Team First Report

MCEN 5151 - Fall 2023

Written by: Avery Fails

With contributions from:
Sarah Hartin, Monica Luebke, Izzy Young

Many people across the world enjoy coffee daily, styled to their personal taste preferences. Milk and sugar are the two most popular additions to black coffee, and I personally enjoy a cup of coffee with a splash of oat milk. As someone who lost all of their sense of taste and smell due to COVID-19, the act of drinking and enjoying coffee for me has shifted from the flavor of seasonal drinks to the texture of the drink. I have noticed in my effort to find an enjoyable texture of coffee that many milks and creamers curdle and so I wanted to use this opportunity, our first team assignment, to see the effects different creamers had in a relatively hot cup of coffee –specifically how evenly oat milk dispersed into my favorite coffee.

My team members were also curious about the dispersion of creamers/milks into coffee, so we four had near identical setups. I would like to thank Sarah Hartin and Izzy Young for holding the enclosure for our experimental setup and Monica Luebke for operating her camera that took the video.

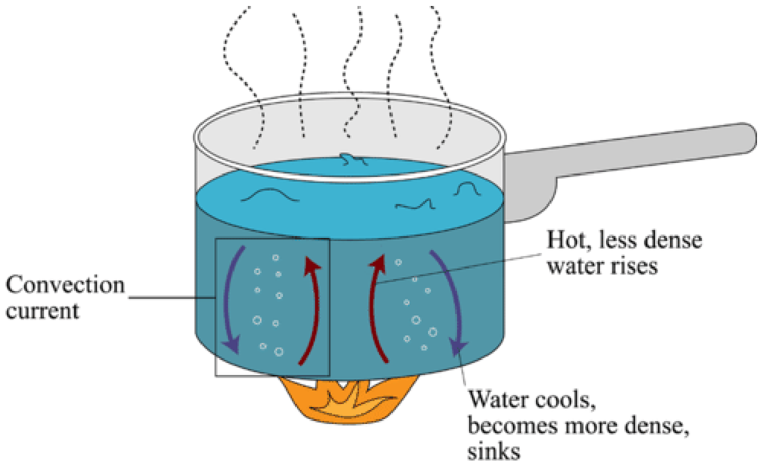

Figure 1: Convective currents as demonstrated by a pot of boiling water [1].

I hypothesized that convective currents would initially be the primary driving factor for dispersion of the milk through the coffee and diffusion would take over after the coffee and milk reached a thermal equilibrium, to lower chemical potential. What was different in my experiment than a typical setup often seen in depictions of convection currents, as seen in Figure 1, is that there was no heat source on the bottom of the glass. However, it can be understood that the bottom of the glass would be warmer than the top, or even the sides, because the glass encasing it and the wood surface it was placed on are poor heat conductors –$1.38\frac{W}{m-k}$ [2] and $0.1\frac{W}{m-k}$ [3] respectively. This temperature difference from the bottom to top is what causes the currents until a thermal equilibrium is reached.

Convective currents in other applications function virtually the same as a simple warm glass of coffee, planetary and stellar bodies are notorious case studies –representing large scale and local relationships with viscosity, Rayleigh number (ratio of buoyancy to thermal diffusivity), and Reynolds number. *The Convection Current Hypothesis* [4], takes into account the factors outlined above, along with other seismic and physical phenomena, to develop harmonic models of the Earth as a function of the depth of the Earth. This is especially relevant because it can be translated into local and global effects for the velocity, density, and compressibility profile throughout the Earth's mantle. My experiment is on a much smaller scale, with significantly less factors that affect heating, but further dissection of this experiment could go on to create theoretical models for simple heating and cooling applications.

The initial impact of the oat milk disturbs the top layer, Figure 2, of the surface before being dispersed by the current below and, as such, the Reynolds number can be approximated separately to understand the full change in flow. The milk stream from the carton is most certainly laminar and is backed up by the reasonable assumptions that: height = 12" (0.308m), $t_{pour} = 4s$, $\mu = 5.0x10^{-6}\frac{m^2}{s}$[1]. The velocity is then found to be

$$V = \frac{0.308m}{4s} = 0.077\frac{m}{s},$$

and the subsequent Reynolds Number is then

$$Re = \frac{(0.077\frac{m}{s})(0.38m)}{5.0x10^{-6}\frac{m^2}{s}} = 4743,$$

which is below the 5,000 upper-end threshold [5] to transition from laminar to turbulent flow and confirms that the pour was transitional.

Figure 2: Disturbance wave on surface of coffee from initial impact of the oat milk.

