Visualizing Free Convection with a Rheoscopic Fluid

MCEN 5151

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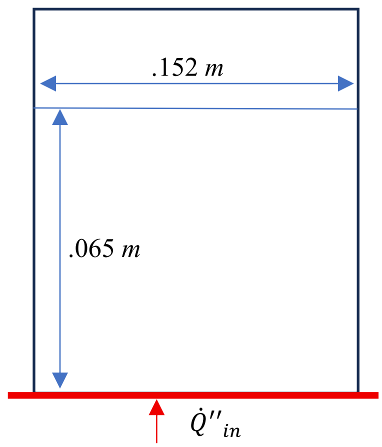
For my first individual project in Flow Visualization, I wanted to explore the free convection in a regular pot of water as it was heated on a stove top. In order to actually see how the convection of the water, edible luster dust (gold tinted) was added to the water, and a clear glass pot was used. Various concentrations of luster dust were tried. Even a small amount of the luster dust was enough to visualize the flow, but more was added to make it abundantly clear. The heat of the stove was carefully controlled, as I intended on capturing convection without boiling.

The flow apparatus was a simple clear glass pot which measured .152 *m* in diameter, and the water height was .065 *m* (*V*=1.18 L). The pot was heated from below with an electric stove element.



In order to understand the forces at play, it would be best to consider an individual particle of the luster dust. To start, the luster dust is composed primarily of mica which has a density of 2.6-3.2 g/cm^3 which means that it is not neutrally buoyant in water. The particle size for edible luster dust is 10-60 μm. Despite the difference in density, the mica powder did remain suspended when heat was applied to the pot. Conversely, when the heat was secured, the mica powder would settle out. There is a significant history of using particles with a density higher than their parent fluid to visualize flow. Some other examples of useful particles are aluminum flakes (2.47 g/cm^3), natural essence of pearl (3 g/cm^3), and guanine platelets, which have the closest density to water (1.62 g/cm^3) (Weidman 1989). The forces on a suspended particle are the buoyant force as well as viscous effects between the particles and the parent fluid. In low viscosity fluids, mica powder would be less advantageous compared to stearic acid crystals, but mica powder does have the advantage of having a much higher melting point, meaning that it performs better for exploring convective flows. (Borrero-Echeverry 2018). A useful dimensionless number for free convection is the Grashof number:

$$Gr_L \equiv \frac{g\beta(T_s - T_\infty)L^3}{v^2}$$

The Grashof number describes the ratio of buoyant forces to viscous forces. The characteristic length can be calculated by taking the ratio of volume to surface area:

$$L = \frac{V}{SA} = \frac{0.00118\, m^3}{(0.0310 + 0.0363)m^2} = 0.0175\, m$$

For water:

$$\beta = 6.52 \times 10^{-4} K^{-1}$$

$$\nu = 3.639 \times 10^{-7} m^2/s$$

$$T_\infty \cong 80°\text{C}$$

$$T_s \cong 200°\text{C}$$

$$Gr_L = \frac{9.81 \frac{m}{s^2}(6.52 \times 10^{-4} K^{-1})(120\, K)(0.0175\, m)^3}{(3.639 \times 10^{-7} m^2/s)^2} = 4.0471 \times 10^7$$

Which means that the buoyant force on a fluid element is much larger than the viscous effects on the element (Bergman 2011).

The particles that were used were edible luster dust. By weight, the ingredients are: 86-90% Potassium Aluminum Silicate, 10-14% Titanium dioxide. The gold color was used. The exact product used can be found here: https://www.amazon.com/dp/B0CTCJZR9H?ref_=ppx_hzsearch_conn_dt_b_fed_asin_title_1. The amount used was approximately .9 cm^3.

For the photographic techniques, I chose a field of view that would clearly show both the convection as well as the fact that it was in a conventional cooking pot as I wanted to show how water mixes while cooking. The lens was a 58mm Helios 44-2, and the aperture was set to the maximum of F16 which gave a shallow field of view. This allowed me to specifically focus on the flow itself while blurring out the background. The camera itself was a Sony α 5100 with a 24.3 MP sensor. The video was captured at 60p 50M and ISO 100. The contrast was adjusted as well as the color curve.

The video reveals the chaotic nature of convection cells in the real world. Rather than being perfectly ordered in an ideal case, they are time dependent and constantly changing. It still shows a relative size to the convection cells (they were on the order of ~5-7cm). I would like to understand more the math associated with calculating the size of these cells. I did certainly fulfill my intent of visualizing convection. I could improve the visuals just slightly. I like the neutral brown background, but I do not like that I have the logo on the pot showing. I could develop this further by simply having more fidelity in temperature measurement as well as finding the heat flux from the stovetop (perhaps by finding the kW output of each burner).

Theodore Bergman, Adrienne Lavine, Frank Incropera, David Dewitt; *Introduction to Heat Transfer Sixth Edition,* Wiley 2011 ISBN 13 978-0470-50196-2

Daniel Borrero-Echeverry, Christopher J. Crowley, Tyler P. Riddick; Rheoscopic fluids in a post-Kalliroscope world. *Physics of Fluids* 1 August 2018; 30 (8): 087103.

Weidman, P.D. (1989). Measurement Techniques in Laboratory Rotating Flows. In: Gad-el-Hak, M. (eds) Advances in Fluid Mechanics Measurements. Lecture Notes in Engineering, vol 45. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-83787-6_10