Making of: Convect!

Get Wet
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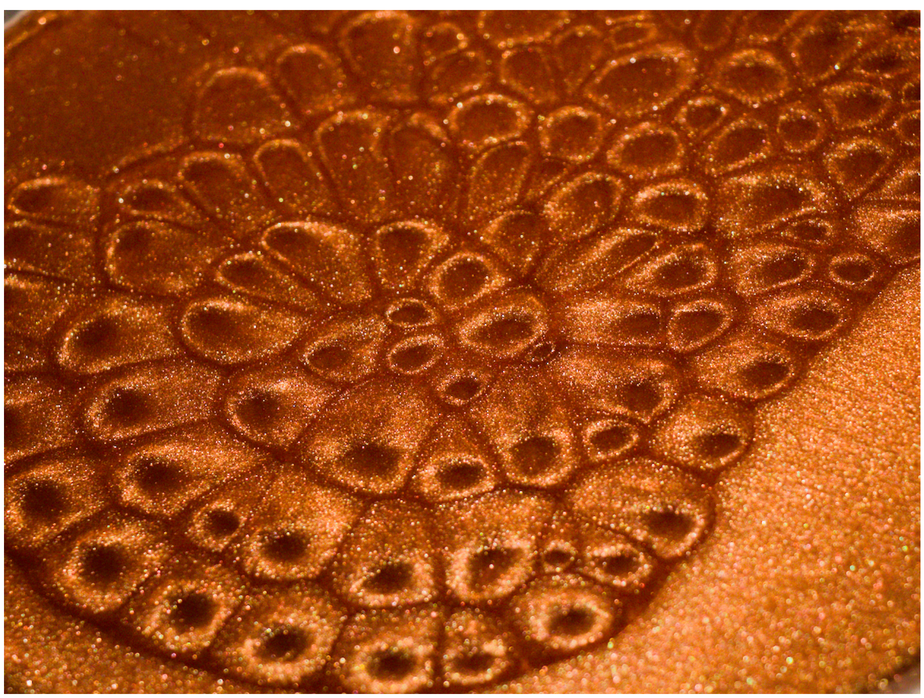

1 Introduction

Convection is a familiar fluid flow to most people, but it is often depicted with abstracted, two-dimensional diagrams. These diagrams fail to capture the reality of fluid forces acting to create intricate patterns of convection cells. Working by myself, I sought to provide a graphic which would not only realistically depict convection, but also demonstrate the multi-dimensional mechanisms at work within convective flows. The following will discuss the experiment, physical theories, and photography used to create the work "Convect!".

2 Apparatus

Figure 1 below depicts the test apparatus. Required materials include a pie tin, vegetable oil, mica powder, lights, oven mitts, induction stove, tripod, and camera.

Figure 1: Test apparatus

The working fluid is made by mixing oil and mica powder together in the pie tin so mica powder is suspended in the oil. Once the fluid is prepared, place the pie tin with the fluid on the stove coil. With the pan in place, this is the ideal time to position the camera and set focus. After focusing, set the stove on the lowest heat setting. Convection will start at the sides of the pan at first, but as the pan begins to more evenly heat, the cells will gradually populate the center of the tin. If convection along the sides of the pan grows too large, turn off the heat or remove the pan from the stove using oven mitts. Let the pan settle for 45-60 seconds and then reapply the heat. This helps to ensure heat is more evenly distributed through the pan.

3 Flow Physics

The work depicts Rayleigh-Bénard convection. This flow phenomena has been studied since Bénard discovered this flow experimentally in 1900. In 1916, Rayleigh offered thermally-driven buoyancy forces as the mechanism for Bénard's observations. Rayleigh's theory posits that fluid density is inversely proportional to its temperature. Buoyancy forces, which are inversely proportional to density, push heated fluid up while cooler fluid sinks to fill the displacement [1].

To start a convection cycle, the thermally-driven buoyancy force within the fluid must overcome viscous forces and heat dissipation. To assess the balance of these forces, Rayleigh theorized a dimensionless number which bears his name. The Rayleigh number, given in equation 1 below, is proportional to nominal density, ρ_0, gravitational acceleration, g, thermal expansion, α, and fluid depth, d, while being inversely proportional to kinematic viscosity, η, and thermal dissipation, D_T [3].

$$Ra = \frac{\rho_0 g \alpha d^3}{\eta D_T} \delta T \tag{1}$$

The critical Rayleigh number is the Rayleigh number at which convection will begin within a fluid. The critical value depends on the top and bottom boundary conditions associated with the flow case. The critical value for stress-free and no-slip conditions are 657.5 and 1708 respectively. In the case of "Convect!", there is a mixed boundary condition with bottom no-slip and top stress-free; this flow case has a critical value of 1101 [2].

4 Visualization and Photography

To visualize the flow, a combination of vegetable oil and copper mica powder were used. The vegetable oil was Safeway signature select brand, while the mica powder was procured from the craft store Michael's. The fluid consists of about 3/4 cup of vegetable oil and 1 tsp of mica powder. The fluid was mixed to suspend the mica powder throughout. After sitting stationary for several minutes, the mica powder will begin to gather at the bottom of the pan. Thus the fluid was stirred continuously for 30-45 seconds before placing on the stove to ensure sufficient suspended powder. Lighting the photograph was the room lighting, above stove lighting, and a desk lamp centered directly above the pie tin.

A Canon EOS 7D Mark II captured the work. This DSLR created an original picture of 5496 x 3670 pixels. This provided sufficient resolution to capture the flow but also allows for cropping. The final work was trimmed down to 3402 x 2536 pixels in order to isolate the flow. With the convection cells centered in the image and boundary cells grazing the edges of the image, the

One of the difficulties of capturing the image was balancing lighting and focus given the constraints of the setup. The photograph was taken at a stovetop with minimal available lighting requiring a large aperture to caputure more light. With such a large aperture and focal length, the depth of field was limited. The final photograph used a 1600 ISO, 5.6 fstop, 1/800 sec exposure, and 71mm focal length. This balance of settings enabled a decent balance of brightness and focus.

5 Conclusion

Overall, this image captures organic and multi-dimensional nature of convective flows. While the focus of the image could be improved to capture more details within the flow, this work successfully depicts fluid motion in a still image. Future works could take a closer examination of the flow in order to see a few cells in much greater detail. Additionally, the

References

[1] *The Simple Rayleigh (1916) Thermal Convection Problem*, pages 55–83. Springer Netherlands, Dordrecht, 2009.

[2] Paul Manneville. *Rayleigh-Bénard Convection: Thirty Years of Experimental, Theoretical, and Modeling Work*, pages 41–65. Springer New York, New York, NY, 2006.

[3] D H Rothman. Fluid dynamics and rayleigh-benard convection, Oct 2022.