IV1 - Peanut Butter Creep

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MCEN 4151 – Flow Visualization

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INTRODUCTION

The purpose of this study is to reveal the interesting flow behavior of peanut butter on an inclined surface. I decided to use our first assignment, *Get Wet*, as an opportunity to play with one of my favorite fluids (and foods), peanut butter. My intent was to capture the gradual flow of a glob of peanut butter down a large cracker using timelapse video, so I set up an experiment in my terribly hot apartment and recorded two trials with the cracker at different angles. My findings were surprising: Even with a steeply inclined cracker, the peanut butter never flowed all the way to the end and dripped off. This surprising result is discussed in Results and Analysis.

EXPERIMENTAL SETUP

Equipment used for the experiment consisted of a box of large gluten-free crackers, a jar of Santa Cruz Organic dark-roasted peanut butter, an instrument tuner, a cardboard box, super tack, a desk lamp, and a Sony Alpha a6300 Mirrorless Digital Camera with a tripod. The cracker was held at the top at a specified angle, 27 degrees from the horizontal in Trial 1 and 41 degrees in Trial 2, by the instrument tuner, which was secured to a cardboard box with super tack. The box was positioned on my desk in front of a small lamp to provide sufficient light. The camera and tripod were placed in front of the desk at the same height as the cracker to capture the flow from an informative angle.

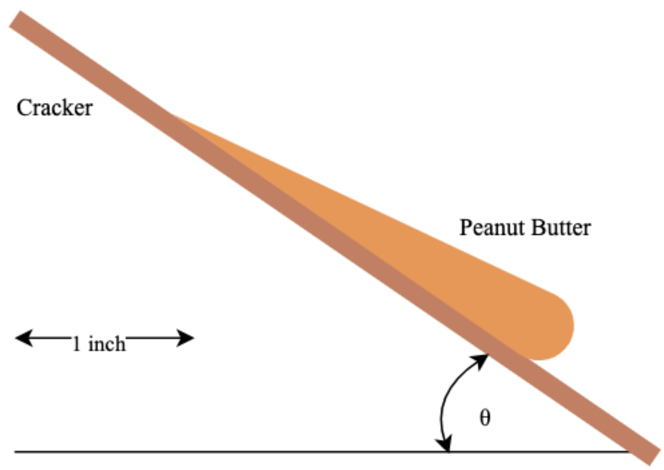

Figure 1: Experimental setup for peanut butter flow capture.

After setup was complete, I began by placing approximately two tablespoons of refrigerated peanut butter at the upper end of the 4-inch-long cracker and started the timelapse. At first, the peanut butter was relatively motionless as it warmed to the temperature of the room (86° F) and its viscosity decreased. Then it started to flow gradually down the cracker before practically stopping after about half an hour. I repeated the experiment with the cracker at a steeper angle, but the same effect occurred. The second time, the peanut butter was at room temperature, so it began to flow right away. Again, it flowed readily at first but stopped before reaching the bottom of the cracker.

RESULTS AND ANALYSIS

To understand the flow phenomenon exemplified here, I had to think about the forces acting on the peanut butter as well as its fluid properties. Gravity is the driving force for flow down the cracker. For any infinitesimally small volume of peanut butter, it's weight is counteracted with a normal force from the cracker or layer of peanut butter below. This normal force has a horizontal component, which causes an acceleration down the cracker. The molecules at the interface of the cracker obey the no-slip condition, an important fluid mechanics rule that fluid sticks to solid boundaries [1]. This results in the emergence of a velocity profile in the flowing peanut butter, where molecules at the top are moving faster relative to those beneath. In Trial 1, the peanut butter didn't flow at all at the beginning because it had just been removed from storage in the refrigerator and had a large viscosity. Viscosity is a function of temperature, where the viscosity of most fluids decreases with increasing temperature. As temperature increases, intermolecular forces are reduced lowering the fluid's resistance to motion [1]. This applies to the peanut butter and explains why it flowed more readily once it had warmed up in the ambient air. But why did it stop flowing before the end of the cracker? Peanut butter is a Bingham plastic, which means it behaves like a solid until a finite nonzero shear stress is applied. It will begin to flow when the applied shear stress reaches τ_{yield}, as shown in Fig. 2:

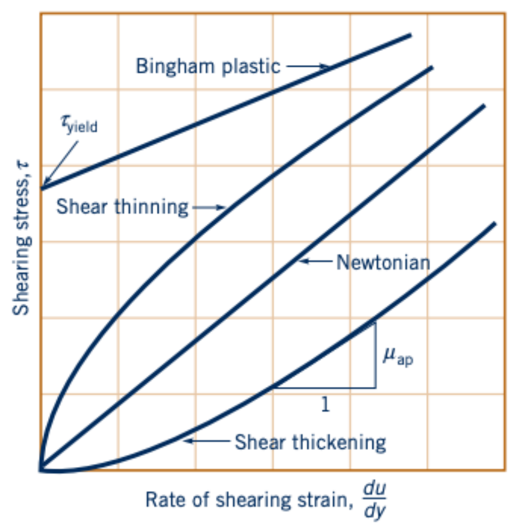

Figure 2: Relationship between shearing stress and rate of shearing strain. [1]

When the cold peanut butter was first placed on the cracker in Trial 1, the internal shear stress from its own weight was not enough to cause flow ($\tau < \tau_{yield}$). As it warmed to room temperature, the viscosity decreased, lowering the yield stress. When the yield stress decreased below the peanut butter's internal stress, it began to flow down the cracker. As it spread out on the cracker, it moved to a form to equilibrate the internal stresses. Once there were no regions with shear stress above the minimum stress, the flow stopped. The same effect occurred in Trial 2, except the peanut butter flowed right away because it was already room temperature and had a low enough viscosity for the stress produced from its own weight to surpass τ_{yield}.

VISUALIZATION TECHNIQUES

Thankfully, peanut butter is quite opaque and textured, so visualizing the flow proved not to be a challenge. My lighting was the only part I had to manipulate to make the peanut butter visible. For this I used a standard desk lamp with a 60W, 4000K bulb, aimed directly at the test jig from the same direction as the camera. I tried to keep it aimed as much in the same direction as the lens as possible without appearing in the frame to minimize shadows, and I kept the light source above the camera to make sure the small shadow that did exist was beneath the cracker. For future experiments I intend to use a light panel that mounts directly to the top of the camera and has brightness and color temperature adjustability.

PHOTOGRAPHIC TECHNIQUES

A lot of conscious thought went into the camera setup for my video. I used a Sony Alpha a6300 mirrorless digital camera with a Sony E-Mount 16-50 mm f/3.5-5.6 OSS retractable zoom lens. The camera was set up on a tripod about 30 inches behind the cracker, and I zoomed in enough to make sure my cracker dominated the frame and had room for the peanut butter to drip out of frame. This made setting up the cracker jig (tuner) quite difficult. Once I had the cracker satisfactorily clamped from above and occupying the entire frame, I adjusted the camera's aperture to F10 to keep the full globule of peanut butter in view. I set the ISO to "Auto" and changed the resolution to 1920x1080px, the maximum available. During editing, I had increased the playback speed to 800x for Trial 1 and 600x for Trial 2, which were fast enough to show the flow in detail. One annoying artifact of the increased playback speed is a mild aliasing effect in the background that appears to sweep up the video repeatedly. Unfortunately, I had no way of editing it out.

REVELATIONS

I must admit, I did not expect the peanut butter to stop flowing before the edge of the cracker. I thought that steepening the cracker angle in Trial 2 would improve the flow but found the opposite. This video does an unexpectedly good job of showing the relationship between viscosity and temperature and the bizarre flow behavior of non-Newtonian fluids like Bingham plastics. I would have liked to do further analysis with fluid concepts, like applying the equations for laminar flow over a flat plate, but Bingham plastics do not hold up well to analysis techniques derived for Newtonian fluids. I do like how my video came out, but I would have liked to have used a better light and found a solution for the aliasing the occurred in post-processing. Overall, I'm satisfied with this experiment, but I do have ideas for how to improve it: I want to repeat the test with a totally flat cracker and one sloped at 90° to the horizontal to see how the peanut butter flows under those circumstances.

REFERENCES

[1] Munson, B.R., A.P. Rothmayer, and T.H. Okiishi. *Fundamentals of Fluid Mechanics, 7th Edition*. Blackwell Handbooks in Linguistics. Wiley, 2012. https://books.google.com/books?id=GQMcAAAAQBAJ.

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