Get Wet Report: Melting Cheddar

Kate French

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Introduction:

I was inspired to capture this image while I was cooking breakfast. I was intrigued by the differences in bubble patterns between my fried eggs and the crisped-up melted cheese I was topping them with. I was also fascinated watching the cheese's development close-up: it went through several stages, from the initial cold, solid shredded bits to a soft yellow puddle with large bubbles, to an increasingly orange raft of solid, crispy cheese with separate fat sizzling rapidly, creating crater shapes in the solid disc. I was interested in the entire process, but, as I attempted to document it, I realized that the later stages, after the fat and solids had separated and the cheese had begun to crisp up, were more visually stimulating than the initial fluid melting phases, as the initial melting was too uniform of a yellow to find engaging contrast and adequately focus on. Thus, I decided to focus my inquiry on the middle-to-late stages of the cheese cooking: between the fat separating out and the fat and water fully evaporating to leave a solid, crispy raft. My goal was to capture the variety of bubble sizes and a sense of the rapid-fire sizzling as the cheese cooked.

Fluid Mechanics:

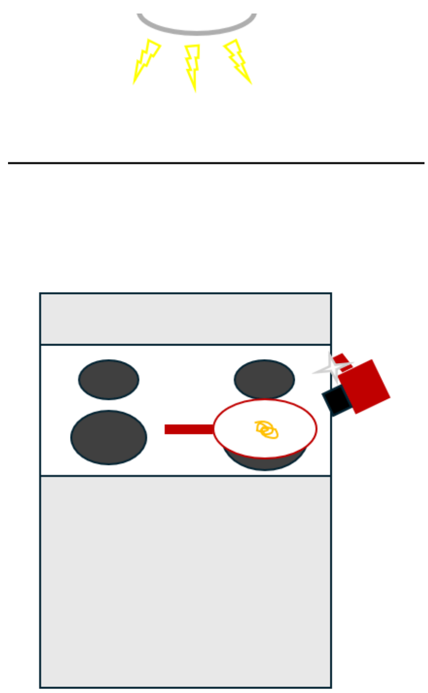

Figure 1. *Set-Up.*

As shown in Figure 1, the flow set-up was a pan on a stove with cheese sprinkled in. The three materials required to complete the scientific portion of the procedure were a pan (10.5 in diameter skillet (T-Fal 26FP2)), cheddar cheese (Kroger brand sharp cheddar shredded cheese taken from fridge prior to the photoshoot), and an induction burner (the larger front burner of a Hotpoint induction stove).

The basic flow being observed was cheese melting in the skillet. The raft of cheese was approximately 8x8 cm in the end, and it had bubbles ranging from approximately one millimeter to one centimeter in diameter. Earlier in the melting process, the bubbles were larger, and they were bubbles in the fabric of the cheese itself, whereas the mid-to-late melting process pictured had smaller bubbles in the fat that had formerly been integrated into the cheese.

Cheese has several sub-components, which come in different proportions, depending on the type of cheese. Casein proteins form a sponge-like structure with fat and water embedded in the holes in the sponge. Cheeses with higher fat and water contents, like Havarti and mozzarella, tend to melt better than drier cheeses, like parmesan.[1] Sharp cheddar is in the middle; its aging process removes some of its moisture content, but it still has a decent moisture content, leading it to "break:" leak greasy melted fat after a certain amount of heating[2]. The fat in cheese begins to soften and melt at around 90 degrees Fahrenheit. Approximately 40-60 degrees above that, the casein protein molecules begin to break apart and disperse throughout the fat and water. If the cheese is melted slowly, the protein will stay evenly dispersed; if it is heated too quickly, the cheese will break, causing the protein to seize up and become firm, squeezing out and separating from the moisture.[3] I heated my cheese swiftly enough to make this separation occur.

The phases of cheese melting are: (1) cheese shreds are unmelted; (2) melting and flowing; and (3) blistering. During the blistering phase, steam pockets form under the cheese, and the fat begins to break out of the cheese. In cheddar, Colby, and edam cheese, after a certain amount of heating, the elasticity of the cheese's casein protein is too low to withstand the steam forces, causing the fat to fully separate from the casein and create steam bubbles independent of the solid casein raft.[4] The steam eventually evaporates, followed by the fat, leaving just the solid casein behind.

