Team Third: Patterns of a Convection Cell

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20 November 2026 | MCEN 5151 Flow Visualization

INTRODUCTION

This report covers the Team Third image submission for Flow Visualization, showing Rayleigh-Bénard convection in heated oil. The scientific goal was to capture the convection cells that form when a shallow layer of fluid is heated from below, while the artistic goal was to highlight the metallic texture of the cells and use a single floating droplet as a focal point. Thank you to Ryan Cross and Jay Hall for helping with the ideas, setup, and photography.

SETUP AND FLOW

The setup (Figure 1) consisted of a 90 mm diameter glass petri dish filled with garlic oil to an estimated depth of $d \approx 5$ mm $(0.005$ m). It was heated underneath by a regular electric stovetop.



Figure 1. *The experimental setup showing the 90 mm glass petri dishes on the electric stovetop burner (slightly out of focus, included to show the apparatus layout).*

As the bottom layer of oil heats up, it becomes less dense and rises to the surface, where it cools and becomes denser, causing it to sink back down [1]. To handle this motion without the rising and sinking oil blocking each other, the fluid sorts itself into convection cells [1, 2]. Because the top of the petri dish is open to the air rather than capped by a solid plate, surface tension also contributes to the motion alongside buoyancy.

To describe the flow, we can estimate the Rayleigh number (Ra), which compares the driving buoyancy force to viscous friction and heat diffusion [1]. Since the photo was taken well after the oil was heated on the stovetop, we estimate a hot top surface ($\sim$ 90–100 °C) and a vertical temperature drop of $\Delta T \approx 20$ K across the 5 mm layer. Using typical fluid properties for hot cooking oil ($\beta \approx 7 \times 10^{-4}$ K^{-1}, $\nu \approx 1.0 \times 10^{-5}$ m^2/s, $D_T \approx 1.0 \times 10^{-7}$ m^2/s) [5, 6]:

$$Ra = \frac{g\beta\Delta T d^3}{\nu D_T} = \frac{(9.81\ \text{m/s}^2)(7 \times 10^{-4}\ \text{K}^{-1})(20\ \text{K})(0.005\ \text{m})^3}{(1.0 \times 10^{-5}\ \text{m}^2/\text{s})(1.0 \times 10^{-7}\ \text{m}^2/\text{s})} \approx 1.7 \times 10^4$$

Convection begins once Ra exceeds the critical value of $Ra_c = 1708$ [1, 2]. Because our estimated $Ra \approx 1.7 \times 10^4$ is roughly an order of magnitude above that threshold, the flow is pushed past orderly cells into a more chaotic and faster convection [1, 2]. This matches what we saw during the shoot, where the oil was moving rapidly instead of sitting in neat and unmoving cells.

The captured image features a single drop sitting on the surface. It was pushed there by the outward surface currents moving away from the rising cell centers. It stays on the surface instead of merging right away with the rest of the fluid because it is slightly cooler than the hot oil pool and that temperature difference drives surface currents (Marangoni flow) that pull a layer of air underneath the droplet and keep it floating [3].

VISUALIZATION TECHNIQUE

To make the flow visible, we mixed mica powder into the garlic oil to create a rheoscopic fluid. Because mica particles are flat, microscopic flakes, the movement of the oil aligns them with the surrounding flow [4]. Where the oil moves horizontally across the top of a cell, the flakes lie flat and bounce light back to the camera, making those areas look, in this case, bright gold. Where the oil rises in the center or sinks at the cell borders, the vertical motion tilts the flakes so they reflect less light. This creates the darker lines that outline each cell [4]. We made the floating droplet by dabbing the mixing spoon onto the oil surface without breaking the surface tension. The setup was lit with overhead ambient lighting, an additional LED panel, and no flash.

