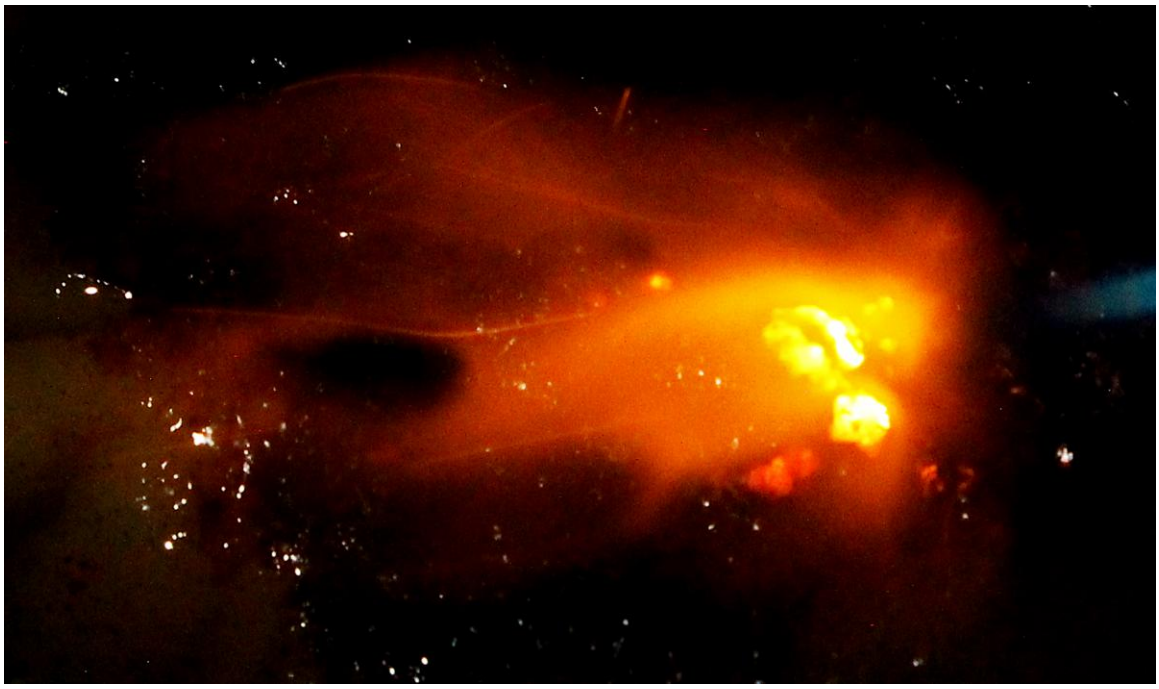
Khalil Sidani

Team Second Assignment | Flow Visualization | ATLS 5151-001

Report date: November 4, 2026

Team members: Maria Cristina Sarno, Jesus Arismendi



Context and Purpose

This image was made for the Team Second assignment in Flow Visualization, a course at the University of Colorado Boulder that pairs fluid physics with photography. Each student in a small team produces their own image, while teammates help build the apparatus and run the experiment. Our team chose combustion: a handheld blowtorch flame impinging on a shallow layer of granulated sugar in an aluminum foil dish of crème brûlée, so that the flame could be seen melting, caramelizing and finally burning the sugar.

The intent was to capture two coupled flows in one frame: the hot gas jet of the flame spreading across the dish, and the slow, viscous motion of the molten sugar beneath it as it bubbles and darkens. We shot the event from both the top and the side; this report covers only the final top view, in which the torch's jet enters from the right of the frame.

Maria Cristina Sarno operated the torch and maintained a close distance to ensure that the sugar burned correctly, and Jesus Arismendi was in charge of positioning the flash and lighting so that no dark spots or reflections from the foil dish were present. I set up the camera and took the photos, changing positions and distances to ensure that we were in focus and the subject was clear in the images.

