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Get Wet: Grilled Cheese Pull

MCEN 5151: Flow Visualization

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Photo Intent

Born and raised in Wisconsin, there was no way I couldn't bring a little bit of my roots to Colorado for this first flow visualization assignment. Grilled cheeses were a staple for my childhood diet growing up in the Midwest. This project was nostalgic for me and also so fun because it was pure authorization to "play" with my food, something that is generally frowned upon. The intent of this photo was to strictly display the perfect grilled cheese pull. Prior to shooting this photo, I knew I wanted to edit the photo so the sandwich was black and white with the cheese in color so the eyes were drawn immediately to the cheese. I wanted the cheese to show different characteristics throughout the pull, some more stringy than others.

Image Description

Figure (1), below, is the raw unedited photo taken of a grilled cheese pull. The image was taken in my kitchen with overhead lighting. The blue background is a towel placed over a wood grain cutting board to reduce the grainy effect of the board and so to not distract from the sandwich. A tripod positioned the camera to achieve the overhead shot of the sandwich. The photo is a snap shot of the overall fluid phenomena. The original size of the photo is 6016 x 4016 pixels for a total RAW file size of 27.8 MB.

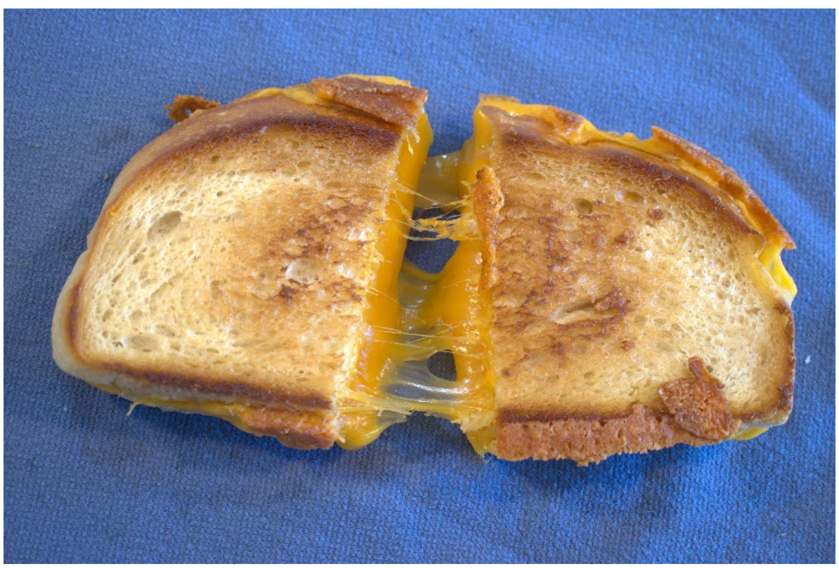

Figure 1: Original Photo Converted RAW to PNG

Table (1) below depicts the characteristics of the camera used to capture the image in Figure (1). I needed the small aperture in order to assist with getting enough light to reach the lens. The aperture was countered with the shutter speed to achieve the proper focus and lighting of the image. A remote shutter was necessary to avoid disturbances to the camera during the opening of the shutter and thus avoiding the option for the sandwich to become out of focus.

Table 1: Image Characteristics

Camera	Nikon D5500
Lens	Nikkor 18-55 mm 1:3.5-5.6G DX VR
Focal Length	38 mm
Aperture	f/4.8
Shutter Speed	1/13 sec
ISO	200
Flash	None
Other	Used remote shutter, UV filter

Figure 2: Final Edited PNG Photo

Photo Editing Process

Darktable, an editing software program, edited the photo from Figure (1) to get the resulting image seen in Figure (2). This image was cropped and compressed to 2268 x 2624 pixels for a file size of 9.4 MB. I chose this cropping selection to bring out the flow characteristics and prevent unnecessary distraction from the rest of the sandwich. I first brought the image to a black and white color scheme using the "color zone" feature and set the image to "Black & White" Film. From there I adjusted the saturation settings; blue saturation to zero and the yellow saturation on high to bring out the color of the cheese and make the color "pop". Lastly, I lowered the lightness of the blue coloring in the image to amplify the black and white contrast. By saturating the cheese coloring, the eye is drawn to the fluid flow phenomena.

Steps to a Perfect Grilled Cheese

1. Purchase a milder based cheese; this image used a medium cheddar.
2. Purchase a thick solid bread; this image used sourdough.
3. Cut your slices of cheese to your preferred quantity.

4. Line the insides of the bread slices with the cheese slices.
5. Stack your sandwich.
6. On a flat griddle, or frying pan, melt butter directly on the pan; once melting is completed, place the sandwich on the melted butter.
7. Cover the sandwich with a lid or another means to prevent the transfer of heat via convection into the surrounding atmosphere; it also helps cook the grilled cheese more evenly.
8. Once the cheese closest to the heat source begins to melt and the bottom bread layer becomes toasted, remove from the heat source momentarily in order to melt new butter on the pan; flip the sandwich and place the uncooked side of the sandwich on the now melted butter.
9. Once both sides of the sandwich are toasted to preference, remove from heat, let cool two to three minutes, then slice sandwich in half.
   IMPORTANT
10. Peel the sandwich apart to reveal the inside melted cheese.
11. Place a new slice of cheese over the cut portion of the sandwich, reassemble the sandwich.
12. Place the sandwich back on the heat source to melt that new layer of cheese.
13. Upon melted cheese, remove from heat source one last time.
14. Let sandwich cool for approximately 2 minutes.
15. Pull the two halves of the sandwich apart and viola you have just created the perfect grilled cheese pull!

