Team Second Report

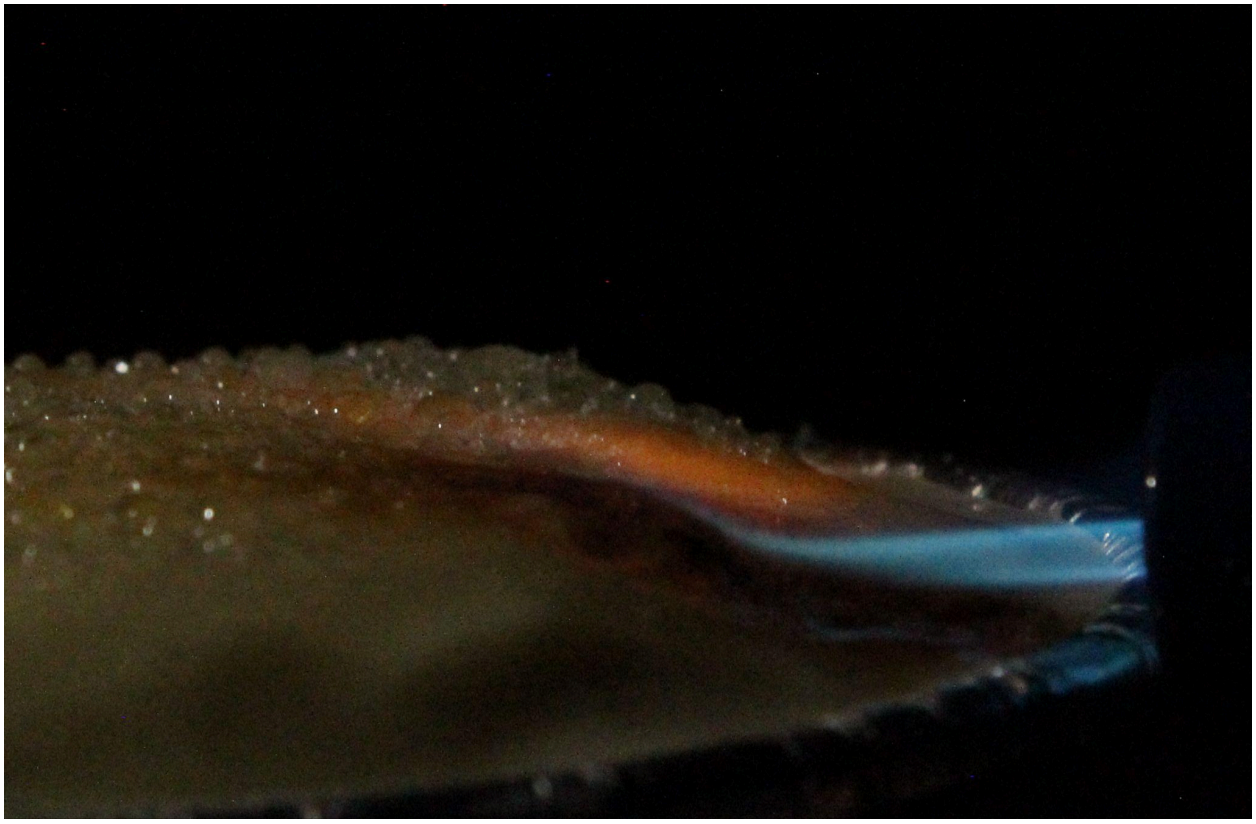
Flame deflecting and sugar caramelizing on pudding

