Image Report – "Get Wet" Assignment

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Flow Visualization

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The inspiration for producing the images shown on the cover page was my own personal fascination with fire, firelight, and the behavior of flames contained within a certain volume. Both the original and altered versions of my selected image are shown on the cover page, at left and right respectively. In the case of the image I selected, it captures the behavior of a flame contained within the glass chimney of an oil lamp. Initially, my intent was to capture the flame of the lamp as it breached the top of the chimney, which occurs with extreme over-extension of the lamp wick. However, this proved to be difficult to successfully achieve, and I decided to attempt a low-angle upward view. This produced several suitable shots, from which I chose my favorite.

The diagram shown in Figure 1 shows the basic components of the oil lamp used, and the relative position of the camera when the selected image was captured.

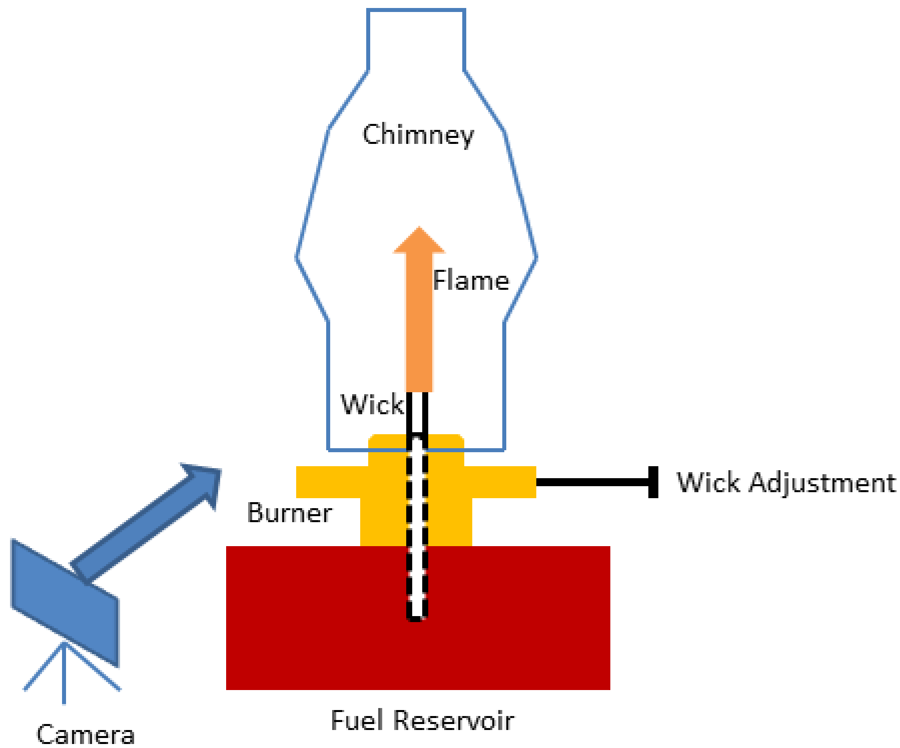

Figure 1: Setup of camera and lamp, with basic lamp components labeled.

To produce the selected image, the wick was lit, glass chimney slid into place, and then the wick was adjusted to a height where the flame would extend approximately ¾ of the way up the chimney. In the process of extending the wick far beyond what is necessary for proper flame height and brightness, the flame would pass a threshold where the flame would change from steady, laminar behavior to unsteady, turbulent behavior. This unsteady behavior was shown in the form of 'flickering'. The flame produced by the oil lamp is an example of non-premixed combustion[1], where fuel is provided through capillary action via the wick, and is then oxidized by oxygen in the atmosphere once exiting the top of the burner apparatus. The flame itself represents the transition region from pure fuel to pure oxidizer, as shown in Figure 2.[2]