Melting Cheese Science

Proteins, casein and whey; carbohydrates, lactose or milk sugar; minerals, calcium; and milk fat; make up the composition of cheese. For the sake of melting cheese, the primary focus lies with the interaction between casein proteins and calcium. The acidity of the cheese determines the number of calcium bridges that bind to the casein proteins. Throughout the aging process, the cheese becomes acidic, as in the pH levels drop. This drop in pH creates a reduction in the number of calcium bridges that are binding to the proteins as a cause of the calcium solubilizing and reacting with the water instead. Reducing the number of calcium bridges allows the proteins to become more soluble and move more freely; thus, as heat is applied, the cheese can “flow”. The fine range for pH levels within cheese is between 5.3 and 5.5. A medium cheddar cheese sits with this pH range and therefore provides a nice melt for the sake of this experiment. Other preferred cheeses to melt include gruyere, fontina, swiss, and mozzarella; however, those cheese are all white based and do not have the “orange” dye like medium cheddar does. In order to get the classic depiction of a grilled cheese sandwich, I selected the medium cheddar. (The Science of a Grilled Cheese Sandwich from The Kitchen as Laboratory, 2012)

Cheese Pull Modeling

Melted cheese acts as a non-Newtonian fluid. Non-Newtonian fluids are typically not researched as much during academic fluid dynamics so the science behind them is less studied to the average individual. A non-Newtonian fluid does not follow Newton’s law of viscosity; the viscosity of Non-Newtonian materials varies as force is applied and creates a shift in the material to more fluid-like properties or solid-like properties. For Non-Newtonian fluids, stress and strain do not form a linear relationship. (Chhabra, 2010) “Models containing more exponential components and residual terms have been used to describe the stress relaxation behavior of Cheddar cheese” (Hajikarimi & Nejad, 2021). Melted cheese acts as a viscoelastic material; more specifically, it acts as a Maxwell material during its more liquid phase. As heat is applied during the grilling of the sandwich, the cheese becomes less viscous; upon cooling the cheese becomes more viscous as it begins to return to a more solid like state. A study conducted on the stress relaxation of four different cheddar cheeses and two different moisture contents indicated that a generalized maxwell model closely reflects the viscoelastic characteristics of cheddar cheese. (Venugopal & Muthukumarappan, 2006) The same study proved that an increase in temperature yielded a decrease in the elastic properties of the cheese due to the melting of the fat molecules, which was to be expected during the hypothesis phase of this experiment. (Venugopal & Muthukumarappan, 2006)

Maxwell Model

The Maxwell Model below demonstrates the spring and damper in series, Figure (3).

Figure 3: Maxwell Model in Series (Hajikarimi & Nejad, 2021)

This model applies to a Non-Newtonian material during the more liquid phase. With this model, under constant stress, the strain consists of two components, elastic and viscous. (Viscoelasticity , n.d.) The material acts elastic, modeling the spring in Figure (3) when the stress is applied and then when the stress is removed, the spring attempts to return to its original position. However, unable to store the energy forever, the spring eventually releases its stored energy and it decays to zero. This feature supports the use of the Maxwell model for elastic behavior only, not viscosity. (Hajikarimi & Nejad, 2021) This is true for melting cheese as well. As the force of pulling the two sections of the bread apart, the cheese will continue to deform, when the stress force is removed the cheese works to return to its original position, but eventually cannot hold the position and it falls down. The second component is the viscosity of the material, as the stress is applied the viscosity of the material continues to grow with time. When the cheese is melted and as one continues to pull apart the bread, the cheese continues to "grow". The cheese works to elastically return to the initial position but the viscosity will continue in a linear growth pattern, hence the use of the Maxwell model.

Further Studies

A study analyzed the stress relaxation behavior of solid-like foods, agar gel, meat, ripened cheese, Mozzarella cheese, and white pan bread. The stress relaxation test results yielded that the Maxwell model sufficiently fit the experimental data. The food composition and structure affected the relaxation times for each of the foods. The relaxation time for the Mozzarella cheese reached zero between 600 and 1000 seconds where as the ripened cheese reach zero in the relaxation time frame of 2000 to 5000 seconds. This difference could be a cause from the water loss capabilities of the given foods. Lastly, the mozzarella cheese proved to be more elastic when compared to the ripened cheese; the mozzarella cheese will return to the initial shape if the applied strain is less than the critical strain unlike the ripened cheese that will show a permanent deformation. (Del Nobile, Chillo, Mentana, & Baiano, 2007)

Conclusion

I was pleased with the resulting image of this grilled cheese pull post editing. I think I captured what I intended to while I was in the brainstorming phase. The experiment was fun to conduct and took multiple iterations until I got the right image depicting the perfect cheese pull. I think the flow of the cheese was portrayed well in this image; in hindsight, a video would have been a good capture to see how the time affected the flow of the cheese as the sandwich halves were pulled apart. Further inclusion in this set up could include measuring the heat applied for various cheese compositions and how the time of heating the cheese affects the results of the cheese pull.

Collaboration

No collaboration was used in the making or editing of this photo.

References

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