PHOTOGRAPHY AND PROCESSING

The original photograph (Figure 2) was captured as a RAW file using a Sony ILCE-6300 digital camera. The camera was placed within roughly 0.30 m (300 mm) above the dish, giving a field

of view of about 128 mm by 85 mm. The original image was 6024 x 4024 pixels, giving a spatial resolution of about 0.021 mm per pixel, which resolves the mica. The focal length was 55 mm, and the aperture was set to f/8.0 to give enough depth of field to keep both the floating droplet and the fluid surface in focus. The shutter speed was 1/60 s at ISO 400 with manual white balance. To check time resolution, the convective time scale from the fluid properties is $\tau_m \sim \frac{\nu}{g\beta d\Delta T} \approx 0.015$ s [1], giving an upper-bound velocity scale of $U \sim d/\tau_m \approx 330$ mm/s. Over the 1/60 s exposure, that scaling suggests an upper-bound displacement of about 5.5 mm, though the actual surface speed is noticeably slower due to drag, and 1/60 s was fast enough to keep the moving boundaries of the cells sharp.

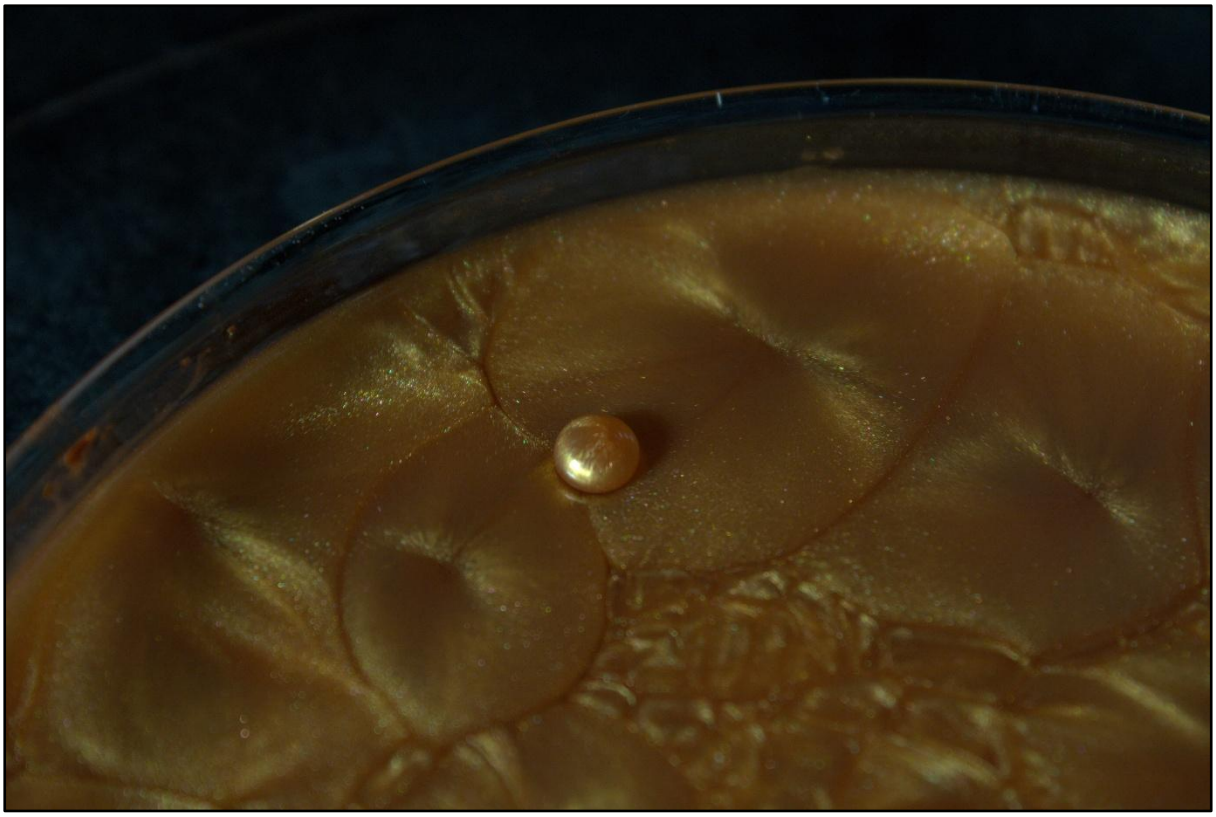

Figure 2. *The original unedited RAW image before post-processing in Darktable, which shows the glare and reflections along the rim of the petri dish.*

Post-processing was done in Darktable without cropping, so the final exported image (Figure 3) keeps the same dimensions as the original (6024 x 4024). I applied a lens deblur preset and tone equalizer to sharpen the cell edges and brighten the mica shimmer. To remove the glare and reflections along the glass rim visible in Figure 2, I used a parametric mask and lowered the exposure to fade the background into black. Additionally, I used the retouch heal tool to remove any specks on the glass wall.

