Team First Report

Isaac Rodriguez, Cooper Wathen, Curtis Dunford

MCEN 4151

9/28/25

Figure 1. Final image of Fuel Gel Flame

Background

This image of a fuel gel flame was taken for the first group assignment in MCEN 4151, a flow visualization class. The team consisted of three people, two classmates Cooper Wathen, Curtis Dunford and myself. The goal of this project was to create a fuel gel and capture the behavior of its flame. The fuel gel consisted of calcium carbonate, acetic acid and 99% isopropyl alcohol, it is commonly known as "canned heat" and used to keep food warm in outdoor applications. The flame burning from the fuel gel, appeared to be laminar, with steady flames. The flame characteristics will be estimated using various dimensionless numbers. The Reynold number to characterize flame flow as laminar or turbulent. The Froude number will determine if the flame is buoyancy-driven or momentum-driven.

Set Up

To create the fuel gel, we crushed up chalk which contains calcium carbonate, we heated 5% acidic vinegar until most of the water was boiled off. Then we mixed the acidic acid (from the boiled off vinegar) with the calcium carbonate and 99% isopropyl alcohol. The proportions of each are as follows: 10g of calcium carbonate (crushed chalk into a fine powder), 200 ml of vinegar (5% acidity) added to the calcium carbonate in a heat-resistant glass container. The solution of calcium acetate (vinegar and chalk) was then boiled on a heat plate until about half the solution remained. 10 ml of this solution was mixed with 75 ml of 99% isopropyl alcohol to create the final fuel gel. The following fuel gel creation process was followed: https://www.youtube.com/watch?v=2miy7M2wO1g.

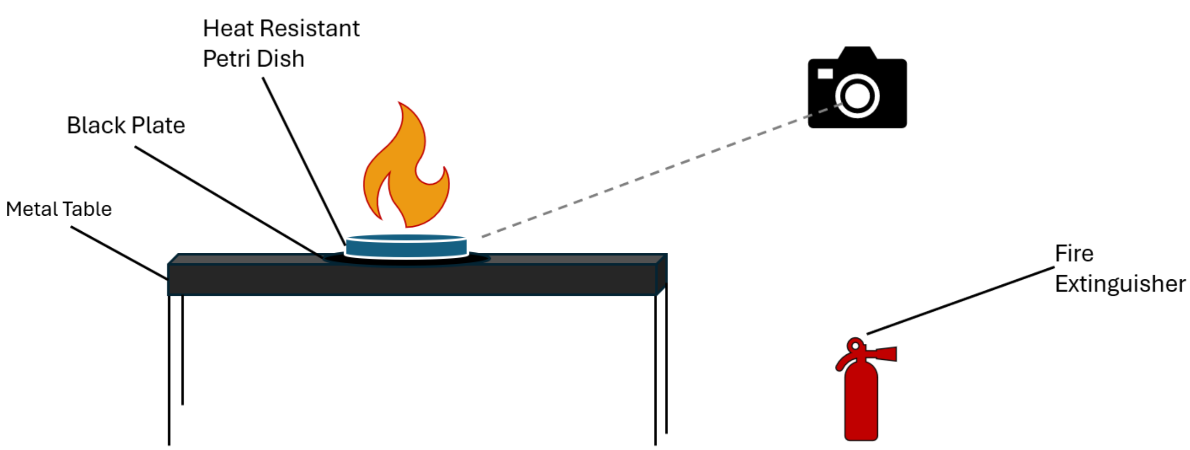

Figure 2: Image showing the set up used

The fuel gel was put in a heat-resistant petri dish and burnt in a well-ventilated area with a fire extinguisher on hand.

Flow Physics

Flame physics:

To characterize the flow of the flame, the Reynolds and Froude numbers will be approximated. The Reynolds number will characterize the flow as either laminar with a smooth and steady flame or turbulent with an unstable fluctuating flame [2]. The Froud number will determine the driving force acting on the flame, whether it is the momentum due to burning the fuel gel, or the buoyancy force of gravity acting on the flame. If the buoyancy force of gravity is impacting the flame more, it will limit the length of the flame [1].

