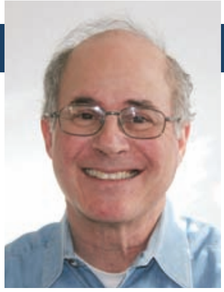

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Engineering: Investigating the Shredding of Wheat

Long-time readers of this column, and attendees of some of the AACC continuing education courses that I participate in, may be aware of my interest in modeling the physics of the wheat shredding, and closely related "Chexing," process. Over the last five years or so I have pursued a solution to this very interesting and challenging mathematical problem. Recently, I have made some observations that may be of interest to readers.

For those not familiar with the process, let me give a brief description. Wheat berries are cooked and "tempered" and then fed into a pair of rolls. For each layer in the finished biscuit, there is another pair of rolls, so a line may have many pairs of rolls, each laying down a layer of shreds. To understand the physics, we only need to consider a single pair of rolls. One of the rolls is grooved, usually with a trapezoidal shape but grooves can be U shaped, and the other is smooth. Figure 1 is a sketch of what the grooves look like. As the surfaces of the rolls approach each other, pressure is developed between the rolls, and the cooked material is forced into the grooves. This flow is indicated by the arrows in Figure 1.

The questions that one would like to answer with a physical model include, among others, such things as:

1. What is the capacity of the rolls?
2. What pressures are developed?
3. What forces are exerted on the rolls?
4. What work is imparted to the processed material?
5. What are the effects of varying the geometry of the system?

To answer these kinds of questions, one must mathematically model the equations that describe the flow phenomena between rolls. The math is very similar to the recent work I've done to describe what happens between flaking rolls, so we have a good starting point. However, we are dealing somewhat different conditions, which modify the mathematics.

Because I personally have no practical experience with this process, before beginning my modeling attempt I asked some questions of people (equipment and product manufacturers) with extensive experience in this area. I repeatedly heard about two key "facts" (boundary conditions) concerning the operation of shredding rolls:

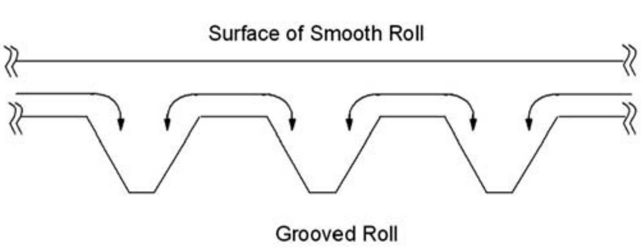

Fig. 1. Geometry of shredding rolls.

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1. The rolls touch each other at the nip between the rolls
2. The grooves are filled by the cooked cereal

With these two key facts, I began my mathematical modeling of the problems. After considerable work on the mathematics and writing of computer code, I made no progress despite my efforts. No matter what I did to the math and the code, I consistently obtained unstable and/or physically unrealizable results. By physically unrealizable, I mean that I observed impossible results, such as negative pressures occurring between the rolls.

After convincing myself that my math was correct, I began to question the truth of some of things I was told. The first condition, that the rolls touch is impossible (I would like to thank Robert Miller for helping me think this through). In fact, the region between the flat areas on the rolls is just like a sheeting process. For the rolls to touch on the flat areas, it is easy show that infinite pressure must be exerted on the rolls! Since infinite pressures don't exist anywhere, except perhaps at the center of a black hole, the condition that states that the rolls touch cannot be true. I questioned my "experts." Some insisted that the rolls touched, some admitted there was a very, very thin film that could sometimes be seen between the rolls. A very, very thin film means the rolls don't touch, which is a very, very different physical situation than assuming the rolls touch.

The question is: Is the film there, and how thick is it? At this point I bought myself a "toy." For very little money, one can purchase a digital camera that fits into the objective of almost any microscope. I bought one of these for my old 20× stereo microscope and began looking at shreds of wheat. It didn't take very many shreds before I observed what is shown by the cross-section of shred in Figure 2. One thing is obvious—the shred is not trapezoidal. Instead, it has a rounded bottom, indicating the groove was not completely filled. However, this was not the source of my mathematical problems.

