University of Colorado
Boulder

Mechanical Engineering

MCEN-5151
Flow Visualization

Get Wet Assignment

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1. Background

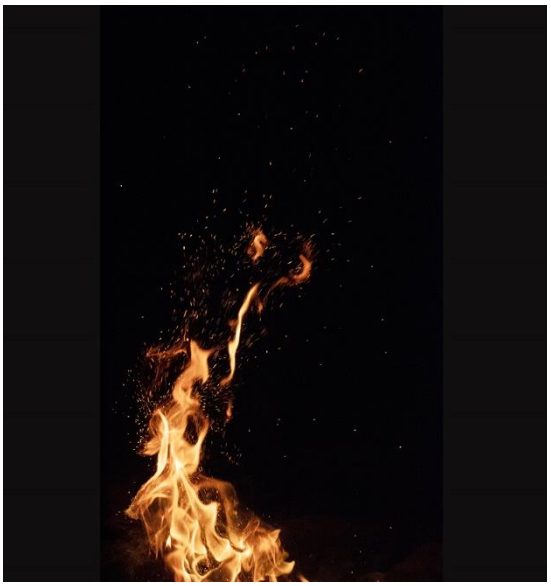

Figure 1: Get Wet Submission

The above image was taken for the Get Wet assignment. I designed the experiment myself but had help from my girlfriend with stoking up the fire as I captured the image. The intent of this image was to capture the flow of fire caused when wood was burned inside a campfire; also known as a chemical reaction called combustion. I also wanted to capture the trajectory of embers that drifted upwards in the campfire—a familiar phenomenon to anyone who has watched sparks fly towards the night sky while sitting around a campfire.

2. Flow Apparatus and Flow Description

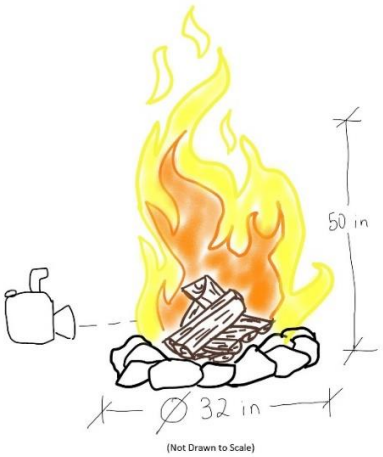

Figure 2: Basic set-up

The flow apparatus consisted of a circular perimeter of large rocks on top of dirt ground. The fuel source was regular cut-up wood, which can easily be purchased from any convenience store in Colorado. The wood was arranged in 3 layers of perpendicular rows; the base layer consisted of 4 parallel wooden blocks, the second layer consisted of 3 wooden blocks at 90 degrees from the base layer, and the last layer at 90 degrees from the middle layer consisted of 2 wooden blocks, also known as a pyramid campfire. The wood was enclosed by a 30-inch diameter pile of large the rocks.

Furthermore, the flow I captured was the result of a chemical reaction of gas with oxygen. The fuel source (wood) releases gases as it is heated. The gas reacts with oxygen in the air, which then release heat energy in the form of visible photons of very specific energy. On earth, when the flame heats up, it affects the surrounding environment causing air to expand, therefore become less dense. Gravity pulls the heavier, denser, cooler air down, causing the less dense hot air to rise; this process is called convection and as the cooler air is displaced downward it provides more oxygen that reacts with the gas released by the fuel source.

The colors that can be seen in the fire are associated with temperatures and specific wavelengths of the visible light spectrum. Photons (packets of energy) are emitted as atoms from the chemical reaction release energy in order to return to stable energy states. The wavelengths of red, orange and yellow range between 600nm – 625 nm and they are commonly seen in a campfire [1]. The colors are also indicators of temperature; the temperatures of the colors red and orange are approximately 900 Celsius to 2000 Celsius respectfully [2].

