Get Wet Report: Marshmallow Flame

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Get Wet Image
MCEN 5151: Flow Visualization
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The Flow Visualization class at the University of Colorado is a course where students learn about flow dynamics and photography techniques by capturing photos of fluid phenomenon. The first assignment in the class involved the photographer getting his/her “feet wet” by taking a photograph of some form of fluid dynamics. Originally, I had a slew of image ideas for unique flow phenomenon I wanted to try. Everything from beer bubbles, to cigar smoke, to snowfall crossed my mind, but unfortunately, I own a point and shoot (Sony Cybershot DSC-S700) camera that does not allow for very detailed, or fast motion pictures. However, the point and shoot camera proved to be very effective at capturing steady flow. I found that a stable flame came out fairly clear on the camera display, which inspired me to search for a viable object to set aflame. I chose a marshmallow for my fuel source, since I enjoy camping, and marshmallow s’mores remind me of my childhood spent with my family in the woods. Also, the flame propagation around the cylindrical fuel source proved to be quite intriguing in its overall shape, and the combustion led to a wide array of colors. I tried to capture a moment where the flame was clearly enveloping the marshmallow, while still leaving visible portions of unburned sugar that had begun to bubble up and brown.

The flow phenomenon within this image can be visualized with the flame, and the marshmallow itself. The flame itself is being fueled by the carbon chains of sugars in the marshmallow, which react chemically with the air and heat to combust. (Dietrich, 2000) This combustion is seen as the area around the marshmallow where there seems to be a break between the flame and the surface of the marshmallow itself. The flame traveling further up is the by products of the chemical reaction. These carbon-based molecules did not undergo full combustion in the marshmallow zone, but have been heated to such an extent so that they glow with internal energy as they propagate upwards. This is a form of blackbody radiation, and causes the spectrum of colors found from the flame. (Dietrich, 2000)

The dynamics of the flame movement are interesting themselves. The picture is taken level with the ground, meaning the flame is traveling upwards around the marshmallow. The flame height peaks closest to the top of the image, meaning the flame is traveling away from the direction of gravity. The overall shape somewhat resembles a teardrop, primarily due to buoyancy forces (Cornia, 1991). Buoyancy forces are created due to the density difference of the atmosphere around the marshmallow. The combustion transfers heat to the atmosphere, decreasing the density, and sending that portion of the atmosphere upwards. Trapped in the atmosphere is the glowing soot, which creates the visible flame (Cornia, 1991). As the soot rises, it cools, which reduces the radiation, causing the flame to give off less of a glow. This is why there is more flame visible around the combustion area than above the flame. (Cornia, 1991) The oxygen flows downwards around the hot column of gas to continue fueling the reaction. The overall dynamics create the teardrop shape typically associated with burning objects. Figure 1 shows these dynamics, along with the approximate position of the camera.

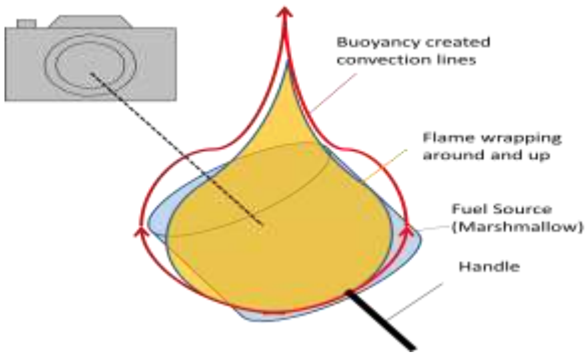

Figure 1: Flame Shape Caused by Buoyancy

The secondary flow phenomenon that can be noted upon the marshmallow is within the un-burnt portion of the marshmallow. In the un-burnt portion, there are a couple locations where the surface has not heated up enough to combust, but is hot enough to cause bubbling and warping. These spots can be seen by looking for the brownish bulges around the edge of the un-burnt portion. This phenomenon is occurring because the marshmallow is composed primarily of sucrose, and sucrose begins a chemical change to caramel near its melting point (~200 degrees Celsius). This chemical change is described as "caramelizing". The caramelizing process causes the sugar to undergo a chemical reaction, where two sugar molecules ($C_{12}H_{22}O_{11}$) lose the equivalent of four water molecules through dehydration, and transform into caramelans ($C_{24}H_{36}O_{18}$). (Shallenberger, 1993) These caramelans appear as a brownish marshmallow, and pop up from the surface because they're heated, causing the chemical bonds between the molecules to loosen, so that the sucrose acts like a molten liquid. (Villamiel, 2006) This can be most clearly seen with the small bulges on the surface, where the smoothness of the marshmallow is disturbed by molten sugar bubbling up due to expansion of the molecules. (Figure 2)

