UNIVERSITY OF COLORADO - BOULDER

Flow Visualization

Get Wet Report

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MCEN 4151 – Professor Jean Hertzberg

The purpose of the “Get Wet” assignment was to capture an image that clearly exhibits the fluid dynamic phenomenon being observed, while introducing the student to different techniques and approaches used in capturing fluid behaviors. This image was created for Professor Jean Hertzberg’s flow visualization course at the University of Colorado in the spring of 2012. The original intent of the image was to display the blue burning of gel hand sanitizer and observe the dynamics of the fluid as it burns on a solid surface. However, after a substantial number of photographs over different object, the chosen image captures the moment that combustion occurs when a flame ignites gel hand sanitizer. Specifically, the image displays the behavior of combusting hand sanitizer as it propagates over a human hand.

In order to produce the image, a dark ambiance was created in a bathroom by turning off all of the surrounding lights. The combustion flow was generated using a disposable lighter, gel hand sanitizer consisting of 62% ethyl alcohol, and a human hand. Gel hand sanitizer tends to burn relatively cool (compared to fuel, plastic, or cellulose fires) with peak flame temperatures reaching 500°F, 1 to 2 inches above the flame [1]. Since a human hand was used in the making of the image safety was the largest factor when attempting to create the image. To minimize any risks to the participant’s hand, the photographs were taken with a sink full of water nearby as well as another person to extinguish the flame with a soaked towel. The photographer stood 6 inches away from the subject with the camera attached to a tripod, which rested on a table. The subject sat in a chair with his hand extended toward the camera. One full pump of the gel hand sanitizer was placed in the center of the subjects hand and spread over the palm and fingers, creating an even coverage of sanitizer. At this point, a disposable lighter was used to ignite the hand sanitizer and combust the ethyl alcohol in the hand sanitizer. The photo was taken at the moment that the lighter sparked a flame and ignited the hand sanitizer. Figure 1 below shows the set up that created the final image.

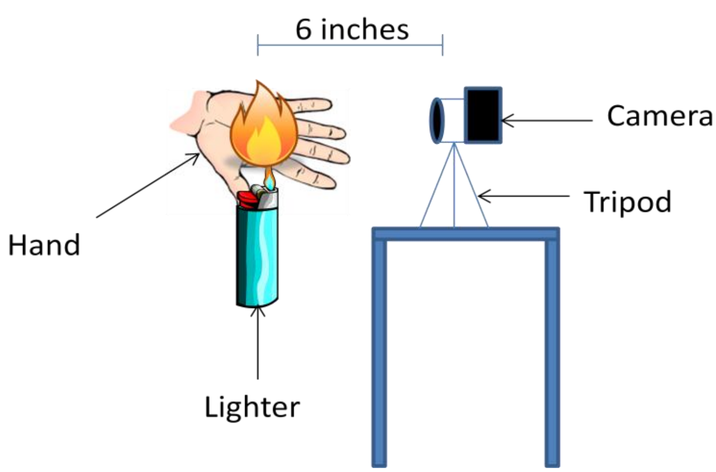

Figure 1: Final image set up

Ethyl alcohol, also known as ethanol, is a colorless liquid that burns a smokeless blue flame when ignited. The chemical equation for the combustion of ethanol is [2]:

$$C_2H_5OH\ (l) + 3\ O_2\ (g) \rightarrow 2\ CO_2\ (g) + 3\ H_2O\ (g) \tag{1}$$

Equation 1 demonstrates that the complete combustion of ethanol yields carbon dioxide and water as byproducts. It should be noted that once the ethyl alcohol contained in the sanitizer was finished burning, the flame extinguished on its own, leaving the remaining gel sanitizer behind.