Flow Apparatus and Flow Physics

The flow is a hot gas jet impinging on a shallow, melting layer of sugar. A handheld Blue Line XXL torch (burner tube inner diameter D = 14 mm) was held about 5 cm from an aluminum foil dish 8.4 cm in diameter, filled with vanilla pudding and topped with granulated white sugar to a depth of 5 mm, as in a crème brûlée (Figure 1). In the final image the jet enters from the right edge of the frame, so the torch was tilted at roughly 30° to the surface rather than pointed straight down. The dish sat on a flame-proof ceramic

tile indoors with the kitchen vent running for safety. The shot was taken in Boulder, Colorado, at about 1650 m elevation, where ambient pressure is roughly 83 kPa.

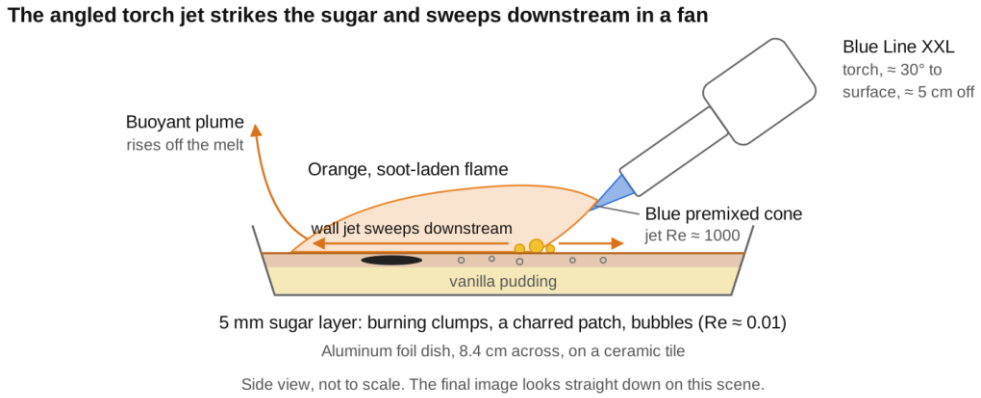


Figure 1. Apparatus sketch (side view, not to scale). The angled jet impinges on the sugar, turns mostly downstream as a wall jet, and lifts off as a buoyant plume.

Two very different fluids move in the image. Above the dish, combustion products leave the torch, strike the sugar near a stagnation point, and turn into a thin wall jet. Because the torch is angled, most of the jet's momentum carries on downstream, so the wall jet sweeps away from the torch and widens into a fan, leading to the shape of the orange glow in the final image. Below, the sugar melts, bubbles and darkens as it caramelizes. Flame impingement is well studied because the impingement region carries the highest heat flux, which falls off with distance along the wall jet (Viskanta 1993; Baukal and Gebhart 1995). That is why the sugar under the jet ignites first, while browning and charring trail downstream.

Gas jet Reynolds number. The exit velocity was estimated from the torch's fuel use. A standard hand torch releases roughly 1.5 kW; with propane's heating value of 46 MJ/kg and a stoichiometric air–fuel ratio of 15.6, the premixed mass flow is about 5.3×10^{-4} kg/s. At Boulder's mixture density (≈ 1.0 kg/m³ compared to Sea level 1.225kg/m³) through a 14 mm tube, U ≈ 3.4 m/s. Using the ambient kinematic viscosity at 83 kPa and 20 °C:

$$Re_{exit} = \frac{UD}{\nu} = \frac{(3.4\,m/s)(0.014\,m)}{1.85 \times 10^{-5}\,m^2/s} \approx 2.6 \times 10^3$$

Combustion changes the picture however: the products reach about 2000 K (Bernzomatic (n.d.)). Thermal expansion raises the velocity to roughly 20 m/s, but gas viscosity rises much faster, to $\nu \approx 4.4 \times 10^{-4}$ m²/s at 2000 K and 83 kPa. Over a hot-gas width of about 2 cm:

$$Re_{hot} = \frac{(23\,m/s)(0.020\,m)}{4.4 \times 10^{-4}\,m^2/s} \approx 1 \times 10^3$$

Heat release therefore pushes the jet back toward laminar flow. This matches the image: the downstream flame shows long, smooth, curved filaments rather than fine turbulent wrinkling.

