Team First

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Figure 1: Still extracted from slow motion video.

Abstract

For Team First, my team and I aimed to investigate the flame dynamics of a shallow diffusion pool flame sustained by a calcium-acetate/isopropanol gel that our team mixed in-house from household materials and cast into Petri dishes. Working together on chemistry choices, filming, and safety, we documented the behavior with still images and slow-motion video in a controlled dark-field setup. Using frame counts and timestamps, we obtained a repeatable puffing period that points to a buoyancy-driven hydrodynamic mechanism set primarily by pool geometry and plume roll-up. Fire salt doping and gel microstructure modulate intermittency, appearance, and occasional atomic emission lines, but only weakly influence puffing timing. The oscillation persists in quiet air without audible resonance.

Experimental Setup and Methods

We prepared a calcium–acetate/isopropanol fuel gel using household materials. First, 10 g of chalk ($CaCO_3$) was finely crushed and reacted with 200 mL of 5% household vinegar (aqueous CH_3COOH). This neutralization produced an aqueous calcium acetate solution, releasing effervescent CO_2 gas and water:

$$\mathrm{CaCO_3(s) + 2\,CH_3COOH(aq) \longrightarrow Ca(CH_3COO)_2(aq) + CO_2(g) + H_2O(l).}$$

To reduce excess water, the stock mixture (100 mL) was gently heated while vapors were vented by a fan. From this stock, two 20 mL working batches were prepared, each tinted with food coloring to improve visibility of the fill level through the 60 mm Petri dishes. After cooling, the solution was combined with 99% isopropanol (IPA). The very low water content accelerated precipitation of calcium acetate, producing a cloudier and grainier gel compared with reference demonstrations. Both gels were further doped with commercial “fire salt” packets, which thickened the mixture and introduced trace metal species for spectral emission.

Each fuel sample was cast to shallow depth in Petri dishes, sealed until use, and subsequently ignited on a metal tray in quiescent air. All handling was performed with adherence to combustion safety and ventilation guidelines. [2]

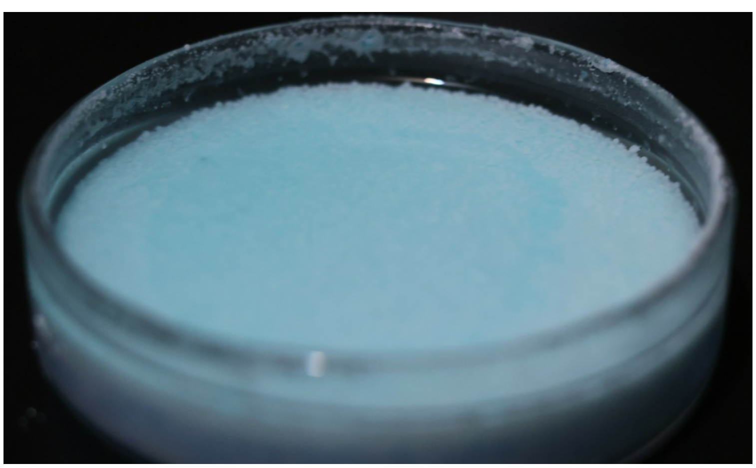

Figure 2: Isaac’s Blue Fuel Gel

Imaging Setup and Post Processing

We each captured our own gel and documented the other's as well. Both specimens—Isaac's blue-tinted gel and my red-tinted gel—were filmed separately, with each of us handling our own camera work. We started with Isaac's powder blue colored gel and my red-tinted gel after. This became the basis for my final Flow Visualization submission. All of our recordings were made at night in a large garage with the front door open for ventilation. The Petri dish was placed on a matte black glass dish, which sat on top of a rolling steel tool cart near the center of the room. This was far enough from the opening to avoid direct drafts, but close enough to allow safe vapor venting. It was a quiescent night, and I waited a few seconds after any movement before recording. The lighting was nearly dark. The experiment was filmed using a Canon EOS R50, a mirrorless APS-C camera, paired with the RF-S 18–45 mm f/4.5–6.3 IS STM kit lens. The lens was set to 18 mm, which is its widest focal length. The footage was recorded in portrait orientation, with the camera rotated 90 degrees and positioned side-on at dish height to capture the lateral flame motion and gel level through the wall of the Petri dish. On the R50's APS-C sensor (1.6× crop factor), which corresponds to an effective field of view of about 29 mm full-frame equivalent. Video was recorded in Full HD (1080p) at 120 fps using the camera's built-in high-frame-rate slow-motion mode. The camera was positioned on the steel cart and manually focused on the Petri dish rim, with settings optimized for depth of field and low-noise performance in the dimly lit environment. Post-processing was done in Adobe Spark, where I adjusted contrast and color saturation slightly. The final video includes background music titled "Future Technology" from Adobe's stock library.