The more important observation concerns the circled area. One sees that there are "wings" of material sticking out of the side of the shred. These wings join the body of the shred at the curved section. This curved section is probably the result of the wear of the roll's steel at this point. This too is interesting but was not the cause of my mathematical problems.

The important observation, as far as my problem goes, is what happens at the end of the "wing." The wing terminates with a short, thin, flat piece. This flat piece is what one would

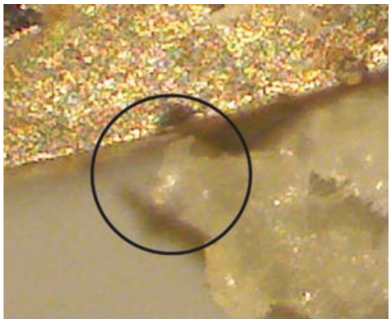

Fig. 2. Cross-section of a wheat shred.

expect to see if the rolls do not quite touch. In fact, if one measures from the center of the shred to the end of the wing, the distance is on the order of one-half the space between grooves.

Figure 3, shows a blown up section of the shred The picture loses some resolution, but the end of the wing is easier to see and can be measured. The thickness is approximately 0.0005 in. If we adjust this dimension for the shrinkage that has occurred due to drying of the shred during baking, we come up with a moist thickness of approximately 0.0007 in.

This thickness is probably not coincidental. Figure 4 illustrates what the force versus gap curve looks like as two rolls approach each other. From the perspective of the machine operator, somewhere below a gap of approximately 0.0007 in. the system behavior is very nonlinear. That is, it takes an increasing amount of force to obtain equal additional decreases in the gap between the rolls. So, if one increases the pressure on the loading cylinders by some "standard," small amount, one sees less and less effect of the increased pressure. Naturally, seeing little or no result, one stops adjusting the pressure on the loading cylinders, and the gap between the rolls never goes below the point where the gap between the rolls appears to stop responding.

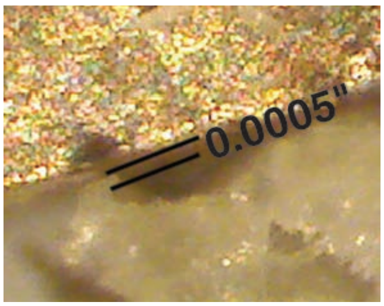

Fig. 3. Close-up of a "wing" on a wheat shred.

Conclusion: there is a very small gap between the rolls, and this situation yields a physical situation for which the mathematics can be solved.

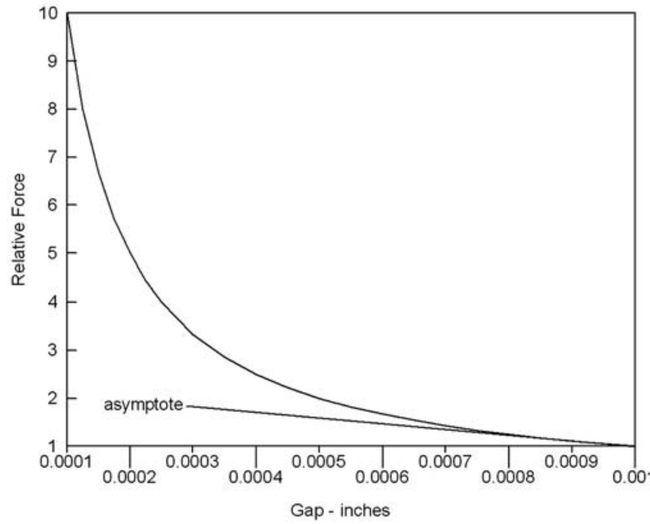

Fig. 4. Force versus gap curve illustrating that force increases as the gap decreases.

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