Momentum versus buoyancy. A Richardson number compares buoyancy with jet momentum over the standoff distance H:

$$Ri = \frac{g(1 - T_\infty/T)H}{U^2} = \frac{(9.81\,m/s^2)(0.85)(0.05\,m)}{(23\,m/s)^2} \approx 8 \times 10^{-4}$$

so jet momentum, not buoyancy, drives the gas onto the sugar. Once the wall jet slows and loses heat downstream, buoyancy wins and the hot gas lifts off the melt as a rising plume. In the top view this lift-off points toward the camera, which is why the far end of the orange fan fades and blurs rather than ending at a sharp edge.

The molten sugar. Sucrose melts and begins to decompose near 160–190 °C. The early stage splits it into glucose and fructose, which dehydrate and release volatile gases (Kroh 1994). Those gases form the bubbles visible in the melt. The pudding underneath is mostly water, so it holds the bottom of the sugar layer far below caramelization temperature; only the top of the 5 mm layer melts and browns, which is the principle behind torching a crème brûlée. The melt is extremely viscous: a Williams–Landel–Ferry estimate from sucrose's glass transition (≈ 62 °C) gives μ on the order of 1 Pa·s at 180 °C (Williams et al. 1955). A 2 mm bubble then rises at the Stokes velocity:

$$v = \frac{\rho g d^2}{18\mu} = \frac{(1500\ kg/m^3)(9.81\ m/s^2)(0.002\ m)^2}{18(1\ Pa \cdot s)} \approx 3\ mm/s$$

$$Re_{bubble} = \frac{\rho v d}{\mu} = \frac{(1500)(0.003)(0.002)}{1} \approx 0.01$$

The gas above the dish runs at Re ~ 10^3 while the liquid below it creeps at Re ~ 10^{-2}, five orders of magnitude apart in one frame. Two forces also drag the melt surface away from the impingement point: shear from the wall jet, and a Marangoni stress, because surface tension is lowest where the melt is hottest. Both carry the melt away from the impingement zone toward cooler sugar.

Visualization Technique and Lighting

No seeding or dye was added; the flow marks itself by its own light. Almost everything else is thermal emission. Sugar decomposing under the jet releases volatile gases that burn in a sooty diffusion flame, and the glowing soot gives the broad orange fan. The brightest yellow-white blobs are clumps of sugar burning directly at impingement, the hottest spot in the frame. Faint curved orange streaks inside the fan are pathlines of glowing particles carried by the wall jet, so they show the flow direction directly.

The melt is visualized by the caramelization itself. Sucrose turns from white to amber to black as it heats, so the dark elliptical patch left of center is charred sugar. Materials were granulated white sugar spread 5 mm deep over a thick layer of vanilla pudding in the 8.4 cm aluminum foil dish. The Blue Line XXL torch burned butane with the flame set to full. The room was at about 24 °C, and the kitchen vent cleared smoke from the burning sugar.

