CFW COLUMN

ENGINEERING

Product Damage in Mixing and Coating Drums

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Tumbling drums play an important roll in the food industry. For readers of this journal, the most familiar applications would be for coating seasonings on snacks and coating sugars on cereals. However, this simple process has widespread application for blending different colored candies, coating pharmaceutical and candy products, "sanding" of candy gums, etc. If one watches "Food Unwrapped" on the U.S. cable news "Food Channel," one would think that these types of coating operations are about the most important unit operation in food processing. These operations are certainly important and widely used, but I don't think they are among the most important or most interesting operations in the food industry. A number of years ago in this column, I discussed the requirements for optimized coating and mixing in these operations, but I don't think I have ever discussed the product damage that is associated with the coating process.

Damage to the products being coating is extremely important to the producer. An extreme example of this problem may be observed in the coating of fragile, brittle snacks, such as potato chips. One can also see damage to cereal flakes, albeit to a lesser degree, in the form of broken flakes or product dust, and one can see damage to sugar-coated pharmaceutical pills and candies in the form of chipped coatings. I have observed, in the pharmaceutical business, tablets that have broken at the scoring line that is embossed onto tablets to allow them to be cut for half-dose intakes. Obviously, one does not want the consumer to see damaged products. In the case of snacks and cereals, we don't want the consumer to experience a high percentage of broken chips in the bag or cereal dust at the bottom of the box.

Without reproducing all the requisite text and explanations of my previous columns on coating uniformity and mixing, let me summarize the conclusions that were given in those older columns about how to ensure satisfactory mixing/coating as one scales up production.

Dimensional analysis and physical reasoning were used to demonstrate that when one scales up a tumbling process such as this, one must maintain two dimensionless numbers.

$$\text{The Froude number: } N^2D/g$$
$$\text{The blend number: } Nt$$

where N is the rpm of the drum; D is the diameter of the drum; t is the residence time in the process; and g is the acceleration of gravity.

This is used as follows: One determines an acceptable combination of drum speed (N) and time (t) on a small (e.g., pilot-plant) scale. From this information, the Froude number and blend number are calculated. As one transfers operations to a larger drum during scale-up, the two dimensionless numbers are kept constant. This tells the designer what speed and residence time are required on the larger scale. The scale-up rules reduce to

$$N_{\text{plant}}/N_{\text{pilot}} = (D_{\text{pilot}}/D_{\text{plant}})^{1/2}$$
$$t_{\text{plant}}/t_{\text{pilot}} = (D_{\text{plant}}/D_{\text{pilot}})^{1/2}$$

This will ensure that the mixing/coating "quality" experienced in the larger facility is the same as that experienced in the smaller facility.

There is only one problem with this design approach, which I didn't discuss in my previous columns. It is well known that a correlation exists between breakage (grinding) and work input (energy input per unit mass). That raises a question: what happens to work input if we follow the scale-up rules given above?

This problem can be approached in a number of ways, but the simplest is to perform a dimensional analysis of the power required to turn the drum and then apply some simple physical intuition. If one does this, one finds

$$P/\rho N^3D^5 \propto g/N^2D$$

where, P is the power consumed, and ρ is the density of the material.

Now we have to do a little algebraic manipulation. Remember that

$$E = Pt$$

where, E is the energy consumed.

So, the energy per unit mass of material in the drum, assuming that both drums are filled to the same degree (same percentage of fill) and have the same length-to-diameter ratios is

$$E/M \propto Pt/D \propto NDt$$

But, if we follow the scale-up rules given above, as the drum gets bigger, it turns more slowly, and the residence time must increase. If we substitute the rules into the equation for energy per unit mass we get

$$(E/M)_{\text{plant}}/(E/M)_{\text{pilot}} \propto D_{\text{plant}}/D_{\text{pilot}}$$

In other words, *as the drum gets bigger, the energy per mass increases in proportion to the drum diameter.* As a consequence, one would expect more product damage, e.g., more broken potato chips, or more cereal flake dust, or more chipped coatings on sugar-coated candies and pharmaceuticals.

One does not have to resort to the abstract concepts of dimensional analysis to see this; it is intuitively correct. If one does the a "Physics 101" analysis of a single particle in a rotating drum, one finds that the angle at which a particle fall off the wall and down to the bottom of the drum is directly related to the Froude number. In other words, once the Froude number is fixed, the

doi:10.1094/CFW-52-2-0081

angle to which a particle will climb before falling is independent of the drum diameter. It doesn't take much imagination to realize that the distance a particle will fall from the annular position is proportional to the drum diameter. In other words, simple physical reasoning leads one to the conclusion that the impact energy, by conversion of potential to kinetic energy imparted to particles as they fall, is proportional to the drum's diameter.

This raises a question. What can one can one do to alleviate the increased breakage with increased scale? The equation above for energy per unit mass (E/M) gives one clue. To get the same energy per unit mass, the equation suggests that we keep ND and t constant on scale-up instead of N^2D and Nt being constant. *This will result in the same breakage between scales, but it will also result in poor coating uniformity*. One must establish experimentally whether this is an acceptable alternative.

There is another alternative. If coating uniformity is the most important issue and *some degree* of increased breakage (energy per unit mass) is tolerable, then one can continue to increase the size of the drum until the breakage becomes unacceptable. At that point, one cannot specify a larger drum. I know of companies that have chosen this option. If larger capacity (diameter) is needed, then multiple smaller-diameter drums are used instead of a single large-diameter drum.

There is, of course, a compromise solution. If one can accept some decrease in the uniformity of coating and some increase in the product breakage, then one can chose a design between the two extremes of scale-up rules, that is, between keeping N^2D and Nt constant and keeping ND and t constant. Again, only experimentation can answer just how valid this compromise solution will prove to be.

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