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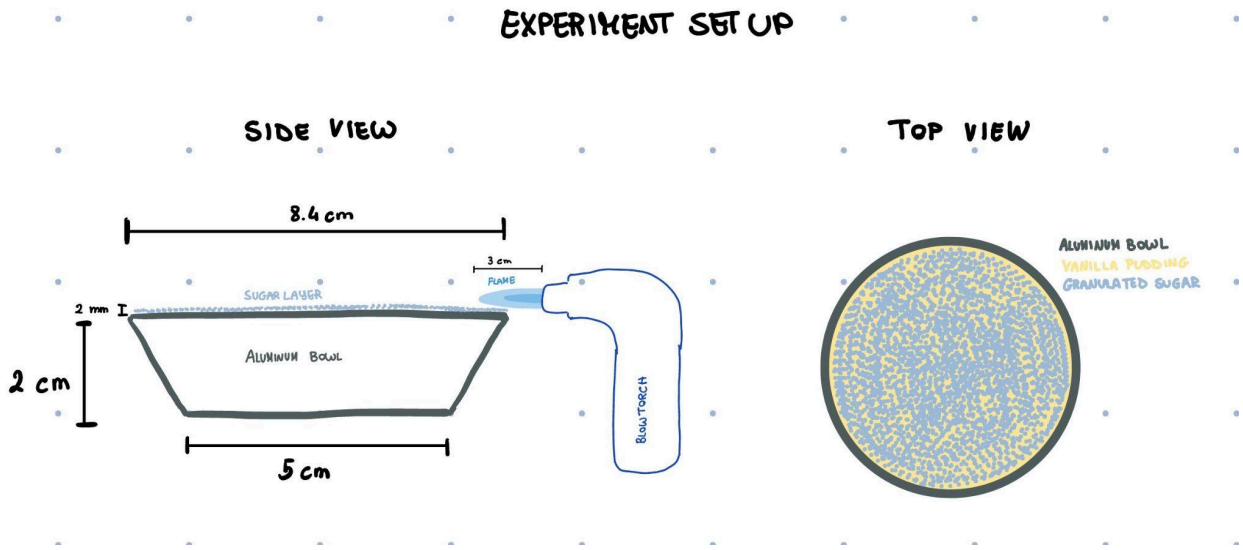
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Collaborators: Jesus Arismendi, Khalil Sidani



For the Team Second assignment, my team's goal was to capture how a blowtorch flame interacts with a sugar-covered surface. Initially, we planned to record videos of sugar burning on top of crème brûlée, with each team member focusing on a different torch angle: horizontal, vertical, and approximately 45 degrees. In the end, my team did not stick entirely to the initial plan; we ended up using vanilla pudding because it was what we could find, and we chose to take photographs instead of videos. We focused on capturing the sugar melting and caramelizing, along with the flame deflecting as it reached the pudding's surface. Our team consisted of Jesus Arismendi, Khalil Sidani, and me. We all helped set up the experiment. Jesus took the photographs, while Khalil and I alternated between holding the blowtorch and positioning the flashlight to improve the lighting.

The experiment used Snack Pack vanilla pudding in an aluminum container with an inner top diameter of 8.4 cm, a bottom diameter of approximately 5 cm, and a height of approximately 2 cm. The container was filled to the top, and granulated sugar was spread over the pudding in a layer estimated to be about 2 mm thick. We used a butane-fueled Blue Line XXL blowtorch with a nozzle opening approximately 0.7 cm in diameter. As shown in Figure 2, the torch was held at a shallow angle, nearly horizontal, with the flame directed toward the sugar-covered surface. The flame was approximately 3 cm long, and the torch was positioned so that roughly the last 5 mm contacted the surface.



This arrangement produced an impinging flame jet, with the hot gases changing direction and flowing along the surface after contact [1]. The photograph captures the resulting deflection of the blue flame, along with the sugar melting and caramelizing. Darkened areas of sugar and a red-orange luminous region are also visible near where the flame meets the surface.

The gas leaving the torch moves toward the pudding and changes direction when it reaches the surface. Pressure forces redirect the flow along the sugar layer. Because the torch was held nearly horizontally, the flame spreads across the surface. Mixing with the surrounding air slows and spreads the flow, while buoyancy causes the hot gases to rise [1].

The blue light comes from excited molecules formed during combustion that release energy as light. This process is called chemiluminescence [2]. The red-orange region may come from hot soot particles glowing through incandescence [2], but the photograph alone cannot confirm this. Heat from the flame causes the sugar to melt and caramelize, with the changes depending on both temperature and heating time [3]. The uneven browning suggests that some areas received more heat than others as the torch was moved.

The Reynolds number was estimated to compare the effects of inertia and viscosity in the gas leaving the torch [4]. The nozzle diameter, $D = 0.007\ m$, was used as the characteristic length because it represents the initial width of the jet. Since we did not measure fuel consumption, I assumed $12\ g/h$, based on the published consumption of a similar butane blowtorch, the

Dremel VersaTip [6]. I also assumed that the fuel mixed with just enough air for complete combustion, requiring approximately $15.4\ kg$ of air per kilogram of butane. The combined mass flow rate of air and fuel is therefore

$$\dot{m}_{mix} = (1 + 15.4)\dot{m}_f = 16.4(\frac{0.012\ kg}{3600\ s}) \approx 5.5 \times 10^{-5}\ kg/s$$