The convective flow from the heat bringing the colder milk to the top shows clouds of varying density, Figure 3, throughout the glass and leads me to believe that it is then turbulent flow. Kinematic viscosity changes as the oat milk diffuses into the water of the coffee and would

---

[1] Literature on viscosity of oat milk is studied in unsuitable units but is generally accepted to be about 5x as viscous as water. Kinematic viscosity of water is approximately 1.0x10^-6 m^2/s.

likely be closer to water due to the ratio of water to oat milk by volume or mass. Flow speed is also reduced, and as measured by time from the video, $t_{pour} = 2s$ and $h_{coffee} = 5'' \, (0.127m)$ giving $V = 0.0635\frac{m}{s}$. The new Reynolds Number is then calculated as

$$Re = \frac{(0.0635\frac{m}{s})(0.127m)}{1.0x10^{-6}\frac{m^2}{s}} = 8064,$$

and is beyond the transitional threshold of ~5000 which makes this turbulent flow –as expected.

Figure 3: Dispersion of oat milk unevenly by convective currents.

This experimental setup is familiar to me, using contrasting fluids to illuminate the flow is a simple and effective way to demonstrate clear streamlines. The coffee is the Starbucks Tribute Blend that was brewed with a filter paper process (removes more oil than other processes) and was stored in a well insulated thermos until it was pour time. The coffee was brewed to meet Boulder's $93^{o}C$ boiling temperature and by the time of the experiment it was still above $80^{o}C$. This coffee, brewed in this method, was made with a brew ratio of 15, giving it a low Total Dissolved Solids percentage (1%-1.2%) to decrease the internal shear.

Spoiled oat milk would have skewed the results (i.e. curdle) so it was refrigerated until an hour before the pour, making it slightly cooler than room temperature by the time of pout.

Figure 4: Experimental setup with Izzy Young (left) and Sarah Hartin (right).

Reflections on the glass were the biggest consideration for lighting the experiment and it came with some pros and cons as light sources needed to be obscured directly to not be seen. We used recycled research posters, Figure 4, to create a background with no sharp edges and to reflect as much white light as possible. The glossy side of the poster was faced away from the glass to not create any focus points from the light, and also partially to not have other people's work reflected on the glass.

To truly appreciate the rate at which the convective currents move the milk, I decided to film the process and leave it as a video instead of stills at certain time intervals. There was also no need to include a lot of background in the video, as it had no visual importance, so the camera was focused to center the cup in frame and have small margins of background surrounding it. The video was shot on a Nikon D5500 with a Nikon AF-P Nikkor (18mm-55mm) lens with the following specs: 55mm focal length, f/5.6, ISO 200, and 59.94 frames/second. These settings were set automatically while in video mode on the camera and worked well given the setup,, so they were not adjusted further. Post-process, I decided to slow down the video to 0.1x speed, reduced frame rate to 30 frames/s, and I believe that it accentuates the direction of flow the best.

The camera was set up on a tripod that was about 4 feet tall, and the lens was about 2.5 feet away from the glass. With the focal length, this distance from the camera put the glass perfectly in frame.

I believe that the video shows the real-time effect of convective currents and that the oat milk is simply there to illuminate the process already in the hot coffee. The oat milk is almost like a dye in water and clearly shows the path (or streamlines) in the coffee; this is the most blatant way to show this phenomena. However, I still take issue with the setup and the fact that there were still focused reflections on the glass. The edges of the glass had white reflections that obscure the clouds of oat milk that are initially created. The tripod also created a glaring reflection on the middle of the glass that I particularly dislike. I am unfamiliar with photographing highly reflective materials like glass and find it difficult to balance illumination and clarity and need to investigate photographic techniques for this. I would particularly like to work on reducing reflections in general because it is my main limiting factor in accomplishing more challenging experiments. Despite the obvious issues, I feel that I have fulfilled the artistic and physical intent that I set out to capture. As mentioned above, the next step for an experiment like this would be to develop a working model that captures the flow of heat, at least rudimentary, for small-scale applications. It would be interesting to also work on scaling the model and find the limitations of it at larger scales.

References:

[1] Wilson, Zachary. "Convection (Read) | Physics | CK-12 Foundation." *cK-12*, www.ck12.org/physics/convection/lesson/Convection-MS-PS/. Accessed 7 Oct. 2023.

[2] "Microsoft Word - TIE-31 Mechanical and Thermal Properties of Glass." Technical Information - Advanced Optics, July 2004.

[3] Pásztory, Z., Fehér, S. & Börcsök, Z. The effect of heat treatment on thermal conductivity of paulownia wood. *Eur. J. Wood Prod.* **78**, 205–207 (2020). https://doi.org/10.1007/s00107-019-01470-3

[4] L, Knopoff. "The Convection Current Hypothesis." *AGU*, 1964, agupubs-onlinelibrary-wiley-com.colorado.idm.oclc.org/action/showCitFormats?doi=10.1029%2FRG002i001p00089&mobileUi=0.

[5] Britannica, The Editors of Encyclopaedia. "Reynolds number". Encyclopedia Britannica, 11 Aug. 2023, https://www.britannica.com/science/Reynolds-number. Accessed 6 October 2023.