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Engineering: On the Compaction of Particulate Materials, Like Granola, Etc., Part III

This column continues my discussions begun in the November-December 2011 and January-February 2012 issues of *Cereal Foods World*. Since writing those columns, I have made considerable progress with the mathematics that describe this rolling process, and I've also run into a considerable road block that is preventing me from going further.

In the January-February 2012 column, Figure 1 qualitatively illustrates what the pressure between a pair of compaction rolls looks like. However, this curve was drawn purely from my intuition about the process. Since then, I have succeeded in solving the mathematical (differential) equations that actually describe what's going on in the process. Using "guesstimates" (more about this shortly) for the physical properties of the material being processed, my quantitatively derived curve looks very much like Figure 1 in the January-February column.

An example of a quantitatively derived pressure curve is illustrated in Figure 1. The differences between the shape of this curve and the intuitively deduced curve, as illustrated in my previous column, are superficial. In the mathematically derived curve, the pressure peak is sharper and occurs closer to the discharge point (the nip). The location of the pressure peak represents the point where the material movement changes from the slab of material moving slower than the rolls to the slab of material moving faster than the rolls. The speed differential after the peak pressure appears to be very small, i.e., the slab is moving <1% faster that the rolls. The peak pressure in the illustration is small at ≈7.5 psi. This curve is based on a moderate-level guestimate of friction between the rolls and the slab of material. As the friction between the rolls and the slab of material is increased, perhaps by making the material stickier or by corrugating the rolls, the conveying efficiency of the rolls increases, and the pressure peak is reduced. This is what I suggested in previous columns would happen.

The solution of the mathematics allows us to test the effects of other variables, such as roll diameter, roll speed, feed pressure, etc. The results indicate

1) Roll speed has no effect on the magnitude of peak pressure
2) Increasing roll diameter results in a significant increase in peak pressure
3) Decreasing feed pressure results in a significant decrease in peak pressure

All of these result are similar to what would be expected when applying intuition to the problem.

So, what is the significance of these three conclusions, as well as the earlier conclusion about increasing friction? Anything that reduces peak pressure will result in decreased compaction (lower density) of the material. Anything that increases peak pressure will result in increased compaction (higher density) of the material and possible crushing of fragile components, like rice crisps. Obviously, increasing the roll diameter when going from the pilot plant to the factory will result in a higher density product and possible crushing of fragile components. Decreasing hopper depth (or increasing the friction between the hopper walls), which in the extreme may cause bridging, reduces product density. In my previous column, I suggested that simply having a smaller hopper would result in decreased feed pressure. When these two facts are taken in combination, one would deduce that the factory made product will always be more compacted that the laboratory made product unless other steps are taken to alter the physical conditions.

The mathematical model illustrates what happens to the density of the material as it passes through the rolls. Figure 2 illustrates the density curve. This curve was developed using a reasonable model for the compressibility of the slab of material. Using guesstimates for the constants in the model, the calculated densities are in reasonable agreement with the densities observed for breakfast bars. Note, material density increases until peak pressure is reached. Since the material is porous, density does not decrease as pressure is reduced beyond the pressure peak.

Now for the road block that I've encountered. One can only go so far with mathematics and the simplest description of the

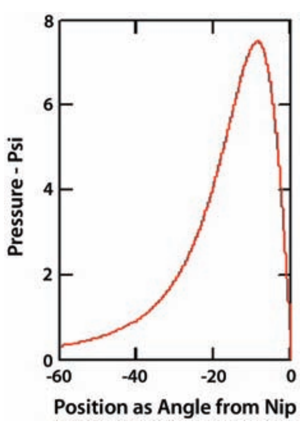

Fig. 1. Quantitatively derived pressure curve.

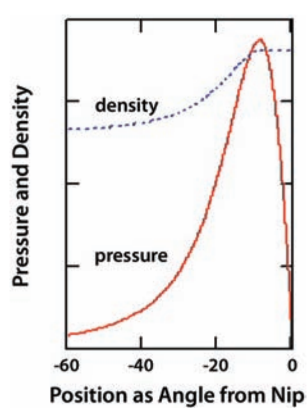

Fig. 2. Density curve.

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friction properties of the material being processed. At some point, one has to measure and characterize the friction and compression properties of the actual materials. Traditionally, these measurements are performed on powders using Jenicke or Peschl test cells. These devices are small and work well for testing fine powders and granular materials. However, the particulate mixture used to make breakfast bars and granola are, in addition to being very cohesive, very coarse. As a result, the particles sizes in the mass may approach the size of the testing cells, or at the very least, their size may be a significant fraction of the size of the testing cells. These large particles make conventional powder testing cells unsuitable for the measurements we need to perform. I have yet to identify any one who can or has measured the physical properties we need to characterize the particulate mass with which we are dealing. This lack of information on actual physical properties limits the progression of our understanding of the process.

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