above, as they come into equilibrium with the air. This was a second team project that focuses on the flow patterns created by fire.

The flow apparatus used to create the video the image consisted of lighter fluid, boron, salt, and a night (low light) scene. The scene setup is shown below.




The camera view was approximately 45 degrees down from the normal surface, directed towards the fire. The flow was captured after the addition of the boron and table salt, which is why the orange and green flames can be seen in the video.

It is important to speculate the Reynolds Number for this flow to understand its properties. Using frame rate analysis, the velocity of the flow was estimated, which led to a calculation of the Reynolds number.




After the frame rate analysis was established, the following calculations were made.

$t$ = *Time of travel by one fluid particle (red triangle)* = 3 *seconds*

$d$ = *Distance of travel by one fluid particle along vertical* = 1$m$

$U = d/t = 1m/3s = .33\ m/s$

$v = 62.53*10^{-6} m^2/s$ (*Engineering Toolbox*, Air @400 *degree* )

| Temperature - $t$ - ($^oC$) | Density - $\rho$ - ($kg/m^3$) | Specific Heat - $c_p$ - ($kJ/(kg\ K)$) | Thermal Conductivity - $k$ - ($W/(m\ K)$) | Kinematic Viscosity - $v$ - $x\ 10^{-6}$ ($m^2/s$) | Expansion Coefficient - $b$ - $x\ 10^{-3}$ ($1/K$) | Prandtl's Number - $P_r$ - |
|---|---|---|---|---|---|---|
| -150 | 2.793 | 1.026 | 0.0116 | 3.08 | 8.21 | 0.76 |
| -100 | 1.980 | 1.009 | 0.0160 | 5.95 | 5.82 | 0.74 |
| -50 | 1.534 | 1.005 | 0.0204 | 9.55 | 4.51 | 0.725 |
| 0 | 1.293 | 1.005 | 0.0243 | 13.30 | 3.67 | 0.715 |
| 20 | 1.205 | 1.005 | 0.0257 | 15.11 | 3.43 | 0.713 |
| 40 | 1.127 | 1.005 | 0.0271 | 16.97 | 3.20 | 0.711 |
| 60 | 1.067 | 1.009 | 0.0285 | 18.90 | 3.00 | 0.709 |
| 80 | 1.000 | 1.009 | 0.0299 | 20.94 | 2.83 | 0.708 |
| 100 | 0.946 | 1.009 | 0.0314 | 23.06 | 2.68 | 0.703 |
| 120 | 0.898 | 1.013 | 0.0328 | 25.23 | 2.55 | 0.70 |
| 140 | 0.854 | 1.013 | 0.0343 | 27.55 | 2.43 | 0.695 |
| 160 | 0.815 | 1.017 | 0.0358 | 29.85 | 2.32 | 0.69 |
| 180 | 0.779 | 1.022 | 0.0372 | 32.29 | 2.21 | 0.69 |
| 200 | 0.746 | 1.026 | 0.0386 | 34.63 | 2.11 | 0.685 |
| 250 | 0.675 | 1.034 | 0.0421 | 41.17 | 1.91 | 0.68 |
| 300 | 0.616 | 1.047 | 0.0454 | 47.85 | 1.75 | 0.68 |
| 350 | 0.566 | 1.055 | 0.0485 | 55.05 | 1.61 | 0.68 |
| 400 | 0.524 | 1.068 | 0.0515 | 62.53 | 1.49 | 0.68 |

*Table from Engineering Toolbox*

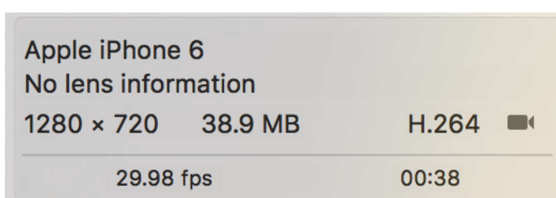
The kinematic viscosity of air was determined by estimating a temperature of 400 degrees celsius. The diameter of the plume of fire is estimated to be .2 m. The Reynolds Number is approximated below.

$$\mathrm{Re} = \frac{UD}{v} = (.33)\frac{(.2)}{62.53*10^{-6}} = 1055.49$$

Since Re>1000, we speculate this is a turbulent flow, with very chaotic mixing of the flames with the surrounding air.

The slow motion image capturing reveals some interesting characteristics of the flow. As it can be seen from the video footage, columns of hot gas begin to form as the fire is created. The parabolic shapes are indications of the way the gases within the flame interact with gravity according to their density. The amount of gas stays constant, while the gas is continuously heated. As it heats, the columns of gas appear as tongue-like shapes, and release from the ground as they heat up. Finally, the parabolic shapes begin to thin out as the gas rises faster and faster due to the loss in density from temperature changes.

The environmental conditions during the video include night time setting and calm wind (<10mph). The wind helped to show the convection currents within the flame. There was no camera flash during the video, which was critical in order to maximize the amount of detail captured in a low lighting scene. The field of view was maintained at approximately 2ft to limit distractions while capturing the entire series of flames. The final video information is highlighted below.




The video was processed by increasing the contrast and vibrance of the flames. The slow motion was captured at 29.98 fps originally, then reduced to half the speed during post-processing in Final Cut Pro.

Overall, this project revealed some amazing features seen in a fire. The parabolic shapes of flames are direct results from fluctuating densities in the gases that excite the fire. These parabolas decrease in thickness as the fire heats the gas, and shoot up a column of gas (as if in a vacuum), disappearing due to the diffusion of gas into the ambient air above. The visual evidence of the termination of these shapes indicates a lack of radiation energy within the gas, which contributes to the equalizing of densities within the gas and ambient air. Although these shapes are not immediately obvious to the naked eye, they can be brought out in slow motion tactics and analyzed by fluid dynamics.

Cited Sources

"Air Properties." Air Properties - Engineering Toolbox. N.p., n.d. Web. 17 Nov. 2016.

"What Gives Flames Their Tongue-like Shapes?" *You Are Being Redirected...* EarthSky, n.d. Web. 17 Nov. 2016.

"Why Does a Flame Burn Upwards?" *ScienceLet*. N.p., n.d. Web. 16 Nov. 2016.