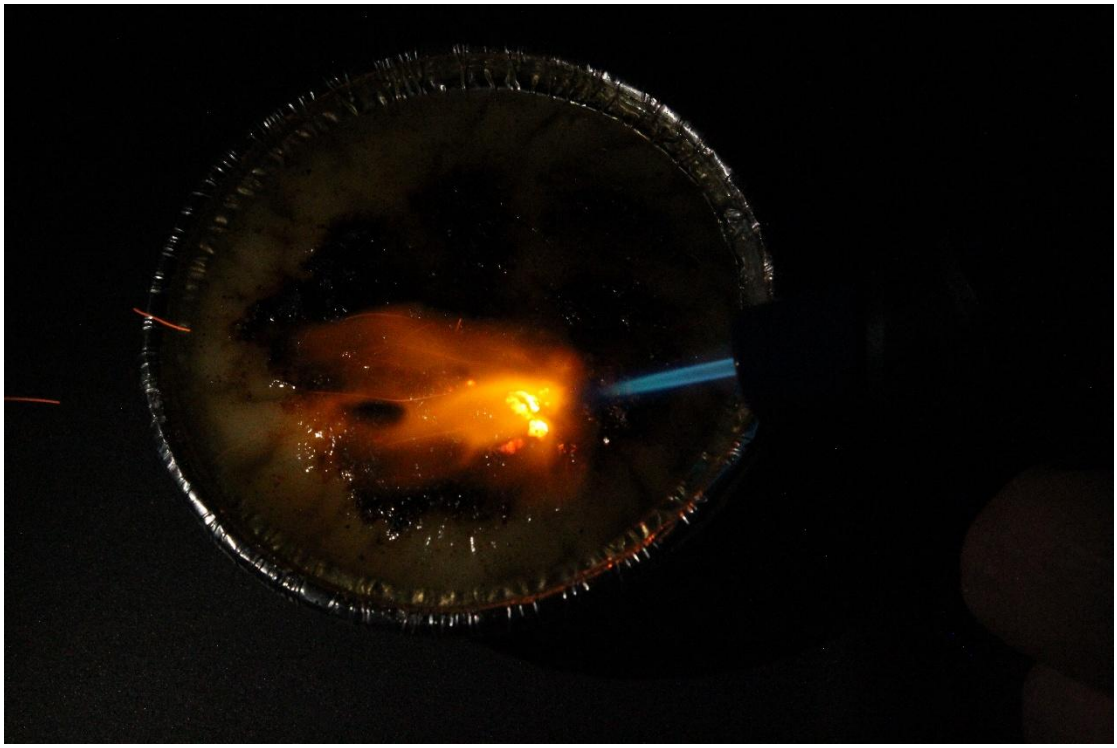
Our lighting combined the flame's own emission with a camera flash that Jesus held above and to the left of the dish to avoid dark spots and glare from the foil. The flash lights the sugar surface for an instant, while the flame glows throughout the exposure. The background beyond the dish stays nearly black, which isolates the glowing gas.

Photographic Technique

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 and framed from directly above with the torch's jet entering at the right edge so the fan spreads across the frame. 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 image was 5184 × 3456 pixels; the final image is 1795 × 1055 pixels after cropping.

The shutter speed sets what can be frozen. A sugar bubble rising at 3 mm/s moves only about 25 μm in 1/120 s, about two pixels, and the flash freezes it further. The hot gas, at roughly 20 m/s, travels about 17 cm in the same interval, longer than the whole frame. The flame therefore appears as a time-averaged glow, which suits the subject: the streaks in the fan are particle paths recorded over the exposure.

Post-processing was done in GIMP: A crop, contrast and color curve were applied to bring out the sugar streak pathlines more clearly. The unedited original is included below for comparison.



Discussion

The image shows an angled flame jet turned by the sugar surface into a fan-shaped wall jet. The color runs from the blue jet at the right, through yellow-white burning sugar at impingement, to a deep orange soot flame that dims downstream as it cools and lifts toward the camera. Curved glowing streaks show the gas spreading sideways as it moves left, and a charred patch marks sugar the flame has already passed over.

What I like: the fan shape and the streaks make the flow direction obvious, and the color gradient reads as a temperature gradient. What I dislike: the blue jet is cut off at the right edge, so the torch and the impingement angle are not visible in the edited image, and the white sparkles and a greenish cast at the lower left compete with the flame. The physics of the melt are shown well; the gas flow is shown only by its glow, so its velocity field must be inferred rather than seen.

I mostly fulfilled my intent of showing both flows together. Open questions remain: how much of the surface motion comes from wall-jet shear versus Marangoni stress, and at what point does the flame begin burning sugar vapor rather than only the torch fuel. To improve the image I would reframe to include the whole blue jet, and schlieren setup to show the non-luminous hot gas. A next step would be a high-frame-rate video from the side to track bubble growth and the moving browning front over time.

References

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AI notice: Claude Opus 5.5 on high was used for rewriting initial drafts for better legibility and was also used to generate the sketch. It was also used for proofreading and review against the assignment document to ensure that most if not all requirements were met.