“Food for Thought” explores the relationship between food/drink and chemical engineering processes/concepts.

TEA TIME

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The realm of food and drink is simply teeming with mass-transfer applications, particularly when it comes to solid-liquid extraction. From the barrel-aging of your favorite vinegar or spirit to the steaming cuppa on your desk, solid-liquid extraction brings the flavor, among a host of other things. And there is no example more venerable yet accessible than the OG of hot beverages, tea.

First, let’s define the food we’re discussing. By “tea,” I mean a whole range of beverages with a diversity of ingredients. The US Code of Federal Regulations has no standard-of-identity for products that use the word “tea” as part of their names. Thus, pretty much any dried plant product can be sold as “herbal tea.” Compositions that include the leaves of the tea plant, *Camellia sinensis* and its variants, are sold without the “herbal” modifier in the name. A notable exception to this naming convention is “beef tea” found in older cookbooks such as the *American Woman’s Cook Book* from 1944.*[1] This is a menu item suggested for someone who is sick and, but for the fact you’re using ground beef rather than dried plant matter, reads very much like any other recipe for tea. Ah yes, nothing better for your cold than drinking the run-off liquids from damp hamburger!

Tea from *Camellia sinensis* is native to Southern China[2] and was an early intercontinental sensation and part of trade for hundreds of years. But just because this gave us the name for the beverage category (drinks you make by steeping something) as well as one particular beverage in that category, doesn’t mean it’s the only or even the original game in town. South America’s yerba mate became known to Europeans in the 1500s and was consumed by the original inhabitants of what is now Paraguay for ages before that.[3] Hawaiians have made a tea from mamaki for nearly as long.[4] Even in China, where tea made from actual tea plants originates, there’s evidence that folks were consuming herbal tea before they were consuming tea tea, a practice that was firmly in place at least 2000 years ago and possibly earlier.[5] Thus, the concept of making some kind of tea-like drink might just be a more universal human experience than even bread — a great way to bridge cultural gaps and reach out to our students.

Like just about every food process, the high-level recipe for tea is simple. Omitting beef tea for the moment, first the flavorful parts of a plant are harvested and processed, usually by drying and sometimes with additional steps such as fermentation to enhance flavor and other properties. Then when it’s time for an afternoon pick-me-up, we drop dried plant matter into hot water, and the flavorful chemicals begin to partition between the now-not-as-dry plant matter and the water in the cup. Also, as with just about every food process, the detailed version is wickedly complex. Even a one-ingredient black tea has thirty chemicals that have been identified as “important to flavor,”[6] not to mention the other chemical species that are also present. How many of them end up in the beverage and in what quantity depends on how much we start with, how soluble a given species is in water at this temperature, and how much time is allotted. This works out to be surprisingly tricky, given that a tea drinker typically only controls two variables — the water-to-tea ratio and how long they’re willing to wait to start drinking. One could argue that the drinker also exerts some level of control over the rate of cooling through their

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* How is “beef tea” distinct from “beef broth”? It’s not a renaming with time, as there are recipes for both in this 1944 cookbook. Broth is derived from simmering bones (and perhaps a little meat), while the tea is steeped meat in water for a day then heated gently at the end.

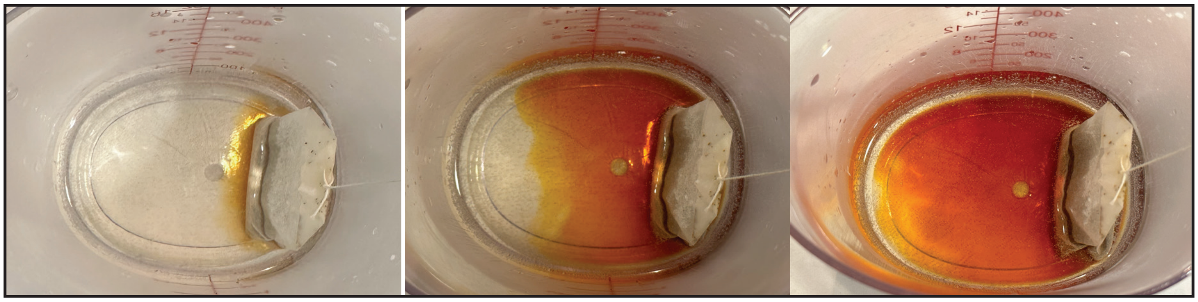

Figure 1. *Tea front captured with cell phone camera. Total elapsed time ~1.5 minutes with boiling water.*

