food for thought

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

HOW DO WE CHEDDAR CHEESE?

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Greetings, colleagues — Margot here, in the italics. Let me introduce Tiffany Jones, a 2024 BS graduate in Chemical Engineering at Bucknell University who spent her senior year with me developing some cheesy ChemE problems that we'd like to share with you now.

The food category "cheese" shares several things in common with the categories of "bread," "beer," and "porridge." All of the above span continents and cultures as a common foodstuff with important regional variations. And all of the above have a deceptively simple base recipe that then, incredibly, with seemingly tiny changes, diversifies into a vast array of outcomes. For cheese, you start with milk. Milk, for our purposes here, may be best thought of as a colloidal suspension of protein and fat in water. Fundamentally, cheesemaking is breaking the colloidal emulsion so that the majority of protein and fat (if present) ends up in the coalesced solids (curds) and the majority-water portion (whey) is mostly filtered away. The curds are then compacted in some fashion and… tah dah! It's cheese! The "how" of breaking the emulsion, compaction, addition of minor ingredients, choice of milk, as well as post-processing steps such as the introduction of microbial cultures and aging, are what make the difference between everything from asiago to zimbro cheeses.

Cheesemaking is not as intimidating as it may sound and can be a tactile and delicious way to bring some fundamental mass-and-energy-balances (MEB) concepts to life. The multiple, time-intensive steps to make cheddar aren't amenable to the classroom. However, simple experiments, such as coagulating milk to make paneer (a fresh cheese that is part of Indian cuisine)[1] can illustrate the fundamental principles on a smaller scale. (*See reference [1] for an easy-to-follow paneer recipe that works on a 50-minute class timescale.*) This activity is an excellent one to illustrate the ChemE MEB concept of product yield. It can be quite surprising for first-time cheesemakers to see just how little of the original mass of milk ends up in the finished product. Using a mass balance on my experimental paneer-making, I find:

$$Yield = \frac{Final\ Mass\ of\ Drained\ Paneer}{Original\ Mass\ of\ Ingredients} = \frac{Final\ Mass\ of\ Drained\ Paneer}{(Mass\ Milk + Mass\ Lemon\ Juice)}$$

$$Yield = \frac{488g}{(1469g + 43.1g)} = 0.32\ or\ 32\%\ yield\ paneer$$

We can calculate a theoretical maximum yield as well using cow milk's chemical composition as shared on the nutrition label. For whole milk, about 12-13% of the mass isn't water. The specifications for commercial paneer require that the cheese be no more than 70%.[2] If our paneer captures <u>all</u> of the non-water elements of the milk and enough water to be 70% water by mass, I find a maximum yield of 21.5% using the above equation — a surprising result that can start a class discussion on quality assurance!

Note an interesting challenge here is that your cheese may be out of spec in two different directions — one, the students may not be capturing all of the dissolved solids from the original milk, resulting in low product yield. But they also may be retaining more than the allowable fraction of water,

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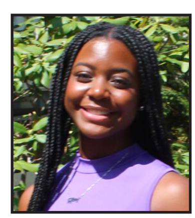
Tiffany Jones *is a 2024 BS graduate in Chemical Engineering at Bucknell University. In her first week on campus, she started talking with Prof. Vigeant about working on food-related research. Tiffany's excited to combine her passion for food with her engineering career as she starts work at Kraft Heintz in Global Manufacturing.*



artificially boosting the yield. This is an excellent opportunity for a class discussion about why specifications such as "no more than 70% water by mass" exist! The least expensive approach to determining retained water in the paneer along with retained solids in the whey is to weigh everything and then dry it all out in a low oven overnight and weigh it all again.

You can build on this paneer-making experiment and calculation as a process design or design of experiments exercise, varying acid concentration, temperature, pressure exerted in the straining step, and/or salt addition and noting the impact on yield. It's also instructive to calculate percent moisture or use this small experiment as a basis for scale-up calculations.

So that's paneer, one of the world's most straightforward cheeses. How might we go about making cheddar? Originating from the village of Cheddar in England, cheddar cheese has not only captured my palate by also my curiosity! Despite being lactose intolerant (along with 75% of the world), my love for cheese remains strong.[3] Join me as I unravel the science and art behind making cheddar cheese, a journey from milk to masterpiece that continues to inspire food enthusiasts and scientists alike.

Cheddar cheese's journey from milk to maturity is not only an art form but also a science that has been perfected over centuries. This process, known as cheddaring, distinguishes it from other cheeses. It involves a series of steps that affect its texture and flavor, creating the difference between a mild cheddar and one that bites back with a sharp tang. The process of creating cheddar cheese begins with the selection of milk, which is the canvas for cheese. The type of milk used significantly influences the final product's flavor and texture.[4] Typically, cheddar cheese is made from cow's milk, which is preferred for its accessibility and balanced composition of fat and protein, which are critical for achieving the desired texture and flavor profile of the cheese.

The milk is first scalded, and then microbial cultures are added to guide the milk's transformation. The culture is responsible for breaking down lactose into lactic acid, which sets the stage for the milk to coagulate into solid curds and watery whey.[5] (*This role was played by lemon juice in the paneer recipe*.) Once the culture has had sufficient time to break down lactose and generate acids, rennet is added to finally break the emulsion and form curds that rise to the top of the whey. *Rennet is a term for a group of enzymes, either isolated from young cow stomachs or cultivated animal-free, that partially digests milk proteins and fats and fully curdles the milk.*

Cheddaring is what truly sets this cheese apart. After the curd is formed, it is cut to allow the whey to escape, and then stacked and flipped. This is a unique process in which blocks of curds are piled on top of each other, which helps to remove moisture by increasing pressure.[6] This labor-intensive process is the actual cheddaring and allows for further acid development, which is pivotal in achieving cheddar's flavor and texture. After the whey is drained, the curds are ground into smaller pieces and then molded, pressed, and aged to give the final cheese. Depending on how long the cheese is aged, the texture can range from creamy and soft to crumbly with a more pronounced flavor. One metric ton of milk yields as much as 140 kg of cheddar, equivalent to a yield of 14%, much lower than that for paneer given the lower water content due to greater pressing and aging.[6]

If you discuss this in class after the paneer experiment, your students may be curious to know the reactions that occur in the aging of cheddar. This is an excellent example about how the processes that get us food tend to be much less straightforward chemically than the processes that get us, say, styrene monomer. There are 41 compounds in just the "nutty" scent of cheddar,[7] so the reaction pathways require not only their own article, but their own full book.

It is both the process of cheddaring and that of aging that make cheddar a poor cheese choice for in-class activities. You need to work with sufficient mass such that the stacking actually impacts the structure, which is not something that happens if you start with the amount of milk that fits conveniently on a side-arm classroom desk!

As we wrap up our exploration of cheddaring, we not only appreciate its complexity but also recognize its significance in the broader context of food science and chemical engineering. The process from milk to a mature cheddar is a great example of the intersection between tradition and science. And so, our scientific journey through the world of cheddar comes to an end, but the invitation to delve deeper into the realms of food science and chemical engineering remains, promising endless possibilities for discovery and innovation!

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