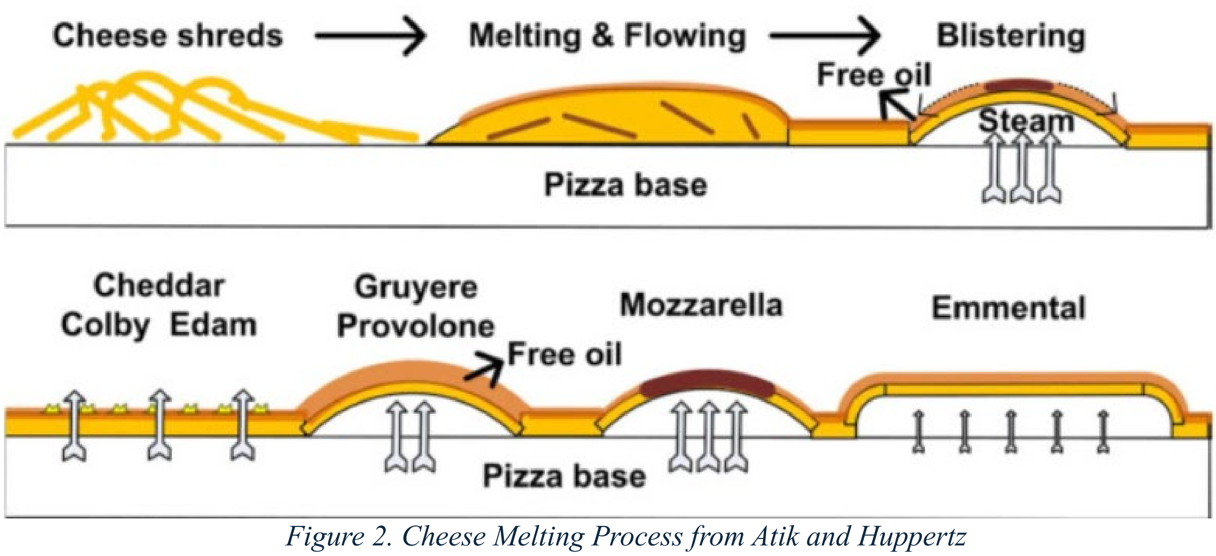

Figure 2. Cheese Melting Process from Atik and Huppertz

It is challenging to identify a non-dimensional number that would be applicable to this situation. Reynold's number is not particularly relevant, as there isn't a "flow" so much as bubbles forming and popping.

For a bubble to exist in the fat, the forces must be balanced, however briefly, between the surface tension and the pressure from the steam inside of the bubble. The governing equation is:

$$p_s = \frac{2\sigma}{R}$$

where p_s is the difference between the internal pressure and the ambient pressure, σ is the surface tension, and R is the radius of the bubble. [5]

The different bubbles had different radii, but the average was, say, 4 mm. The surface tension of heated cheddar is, according to one source, 1 dyne/cm.[6] This makes the pressure difference $5*10^{-5}$ Pa.

Photographic Procedure:

As described in the section above, the set-up involved cheese, an induction burner, and a skillet. The induction burner was set at 3.5: attempts were made at 4 and 5, but a lower setting closer to 3.5 caused the cheese to cook more slowly, making it easier to capture the dynamics of the entire process. Environmental conditions included a relatively normal room temperature, perhaps as high as 75 degrees Fahrenheit, but unknown, due to a lack of air conditioning in the facilities utilized.

The cheese started out from a near-refrigerator temperature, which provided time between the burner being activated and the cheese fully melting to allow for final tweaks of the set-up and camera settings. The pan was also allowed to cool down between different cheese raft attempts for the same reasons. The cheese was centered in the pan and the pan was centered over the burner to prevent irregular melting or circulation patterns. A solid pinch of the cheese was sprinkled evenly and not very densely over a 6 cm by 6 cm area in the pan which then expanded to approximately 8 cm by 9 cm.