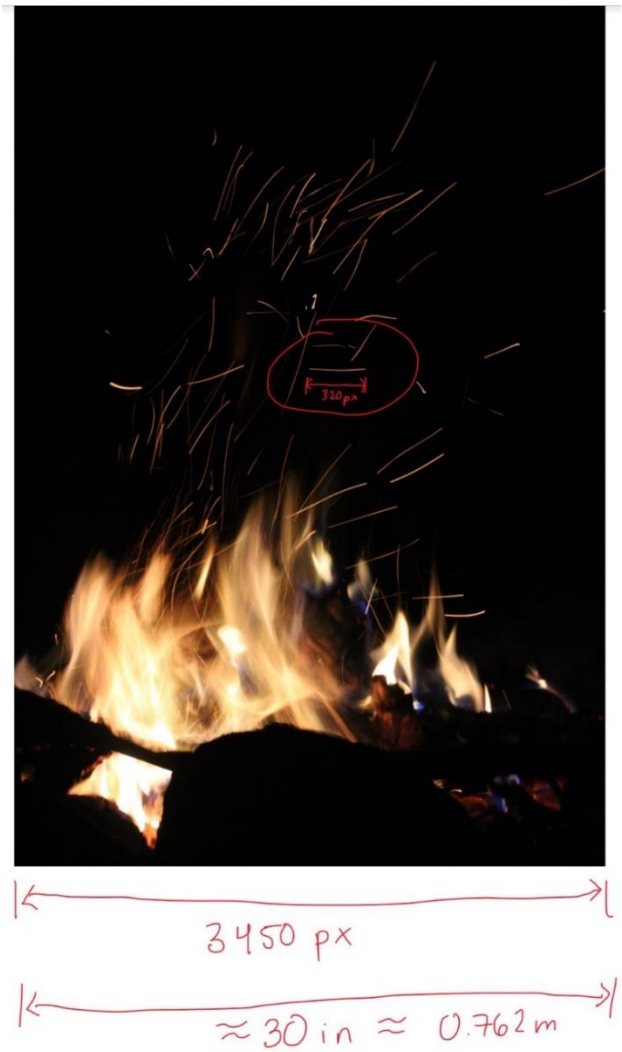

Figure 3: Ember Velocity Calculation

Using the raw data from the camera, the velocity of the embers can be found. Using the ratio between the field of view and the selected ember streak (in pixels) I calculated the distance the selected ember streak travelled in meters.

$$\frac{320\ px}{3450\ px} = \frac{X}{0.762\ m}\ m$$

$$3450X = (320)(0.762)$$

$$3450X = 243.84$$

$$X = \frac{243.84}{3450} = 0.0707\ m \quad \text{(Distance)}$$

Using the distance traveled, I then use the shutter speed (1/25 sec) this photograph was taken with to calculate the velocity of the ember using v=d/t [m/s].

$$V = \frac{0.0707\ m}{1/25\ sec} = \frac{0.0707\ m}{0.04\ s} = 1.76\ m/s$$

Finally, fluid flow can also be categorized into types of flow (laminar, transitional, or turbulent) that characterize how the fluid is moving using a metric called the Reynold's number. Using the data found previously for the ember and pairing that with the kinematic viscosity of air, the Reynold's of the ember as it flows in the air is approximately 2700. This value is associated with the unstable transitional region of the Reynold's number.

3. Visualization Technique

The visualization technique used for this assignment was particle tracking. Applying a bit of force to the burning wood allowed embers to escape. The embers were carried by the convection current and sped up by the wind. At night, the absence of light in the environment provided a perfect contrast to the light emitting embers flying out of the fire. The embers were still hot and releasing photons of energy, so they were able to be captured by the camera. A shutter speed of 1/400 second and an aperture of 10 was used to capture the final image in figure 1.

No flash or external lighting was used for this photograph; the light emitted by the fire was enough to capture the desired flow.

4. Photographic Technique

The field of view was 30 inches in width and 50 inches in height (3456 px by 5184 px); this was necessary to capture the height of the fire, which was longer than the base. The distance from lens to the base of the fire was about 8 inches. A 40 mm focal length lens was used for the image in figure 1. The camera used was a Canon Rebel T6. The ISO was set to 3200. Moreover, processing was done in

photoshop to increase the contrast. Using the curves feature, the output was increased slightly to increase the brightness of the fire and the embers.

5. Conclusion

Overall, the photograph in figure 1 reveals the physics of flow phenomenon as well as the chemistry involved in combustion. The type of flow can be understood without the need of complex mathematics; the bottom of the fire displays smooth flow trajectories (laminar flow) whereas the top of the fire displays chaotic trajectories (turbulent flow). In addition, the chemistry of compounds reacting, and giving-of photons is beautifully displayed in this image. I like that this image evokes familiar experiences of sitting around a campfire; that was the intent of this photograph and I believe I was successful in this pursuit. Furthermore, one aspect that I would like to explore further is the behavior of embers and how they contribute to the spread of wildfires; this topic is important because, as wildfires become more prevalent with rising global temperatures, understanding the behavior of embers can help to mitigate the damage caused by wildfires.

References

1. VanCleave, Janice. “Flame Colors: Photons.” *VanCleave's Science Fun*, 2 Apr. 2010, scienceprojectideasforkids.com/flame-colors-photon/.

2. “Fire II: Color and Temperature.” *Maggie Maggio*, 30 Aug. 2011, maggiemaggio.com/color/2011/08/fire-ii-color-and-temperature/.