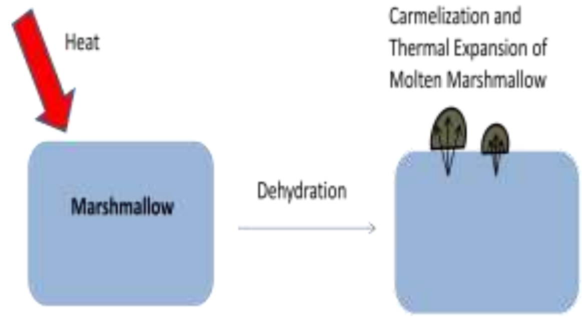

Figure 2: Heat Induced Bubbles Forming on Surface of Marshmallow

To get an idea of how big the bubbles are when looking at the reaction, it is necessary to get an idea of the photograph's field of view. A good reference for the field of view comes from the marshmallow itself. The marshmallows used for this experiment were standard size, meaning they were approximately 1 inch in diameter, and 2 inches long. This indicates that the field of view of the photograph was about 3 inches across, and 4 inches tall. (after edits) Therefore, the bubbles that formed up on the surface of the marshmallow were approximately from .01 inches to .1 inches. The flame itself was about 3 inches long.

With these numbers in mind, it is possible to calculate the flow resolution in the photograph. In terms of visualization scale, the smallest viewable flow phenomenon was approximately .01 inches. The entire field of view for the flow phenomenon in the photograph is approximately four inches across. Therefore, with the following equation, the scale of the resolution can be determined:

$$Resolution = \frac{Entire\ field\ of\ view}{Smallest\ viable\ flow}$$

$$Resolution = \frac{5\ inches}{0.01\ inches} = 500$$

$$Resolution = 4\ e2$$

Therefore, since the resolution is in the hundreds, the scale of resolution is two decades, which is well resolved for the flow shown in the photograph.

The image was taken in an environment that made the flame as vivid as possible. In order to produce the image, a marshmallow was stuck on the end of a stick and lit from below with a lighter, while holding the stick at an approximate forty-five degree angle. The marshmallows were obtained from the grocery store, and the image was captured in the garage with the lights turned off. The marshmallow was lit in a fully darkened room, making the flame the only light source. The emission of the flame was quite beautiful, having blue, yellow, and orange colors produced by the combustion of the sucrose. The flame gave lighting to the un-burnt portion of the marshmallow, which reflected into the camera with a nice orange-ish hue as well. It is best to wait until approximately half of the marshmallow is consumed by the flame, in order to capture the maximum amount of flame from the fuel source.

The depth of field was large for the object, showing all portions of the flow in a clear manner. The depth of field was captured by setting up the camera approximately three inches away from the marshmallow. The camera was fully zoomed out and the auto-focus was set and maintained by pushing halfway in on the shutter button while holding a lighter flame approximately three inches away. Once the focus was set, the flaming marshmallow was held the same distance away, and the shutter button was pushed fully down to capture the image. The image was captured in jpeg format with 7.1 Mpixel resolution (the maximum resolution for the Sony Cybershot DSC-S700) with a width of 3072 pixels, and a length of 2304 pixels. The original image had The image had an ISO of 320, an aperture size of 6.3 mm, a focal length of 2.8 mm, and a shutter speed of 1/8 seconds. When the image was altered, the original picture was cropped down to 2028 pixels by 2304 pixels, the image was sharpened to a setting of +42, the colors were mildly saturated, the temperature was decreased by -7, and highlights were increased by +9. These changes allowed the flame to be more vibrant, and allowed the stick at the lower left corner to be more visible in the final image. The image before all the modifications is displayed in the Appendix.

Overall, both the flame and the marshmallow itself exhibited interesting fluid dynamics during the burning process. I really enjoyed watching the marshmallow caramelizing transformation, and the natural flame lighting on the un-burnt portion in the middle works very well in my opinion. The fluid physics are fairly evident, and any questions I had about the fluid process were answered in the literature research. I would say that I fulfilled my intent of capturing an artistic image of common fluid flow, presented in a unique manner. I would have liked more detail on the flame portion of the flame itself, but it’s almost better that the flame is out of focus, since it draws the eye to the marshmallow surface. In future development, I would like to do a bit more editing on the flame colors in the image, since the vibrancy of the flames stand out quite vividly against the black background and white marshmallow. All in all, this image was successful in that it showed good fluid dynamics, while revealing a familiar artistic impression of childlike joy and the American spirit.

Bibliography:

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Appendix:

Figure 3: Marshmallow Image without Edits