Using air properties at 20°C and standard atmospheric pressure as an approximation for the unburned mixture gives $\rho = 1.2\ kg/m^3$ and $\nu = 1.51 \times 10^{-5}\ m^2/s$ [5]. Assuming the mixture occupies the full circular opening, the average exit velocity is

$$U = \frac{\dot{m}_{mix}}{\rho A} = \frac{5.4667 \times 10^{-5}\ kg/s}{(1.2\ kg/m^3)[\frac{\pi(0.007\ m)^2}{4}]} = 1.184\ m/s$$

Unrounded values were retained in subsequent calculations. The Reynolds number is then

$$Re_D = \frac{UD}{\nu} = \frac{(1.184\ m/s)(0.007\ m)}{1.51 \times 10^{-5}\ m^2/s} = 549 = 5.5 \times 10^2$$

This estimated Reynolds number is consistent with relatively smooth flow near the nozzle, which matches the appearance of the blue flame. However, this estimate applies to the gas leaving the nozzle and does not confirm that the flow stays laminar after reaching the surface. The estimate depends on the assumptions about fuel consumption, air mixing, the nozzle opening, and gas properties before combustion.

The approximate time for gas traveling at the estimated velocity to move one flame length, $L_f = 0.030\ m$, is

$$t_f = \frac{L_f}{U} = \frac{0.030\ m}{1.184\ m/s} = 0.025\ s$$

To estimate the image's spatial resolution, we used the edited image's horizontal field of view of approximately $W = 0.055\ m$ and its final exported width of 2194 pixels. The distance represented by each pixel is

$$\Delta x = \frac{W}{N_x} = \frac{0.055\ m}{2194\ pixels} = 2.5 \times 10^{-5}\ m/pixel = 0.025\ mm/pixel$$

To limit motion blur to one pixel, the maximum exposure time for a feature moving at the estimated velocity of 1.184 m/s is

$$t_{exp} \leq \frac{\Delta x}{U} = \frac{(0.055/2194)\ m}{1.184\ m/s} = 2.1 \times 10^{-5}\ s$$

This corresponds to roughly 1/47,000 s. However, the actual shutter speed was 1/80 s, which is much longer than the calculated time. Therefore, the photograph does not freeze individual moving flow structures, but it can still capture the flame's overall shape if it remains relatively steady. Focus and image noise also affect how much detail is visible.

The flow was visualized through the visible butane flame, so no dye or smoke was added. We used a Blue Line XXL torch to heat a layer of granulated sugar approximately 2 mm thick on top of Snack Pack vanilla pudding in an aluminum container. The experiment took place indoors in a kitchen at room temperature. As a safety precaution when working with an open flame, we placed the container on a baking sheet on the stovetop. All kitchen lights were turned off, and an iPhone flashlight was the main light source used to illuminate the pudding and sugar. One team member held the flashlight at a low brightness setting approximately 15 cm from the pudding while the photographs were taken. The flame emitted its own visible light but was not bright enough to illuminate the pudding's surface on its own.

The photograph was taken with a Canon EOS Rebel T5 digital camera using an EF-S 18–55 mm lens at a focal length of 55 mm. The camera was approximately 35 cm from the pudding. Jesus selected the camera settings, using manual exposure with an aperture of f/11, a shutter speed of 1/80 s, ISO 6400, and daylight white balance. The original photograph measured 5184 × 3456 pixels. I used Darktable to crop the photograph; the final edited export measured 2194 × 1431 pixels and has a horizontal field of view of approximately 5.5 cm. The close framing emphasizes the flame bending along the surface and the sugar's texture. No other adjustments were made. The original, unedited photograph is included in Figure 3 for comparison.



The image reveals how the blowtorch flame bends and spreads along the pudding's surface while heating the sugar. I like that it captures several details at once: the sugar melting and burning, the original blue flame, its deflection along the surface, and the red-orange luminous region. The flame's shape makes the change in flow direction easy to see, although

the photograph does not show the motion over time. I dislike how grainy the image is. We kept the lighting low so the flame would remain visible, and the high ISO setting contributed to the grainy appearance. I tried reducing the grain in Darktable, but none of the adjustments seemed to improve the image, so I did not keep them. Overall, I fulfilled my intent of capturing the flame interacting with the sugar-covered surface. My main remaining question is what causes the red-orange region. To develop this idea further, I would compare different torch angles and distances to see how they affect the flame's deflection and the sugar's heating pattern. I would also experiment with the flashlight's position and brightness to capture more surface detail while keeping the flame visible and reducing image noise.

References

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