The Reynolds Number calculation is an approximation, given the limited resources available to measure fluid properties and characteristics. The Reynolds number was calculated using a velocity of .5 m/s (based on a study on flame characteristics with similar experimental conditions) [3]. A flame length of .05 meters was used as the characteristic length. The properties of air at 500°C were used for this estimation of the Reynolds number [2].

$$Re = \frac{\rho V l}{\mu} = \frac{.4565\left(\frac{kg}{m^3}\right) * .5\left(\frac{m}{s}\right) * .05(m)}{3.64 * 10^{-5}(N * \frac{s}{m^2})} = 313.53$$

The Reynolds number was low; this indicates it was a steady and stable flow. This matches with the image captured and the overall flow of the flame as it burned. A smaller value makes sense as it was a small flame with minimal movement.

The Froude number represents the ratio of inertial forces over gravitational forces. It will determine which has a greater effect on the flow of the flame. The same velocity used in the Reynolds calculation was used, while gravity and diameter of the petri dish are used in the denominator of the equation.

$$Fr = \frac{V}{\sqrt{gL}} = \frac{.5(\frac{m}{s})}{\sqrt{9.81\left(\frac{m}{s^2}\right) * .063(m)}} = .636$$

The Froude number was less than 1 which indicates that the gravitational forces were stronger than the inertia forces. This means that gravity was impacting the flow of the flame and restricting the flame length. This also further confirms that the flow of the flame was laminar in nature as Froude numbers less than 1 are seen in slow liquid flow.

Visualization

To visualize the flame, multiple visualization techniques were used. The flame creates a natural boundary layer with the background. Therefore, the most important part of creating this image was the lighting. The flame was the sole source of light, as it would have a clear contrast with the black background. Additionally, the image was shot from slightly above to capture the flame without being distorted by the refraction of the petri dish.

Post-Processing

This image was taken with a Canon Rebel t3i digital camera. The flame fluctuated while taking pictures, so a faster shutter speed of 1/100 sec was used. The image was taken in the dark with the fuel gel flame the sole source of light, because of that an ISO of 6400 was used to try to capture as many characteristics of the flame as possible. A medium aperture was used (f/5.6) to capture the flame and blur the background, since there was not a larger area to focus on. The focal length used was 300mm at 1 meter away. The calculated field of view was 2.9 in x 1.9 in.

Figure 3: Post processed image on the left, original photo on the right.

The original photo is 5202 x 3464 and the post-processed image is 4363 x 3464. The original was cropped to center the petri dish. The contrast was increased to darken the background and make the flame stand out. The saturation of the oranges in the original was increased to create a more colorful and livelier image. Lastly, the saturation of the blue was increased slightly to make the highlight around the base of the flame stand out.

Conclusion

Overall, the final image captures the fuel gel flame well. There are interesting flame features captured, such as the distinct two flames. The image could have been captured more clearly with locking the auto focus at the flame area before lighting the fuel gel. Additionally, having a faster shutter speed could have also meant a clearer image. The flame appeared slow and laminar when burning, however the calculations add mathematical justification of what is shown. The flow was laminar and affected by gravity limiting the flame length. This would explain why it was such a small flame. In the future, taking a video of the flame as it burns would have shown the flow of the flame better. This could be further explored by taking a slow-motion video of the flame. To capture this slow-motion video, a tripod and a smaller lens would need to be acquired.

References

[1] H. Sato, K. Amagai, and M. Arai, “Diffusion flames and their flickering motions related with Froude numbers under various gravity levels,” *Combustion and Flame*, vol. 123, no. 1–2, pp. 107–118, Oct. 2000. doi:10.1016/s0010-2180(00)00154-1

[2] P. M. Gerhart, *Munson, Young and Okiishi’s Fundamentals of Fluid Mechanics, Enhanced Etext*. Wiley, 2018.

[3] J. D. Martínez, K. Mahkamov, R. V. Andrade, and E. E. Silva Lora, “Syngas production in downdraft biomass gasifiers and its application using internal combustion engines,” *Renewable Energy*, vol. 38, no. 1, pp. 1–9, Feb. 2012. doi:10.1016/j.renene.2011.07.035

[4]Rapp, B. E., 2017, “Fluids,” Microfluidics: Modelling, Mechanics and Mathematics, pp. 243–263.