By analyzing the image and assuming that the hand is perfectly rectangular with dimensions of 4 inches (wide) x 8 inches (length) the surface area of the hand can be estimated to be 32 in^2 (0.021m^2). Additionally, the perimeter of the hand can be estimated to be 24 in (0.6096m). The Nusselt number is a ratio of the convective to conductive heat transfer across a surface. Since natural convection is occurring in the image, the average Nusselt number can be roughly calculated using equation 2 below [3].

$$Nu = \frac{hL_c}{k} = 0.15 Ra_L^{1/3} \tag{2}$$

In order to determine the Nusselt number, the Rayleigh number (Ra_L), must first be estimated using equation 3 below [5]. Where g = gravitational acceleration (9.8m/s^2), β = coefficient of volume expansion (estimated to be 0.0024 at the film temperature of 414K), T_S = temperature of the surface (assumed to be the max flame temperature of 500°F = 260°C), T_∞ = temperature of the fluid sufficiently far from the surface (assumed to be the air temperature of 72°F= 22°C), v = kinematic viscosity of air (2.745E-5 m^2/s at the film temperature of 414K), Pr = Prandtl number of air (0.7041 at the film temperature of 414K), and L_C = the characteristic length of the hand (estimated to be 0.021 m^2/0.6096m = 0.34m) [5]. From equation 3, the Rayleigh number for the burning hand can be estimated to be 2.06E8.

$$Ra_L = \frac{g\beta(T_s - T_\infty)L_c^3}{v} Pr \tag{3}$$

After obtaining the Rayleigh number for the burning hand, equation 2 was used to estimate a Nusselt number of 88.59. With this value, the rate of heat transfer from the hand, assuming natural convection, can be estimated using equation 4 below [5].

$$\dot{Q} = hA_s(T_s - T_\infty) \tag{4}$$

Where h = convective heat transfer coefficient of air at the film temperature of 414K (estimated to be 8.79 W/m^2 * K). From this equation, the rate of heat transfer from the hand can be estimated to be 43.9 W. This amount of heat transfer shows how the hand can remain cool for a short time, while the hand sanitizer is burning on the surface.

The visualization technique used to capture the final image was the combusting of 62% ethyl alcohol gel hand sanitizer over a subject's outstretched hand. One full pump of gel hand sanitizer was placed in the center of the subject's hand and spread over the palm and fingers, creating an even coverage of sanitizer. A disposable butane lighter was used to spark the combustion of the sanitizer in the participant's hand. The intent of the image was to have the blue flame of the burning sanitizer as the only lighting in the image, due to this, no flash or external lighting was incorporated into the image. The only preparation to the room consisted of turning off all of the lights and closing all of the doors so that the room would be as dark as possible. The surrounding air temperature of the room was 72°F.

The field of view in the original image was approximately 9 inches (depth) x 12 inches (width). A Canon PowerShot SX230 HS digital camera was held on a tripod slightly above the subject's hand at a distance of 6 inches from object to lens. Along with the tripod, the camera had a built in image stability option that was used to reduce any motion blur. This orientation created an original image with pixel dimensions of 4000 x 3000. The final pixel dimensions were 3140 x 3000 after being cropped in Gimp. In order to capture the vividness of the flame, the camera was placed into aperture priority mode and the settings were then adjusted to attain the necessary light. The aperture was set to f/4.5 and a corresponding shutter speed of 1" was chosen by the camera to allow for sufficient light to enter the lens. The timing of the image was obtained through having the camera in continuous shooing mode. This allowed multiple images to be continuously taken, while the lighter and hand sanitizer were trying to be lit. Additionally, the image was taken with an ISO setting of 1600 to increase the shutter speed in the low light setting, ensuring the capture of the combusting hand sanitizer. Furthermore, the image was taken in macro mode, with the focal length of the lens being 5 mm (35mm equivalent focal length = 28.5mm). The original image before edited in Gimp can be seen in figure 2 below.

Figure 2: Original image before editing

After the original image was captured it was imported to Gimp and converted from a JPG to TIF file so that the image would maintain its format. The original image was then cropped in Gimp to get rid of all the wasted black space to the right of the hand. Additionally, the curves tool was used to brighten the colors in the image and darken the blacks. The image was then enhanced with the unsharp mask tool to create a sharper overall image. The final edited image can be seen in figure 3 below.