The lighting used was a combination of kitchen overhead lighting (5000K, 1365 lumens[7]) and camera flash. The flash added more life and helped capture a snapshot of a particular set of bubbles. The camera was positioned to the side above the pan such that it did not cast any shadows from the overhead lighting.

The original photo was taken with a Nikon COOLPIX P500, a type of compact, digital camera. The focal length was 14 mm, the lens was held approximately 10 inches away from the cheese, and the original picture dimensions were 4000 x 3000 pixels. The f-stop was f/5, the exposure time was 1/10 sec, the ISO was 160, and the max aperture was 3.5. These settings were chosen via experimentation prior to the official photo shoot beginning. The temporal resolution is thus .1 sec. The goal was to get the cheese to be well lit and adequately exposed without being washed out by too long of an exposure or too wide of an aperture; many test shots were taken to ensure that the correct combination was chosen, particularly after I decided to use flash.

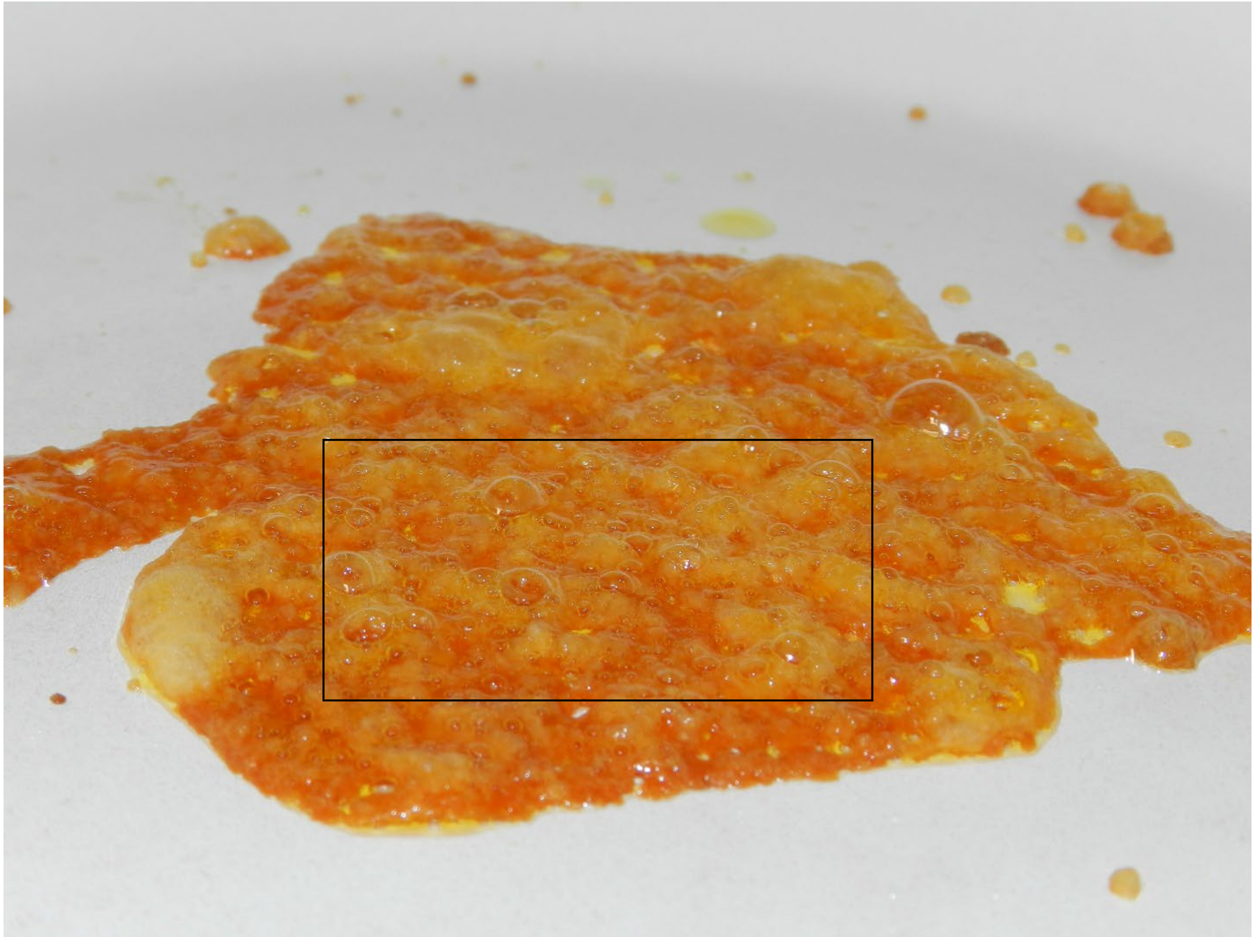

***Figure 3**. Unedited image, with a box around final picture to show the subfield present in the final photo.*

I edited the original image in Darktable. I cropped it to final dimensions of 1748 x 966 pixels. This leaves the final field of view being approximately 3.5 cm by 1.94 cm. As shown in Figure 2, I then adjusted the RGB curve into an s-curve, preserving luminance for the colors. I experimented with several different possible s-curves and intensities of editing. I wanted to enhance the contrast to make the bubbles as visible and eye-catching as possible, while still preserving some of the essential cheesy colors. It was possible to create further contrast, but the colors became browner, which, I felt, reduced the aesthetic appeal and reduced the thematic clarity of the original phenomenon being observed.

