Candle Flame Flow Visualization

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Course: Flow Visualization – MCEN 4151
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Collaborators: Independent work

Context and Purpose

This image was created for the Flow Visualization course as part of the Get Wet assignment. My intent was to capture the complex motion of a candle flame and to highlight the interplay between fluid flow and combustion. I was particularly interested in the way a flame bends when exposed to small disturbances in the surrounding air. This final image resulted from several attempts in a darkened environment, where I experimented with flame motion by pulling the flame in different directions with the use of a handheld vacuum. The goal was to freeze the shape of the flame in a way that reveals both its structure and the physics driving its curved motion.

Flow Apparatus and Flow Physics

The flow apparatus for this image consisted of a single household candle mounted vertically on a flat surface. The candle was approximately 25 cm tall, with a diameter tapering from about 2.5 c at the base to 1.5 cm at the top. The visible flame measured roughly 2.5 cm in height and 0.5 cm in width. A black greenscreen was positioned behind the candle to eliminate reflections and isolate the flame in the final image.

To bend the flame, I used a HART Portable 20V battery-operated handheld vacuum cleaner, oriented so that the suction intake was directed toward the flame from a distance of about 15 cm. This created a weak, steady crossflow of air that displaced the normally vertical buoyant plume. A sketch of the setup is shown to the right, illustrating the candle, background, camera position, and airflow source.

The basic flow in this system is a buoyant plume generated by combustion. As the candle burns, hot gases are produced at the wick and expand upward due to reduced density compared to the surrounding air. In the absence of external disturbances, this results in a steady, laminar flame with a teardrop shape. When exposed to an external flow, the plume is deflected sideways as inertial and convective forces compete with buoyancy. The result, as captured in the image, is a smooth arc of the flame away from the vertical axis.

To better understand the flow regime, nondimensional numbers can be estimated. The Reynolds number, characterizing the ratio of inertial to viscous forces, is given by:

$$Re = \frac{UD}{v}$$

where U is the velocity of the rising gases, D is the characteristic width of the flame, and v is the kinematic viscosity of air. Taking $U \approx 0.1\ m/s$, $D \approx 5 \times 10^{-3}\ m$, and $v \approx 1.5 \times 10^{-5}\ m^2/s$:

$$Re = \frac{(0.1)(5 \times 10^{-3})}{1.5 \times 10^{-5}} \approx 33$$

This low Reynolds number indicates that viscous forces dominate, and the flow remains laminar. This matches the smooth flame edges observed in the photograph.

The Grashof number, representing the relative importance of buoyancy compared to viscous forces in natural convection, is:

$$Gr = \frac{g\beta \Delta T L^3}{v^2}$$

where $g = 9.81\ \frac{m}{s^2}$, $\beta \approx 1/T \approx 3.3 \times\ 10^{-3} K^{-1}$ for air at 300 K, $\Delta T \approx 1000K, L \approx 0.02m$, and $v = 1.5 \times 10^{-5} \frac{m^2}{s}$. Substituting values:

$$Gr \approx \frac{(9.81)(3.3 \times 10^{-3})(1000)(0.02^3)}{(1.5 \times 10^{-5})^2} \approx 1.2 \times 10^5$$

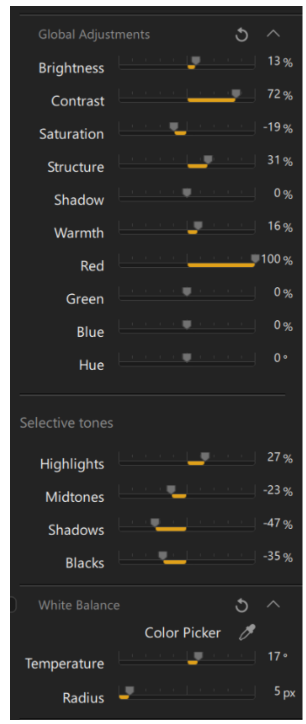
This value falls below the transition threshold for natural convection, confirming that the flow is laminar. In practice, this means the flame retains its smooth structure but is highly responsive to small perturbations like the weak vacuum-induced airflow.

Thus, the apparatus and conditions created a laminar buoyant plume bent into a stable arc by an imposed external flow. The forces of buoyancy and viscous damping balanced against the weak crossflow, producing the elegant shape visible in the final image.

Visualization Technique

The flame itself provided the visualization medium through light emission from hot gases and soot particles. No additional dye or smoke was introduced; instead, I relied on the natural incandescence of the flame. The experiment was performed in a dark room with a black screen behind the candle to eliminate background light, ensuring that only the flame and wick were visible. This contrast highlights the flame's curvature and the heated region around the wick. The only external influence was the airflow generated by a handheld vacuum, which tilted the flame and introduced visible asymmetry in its structure.

Photographic Technique



The image was taken with a digital DSLR camera (Canon EOD 7D Mark II) equipped with a sigma 18-300mm 1:3.5-6.3 lens. The distance from the camera to the flame was approximately 25 cm, and the field of view spanned about 5 cm across the candle top. The exposure settings were aperture f/6.3, shutter speed 1/640, and ISO 800. These settings allowed me to capture the flame sharply while freezing the motion of the hot gases.

Post-processing was applied in Photoshop using the Nik Collection plug-in. Adjustments included increasing contrast and blacks to remove background noise and slightly enhancing the red to emphasize the flame's brightness. The specific Nik Collection Viveza 3 edits can be seen to the right. No major structural edits were made.

Discussion and Reflection

The final image reveals the smooth laminar nature of the candle flame, bent into an arc by a weak air current. I particularly like how the dark background isolates the flame, making its curvature the focus of attention. The detail of the wick is also visible, anchoring the flame and giving scale to the image.

Overall, the image successfully fulfills my intent of showing the elegance of natural convection in a simple, everyday system. Going forward, I could extend this project by capturing multiple flame interactions, such as two candles close together, or by introducing controlled oscillations with a fan to study unsteady flame dynamics.

References

Roshani, Hassan et al. “The effect of buoyancy force on natural convection heat transfer of nanofluid flow in triangular cavity with different barriers.” *Heliyon* vol. 10,16 e35690. 8 Aug. 2024, doi:10.1016/j.heliyon.2024.e35690

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