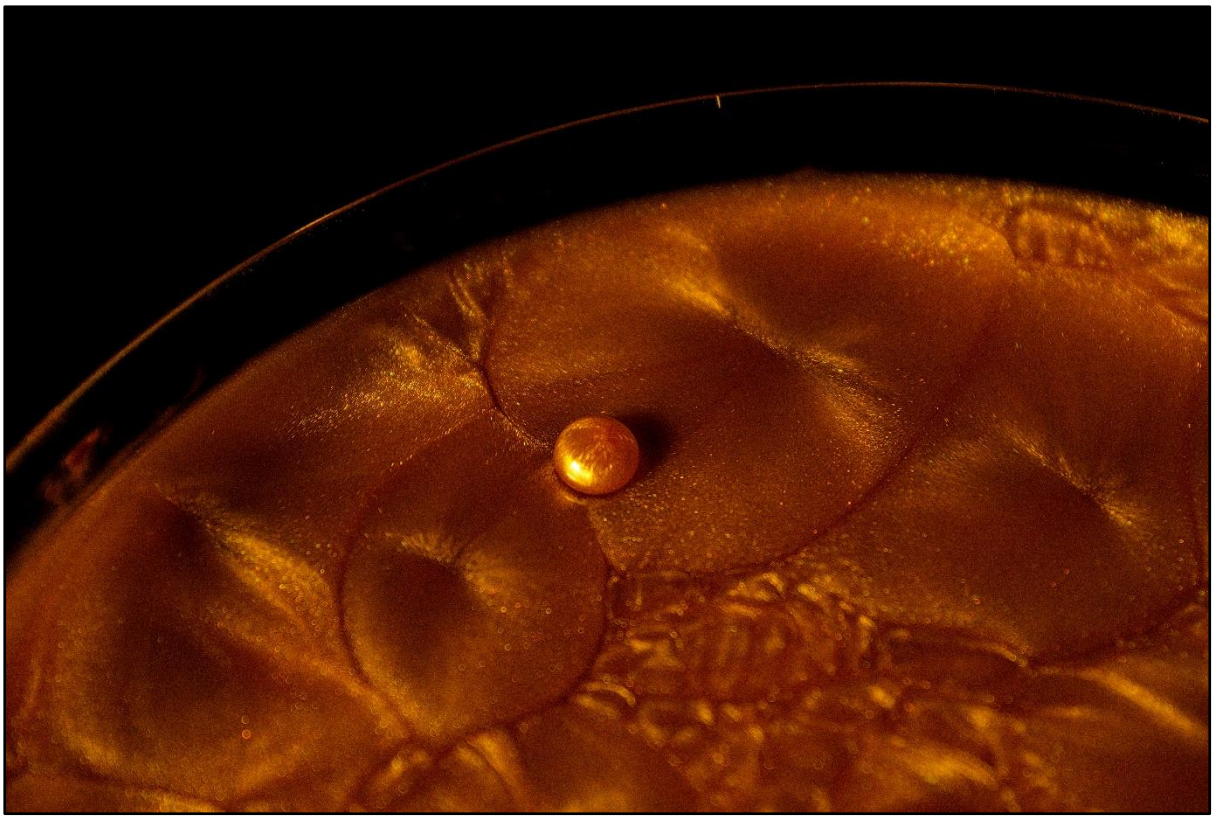

Figure 3. *The final edited image after post-processing in Darktable.*

DISCUSSION

The final image (Figure 3) fulfills both the scientific and artistic intent by displaying the convection cells with their boundaries as well as the droplet on the surface. I like how the mask removed the glare seen in Figure 2 while keeping just enough of the rim reflection for context. One analytical limitation of this experiment was having to estimate ΔT and the oil properties rather than measuring them directly, which would be something to keep in mind in any future variations of this visualization. To improve this setup and develop the idea further, I would test a few different fluid depths to see how the cell size scales.

REFERENCES

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