choice of tea cup and room conditions, but that's a bit of a stretch given that the room condition is often set by someone else or Mother Nature, and the choice of tea cup is generally "the clean (or cleanest)" one available.

Even though teas are chemically complex, we can still do some informative modeling at the undergraduate level if we accept color change as a proxy for the extent of extraction. As noted above, the chemical mixture is complex, and I don't want to imply that I think the perfect cup of tea is best modeled by its color. But the tannins that give a classic cup of tea its brown color are easy to spot with a readily accessible instrument (eyeballs, cell phone cameras) and are complex enough (tannin molecular masses range from the hundreds to the tens of thousands) to move at a rate more characteristic of molecules like caffeine rather than smaller flavor molecules or water. For a qualitative interest-building experiment, a flat-bottomed clear two-cup measuring cup (especially one with an oval rather than circular footprint) makes a terrific vessel for direct observation of diffusion. Set the measuring cup on white paper for contrast, pour in 100mL of boiling water, and carefully lean a teabag against one of the skinny ends. In less than a minute, you'll get a clearly visible "tea" front extending across the fluid, further darkening as you wait longer (see Figure 1). Want to have the students probe the impact of factors such as temperature and particle size? Make some different temperatures of water available and encourage students to smash the teabag further (without breaking it) and re-run the experiment. With consistent lighting and cell phone cameras, this experiment can easily become semi-quantitative, as you capture and compare images of tea with the same elapsed time but different temperature or particle size conditions.

I've tried running this in a slightly more quantitative manner with upper-level students in an advanced transport course. If we start with Fick's Law

$$\frac{\partial c}{\partial t} = -D\frac{\partial^2 c}{\partial x^2}$$

then approximate our system as one-dimensional diffusion of "tea" with initial concentration of zero everywhere but the tea bag, which has concentration C_0** and a diffusivity of D, we can approximate the concentration with:

$$c(x,t) = \frac{C_0}{\sqrt{2\pi Dt}}e^{\frac{x^2}{4Dt}}$$

We can see how well our system conforms to this model and even estimate the diffusivity of tannins live in class. Using my phone***, I tried tracking absorbance at a static point. I say "static," but I was holding my phone, so take that with a grain of salt. Nevertheless, over the span of two minutes, I was able to capture a plot of absorbance versus time that is a pretty good match for what you'd expect for one-dimensional diffusion through a static medium. The error bars are considerable, but the distinction between boiling water and room temperature water is clearly distinguishable. And, after we've captured our measurements, we can pass around biscuits and invite the class to drink their experimental system!

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** There was a bit of a debate in class as to whether the tea bag should be treated as an infinite constant-level source or as a Dirac delta function pulse-input of finite concentration. Much thanks to colleague Jim Maneval who took on the task of re-deriving the fixed-amount version shown here!

*** How to use a cell phone to capture absorbance? First, the data will be best if the camera can be truly static and consistently illuminated, so a tripod and a light are helpful. There are a couple of ways to turn the qualitative pictures into data. In one, the person operating the phone either takes video or takes a still image every 10 seconds. Then bring still frames / images into an app that allows color valuation and grab the "R" of the RGB (red-green-blue) color value for the same spot in each image at every 10 second interval. Another option is to do the data-capture within an app designed to sample color data continuously. The free app FizziQ™ for iOS is a little buggy but time-logs inputs from any of an iPhone®'s sensors and outputs them as a CSV file that can be brought directly into a spreadsheet or MATLAB® for analysis.