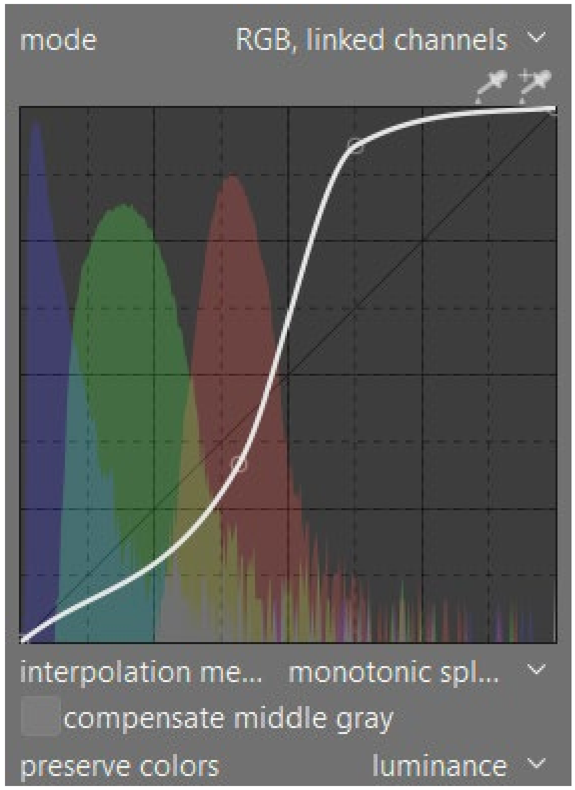

Figure 4. *RGB Curve settings in Darktable used to achieve final photo.*

Conclusion:

Overall, I am pleased with my image. There were, of course, shortcomings and other things I was interested in capturing, but, for a first attempt at flow visualization, I feel that I was quite successful.

I was disappointed that I was forced to crop so much of the image instead of being able to get the zoom and focus to line up as I desired for an original image where the cheese would take up a larger portion of the field of view. Additionally, I was interested in the changes between stages of the melting process, but I was unable to get a satisfactorily high-resolution, high-contrast image for the earlier stages, as the blister bubbles were too uniformly yellow and formed smooth, rolling hills that were challenging to capture satisfactorily. I would be interested in the future in taking a video or time-lapse that captures the entire melting and breaking process. However, overall, I am pleased with my end result. I feel that it did, overall, capture the physics I intended to show in the mid-to-late stages of cooking. I would be curious to compare the results and timeline of this cheddar melting to the timelines and results of other types of cheese, as well as corroborate the internet's suggestions that melting cheese slowly prevents the casein from solidifying in the same way, leaving the cheese gooey for long periods of time.

References

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