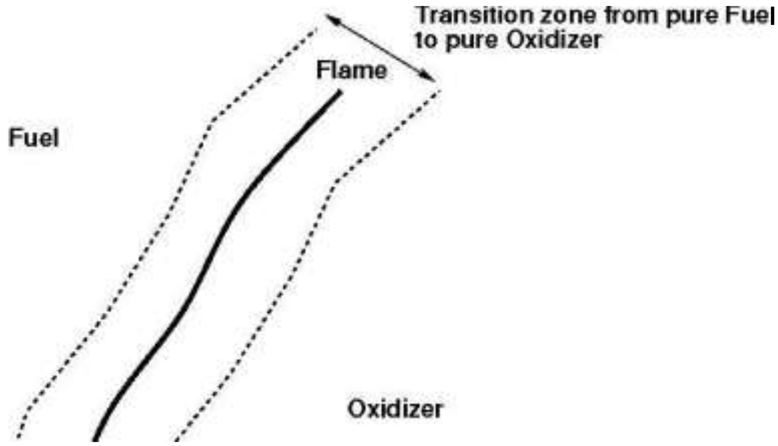

Figure 2: Lamp flame is the oxidation of fuel and oxidizers in atmosphere.

When the wick is kept at a lower length, the ratio of the oxidizer (air) being drawn into the bottom of the chimney thru the base of the burner is balanced with the amount of fuel being provided by the wick. However, as the wick is lengthened, the amount of fuel being supplied surpasses the available amount of air (oxidizer) that the burner openings can provide. This imbalance in fuel/oxidizer ratio may cause the flame, and the oxidation reaction, to be 'starved' for additional air to facilitate a proper combustion reaction. The need for more oxidizer appears to cause an oscillatory suction of air thru the burner, combustion, and then another intake of air. If my reasoning is somewhat correct, then the flame flicking in this particular case is not irregular, but instead an oscillating system of increased and decreased combustion reactions, which cause the visible change in the flame size and undulating behavior.

During my research, I was able to find analysis of the flickering of a Bunsen flame which included the Strouhal (oscillating flows), Richardson (potential to kinetic energy ratio), and Reynolds (ratio of inertial to viscous forces) numbers, used in dimensional analysis of fluid dynamics[3]. I am not certain, however, what the specific values for a flickering flame under the

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[1] CFD Online, http://www.cfd-online.com/Wiki/Combustion

[2] Figure 2 Image Source: http://www.cfd-online.com/W/images/d/df/DiffusionFlame.jpg

[3] http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFK-4M9RMN1-9&_user=918210&_coverDate=03%2F31%2F2007&_rdoc=1&_fmt=high&_orig=search&_origin=search&_sort=d&_docanchor=&view=c&_searchStrId=1638731470&_rerunOrigin=google&_acct=C000047944&_version=1&_urlVersion=0&_userid=918210&md5=c27c4c1fe4b214b02984cde42a0b64af&searchtype=a

specific conditions within the glass chimney of an oil lamp. The values of the variables within each equation would be dependent upon many factors. For example, the velocity of the flow of air into and out of the chimney would depend on the constriction of the chimney neck, which provides the increase in the exit velocity (commonly called the 'draft' of the chimney).

This flame image was captured indoors, in a room heated to approx. 65°F (18°C). There was no measureable air movement near the oil lamp. Light source was exclusively from flame emission. Flame was produced by the burning of normal paraffin *LAMPLIGHT ULTRA-PURE LAMP OIL*[4], using a 3 inch diameter, 8 inch tall glass chimney. The size of the field of view (for the final image) is approx. 4 inch X 6 inch, with the distance from object to lens being approx. 6 inches. The digital camera used is a Canon PowerShot SD 500, with an F-stop of f/4.5, image focal length of 18.8 mm, and shutter speed of 1/320 sec. Again, no flash was used to produce the image, which was created on 1/27/2011 at 8:50:03pm MST.

Alterations using Adobe Photoshop were confined to minimal cropping, and the altering of the image to a black and white color scheme. This was done by using Photoshop's built-in B&W preset called "Darker". I adjusted the contrast a bit more to bring out the features of the flame, but this was all I felt needed to be changed in the image.

This image revealed to me a previously unknown element in the behavior of a flickering flame – the curvature present near the top of the image was a great surprise to me. I was very well pleased and surprised at how clearly the direction and behavior of the fluid flow of the flame was shown. I am curious to try this same photographic experiment using different wick sizes (width), as well as observing the behavior of differently-shaped flames caused by cutting the wick in different shapes. The shape of the wick will dictate the shape of the flame generated, as I have tried myself before. However, I would like to see if this change in flame shape will have an effect on the flame's behavior as it travels up the chimney.

[4] Lamplight Ultra-Pure Lamp Oil Material Safety Data Sheet: http://www.nafaa.org/ultra-pure.pdf