Physical Phenomena

The oscillations in our calcium–acetate/isopropanol pool flame arise not from chemistry but from the **buoyancy-driven instability** of the hot plume above the fuel surface. Combustion decreases the gas density near the flame relative to the surrounding air, and the resulting density differences drive upward acceleration. As with idealized buoyant plumes, this process can be captured through dimensionless parameters that balance inertia, buoyancy, viscosity, and diffusion.[4]

Key Dimensionless Numbers

$$Re \equiv \frac{\rho U L}{\mu} \quad \text{(Inertia / Viscous = “flow regime”)}$$

$$Ri \equiv \frac{\Delta\rho g L}{\rho U^2} \quad \text{(Buoyancy / Inertia = “buoyancy importance”)}$$

$$Pr \equiv \frac{\mu C_p}{k} \quad \text{(Momentum diffusivity / Heat diffusivity = “heat vs. momentum spread”)}$$

$$Le \equiv \frac{\rho C_p D}{k} \quad \text{(Mass diffusivity / Thermal diffusivity = “species vs. heat spread”)}$$

Here ρ is density, U a characteristic velocity, L the pool diameter, μ viscosity, k thermal conductivity, C_p specific heat, and D a mass diffusivity.

Oscillation and Strouhal Scaling

The **Strouhal number**, which captures unsteady oscillation relative to convection, is defined as

$$St \equiv \frac{fL}{U} \quad \text{(Oscillation frequency} \times \text{length / velocity = “flicker per convection time”).}$$

Because buoyancy dominates, the Richardson number simplifies to

$$Ri = \frac{\Delta\rho g L}{\rho U^2} \sim \frac{gL}{U^2} = \frac{1}{Fr},$$

with

$$Fr \equiv \frac{U^2}{gL} \quad \text{(Inertia / Buoyancy = “plume balance index”).}$$

Thus the Strouhal number is primarily a function of the Froude number:

$$St = \Psi(Fr).$$

Empirical studies of pool flames show that this collapses to the scaling law

$$St \sim Fr^{-1/2},$$

or equivalently

$$f = C\sqrt{\frac{g}{L}}, \qquad C \approx 0.3\text{–}0.5$$

Application to Our Flame

For our $L = 0.06$ m Petri dish:

$$f \approx 3.8\text{–}6.3\,\text{Hz}, \qquad T \approx 0.16\text{–}0.26\,\text{s},$$

consistent with the period measured from high-speed video. This agreement confirms that the puffing frequency is set by **geometry and buoyancy**, not detailed combustion chemistry.Addition of trace “fire salts” introduces spectral emission features; copper, in particular, yields green emission near 510–530 nm, observed here as momentary spark-like flashes along the flame contour. These phenomena add visual structure but do not alter the hydrodynamic frequency.[3]

Conclusion

This project pulled together simple household chemistry and serious visualization to create a working calcium acetate–isopropanol gel fuel system. Starting from crushed chalk and vinegar, we built a stock solution, refined it into gelled working batches, and ultimately cast shallow pool flames that revealed complex, dynamic combustion behavior. The cloudiness, graininess, and color doping we observed reinforced just how sensitive this system is to water content, mixing, and additives, and the resulting flames gave us a platform for exploring instabilities and fluid motion up close. Equally important, this was a team effort. Cooper Wathen, Isaac Rodriguez, and I each brought hands-on experimentation, While geometry and buoyancy control the oscillation timing, *chemistry and microstructure* tune the appearance. Uneven vapor release yields fuel-rich pockets that produce yellow soot luminosity, while halide salts contribute sharp green emission lines. These modify flame color and intermittency but leave the buoyancy-driven puffing frequency unchanged.

References

[1] Chem Camp with Mrs. Newman. *Canned Heat - How to Make Sterno Gel Fuel*. YouTube, 2023. https://www.youtube.com/watch?v=2mjy7MzwO1g.

[2] Flow Visualization Course, "FlowVis.org – The Physics and Art of Fluid Flow," University of Colorado Boulder, 2025. https://www.flowvis.org/.

[3] Malalasekera, W. M. G., Versteeg, H. K., and Gilchrist, K. "A Review of Research and an Experimental Study on the Pulsation of Buoyant Diffusion Flames and Pool Fires." *Fire and Materials*, vol. 20, no. 6, 1996, pp. 261–271.

[4] Turns, Stephen R. *An Introduction to Combustion: Concepts and Applications*. 2nd ed., McGraw-Hill Science/Engineering/Math, 1999.

[5] Dunford, Curtis. *Team First*. Vimeo, 22 Sept. 2025. https://vimeo.com/1121018914.

[6] OpenAI ChatGPT - 4o/5 w/ additional support for writing and technical checks provided by ChatGPT 2025.

Additional Images Shot During Flow Visualization

Figure 3: Blue fuel gel burn top down

Figure 4: Puffing and necking dynamics of plume