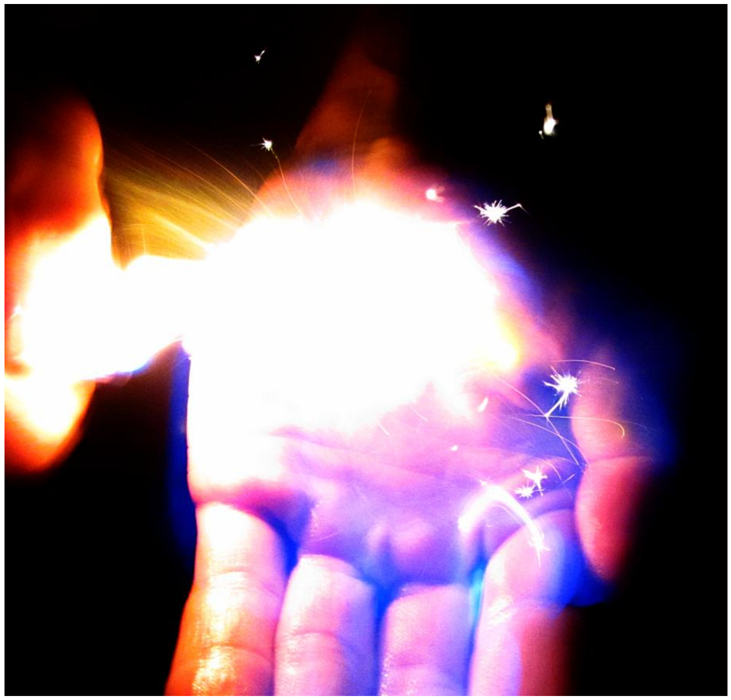

Figure 3: Final edited image

Ultimately, the image reveals the moment that combustion of gel hand sanitizer occurs over a solid surface, revealing beautiful colors and a very interesting fluid phenomenon. By incorporating the human hand as the object in which the hand sanitizer was spread over, I was able to create an image with a "WOW" factor that is especially intriguing and exciting to look at. I really like the vividness of the blue burning hand sanitizer as well as the clarity of the hand. This creates a great contrast in the image with the black surrounding environment. I also like how you can see the sparks as they escape from the lighter. Even though the flame appears as a very bright white spot in the center of the hand, I feel that it makes the subject appear as if he is holding all the light in the room, which gives the image a cool artistic expression. However, with the blurring that occurred from the slow shutter speed, the flame from the lighter was not clear and also very bright. This made the glowing of the hand sanitizer harder to focus on since the bright white color of the flame was so prominent. In the end, the slow shutter speed made it difficult to clearly see all of the fluid dynamics that were occurring within the image. Additionally, because of the high ISO parts of the image look grainy. I believe that by experimenting more with the camera settings I would have been able to achieve a clearer and less grainy overall image that may appeal to more viewers. However, because a human hand was being used as the surface, safety became a concern, which ultimately made it difficult to fine tune the settings of the camera. If I were to do this again, I would fine tune the camera settings on an object that could not be hurt from the burning flame. Then once I had the settings on my camera to where I wanted them to be I would attempt the image on the human hand, thus hopefully creating a clearer overall image.

Works Cited:

[1] Cavage, William M. "Flammability Test of Alcohol-Based Hand Sanitizer." *Fire Safety Branch*. Aug. 2010. Web. 12 Feb. 2012. <www.fire.tc.faa.gov>.

[2] Frederick D. Rossini (1937). "Heats of Formation of Simple Organic Molecules". *Ind. Eng. Chem.* 29 (12): 1424.

[3] "Nusselt Number." *Wikipedia*. Wikimedia Foundation, 05 June 2012. Web. 07 May 2012. <http://en.wikipedia.org/wiki/Nusselt_number>.

[4] Buffam, Julie, and Kevin Cox. "Measurement of Laminar Burning Velocity of Methane-Air Mixtures Using a Slot and Bunsen Burner." *WORCESTER POLYTECHNIC INSTITUTE*. 23 Apr. 2008. Web. 12 Feb. 2012. <http://www.wpi.edu/Pubs/E-project/Available/E-project-042308-085413/unrestricted/Laminar_Burning_Velocity_of_Methane-Air_Mixtures.pdf>.

[5] Çengel, Yunus A., and Afshin J. Ghajar. *Heat and Mass Transfer: Fundamentals & Applications*. New York: McGraw-Hill, 2011. Print.