Understanding Degradation Fundamentals

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The use of nano-particles in bulk solid materials has led to enhanced ability of these materials. There is a movement in industry to create large size particles (agglomerates) with a high degree of porosity and large surface areas where nano-particles on the surface perform various functions. Herein lies the dilemma. Large particles are preferred due to the lack of cohesive flow problems. However, large particles have low surface area and, hence, limited chemical functionality. One solution to this particle design process quandary is to use an agglomeration process that creates a large porous particle from a series of small nano-particles. Unfortunately, these engineered materials are generally both highly porous and friable, resulting in significant degradation during use. Whatever the reason, particle size degradation of particles is a problem in today's production facilities. Degradation produces fines that limit the life of catalysis in fluid bed operations. It causes fines production in pharmaceutical products that subsequently segregate, resulting in quality issues. Particle size degradation causes consumer acceptance issues with many products from food to bath products. Degradation issues also lead to dust generation problems and environmental discharge concerns.

Thus, measuring and understanding degradation is critical to help engineers and materials scientists design processes and products that minimize these effects. There are several key issues to developing a robust method to mitigate size degradation effects. Degradation is caused by different external influences. Placing material in a condition where it is exposed to large stresses and high strains can cause a reduction in particle size due to particle breakage under the stress/strain behavior. Impact can also result in particle breakage. Particle size degradation can be quantified by observing the shift in particles size after subjecting particles to a controlled impact condition or a controlled strain condition.

For example, Figure 1 shows a typical shift in the cumulative particle size as bran buds are subjected to repeated impact conditions. Notice that this shift is not equal for all particle sizes. The maximum shift appears to occur at particle sizes around 2000 microns. If the particular process of interest operated at material impact velocities of 11.8 ft/sec, then this figure could be used to estimate the amount of fines generated during plant operation. However, real plants operate within a range of impact velocities, and also a range of stress and strain conditions. Thus, degradation should be measured at various conditions and used with process models to compute the integrated effect of particle size degradation based on the range of impact velocities and stresses in the prescribed process equipment (Figure 2).

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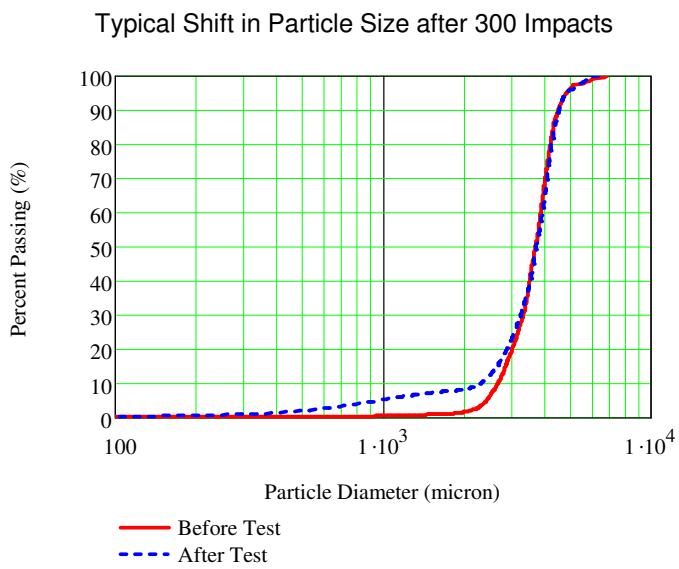

Figure 1. Shift in particle size of bran buds when subjected to 300 impacts at 11.8 ft/sec impact velocity.

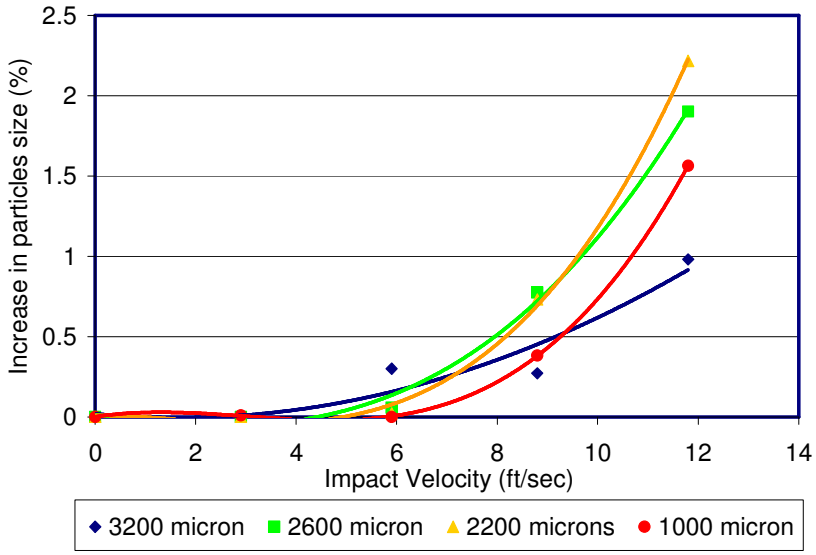

Figure 2. Shift in particle size of bran buds when subjected to 300 impacts at 11.8 ft/sec impact velocity.

Figure 2 shows the increase in bran particle size for 100 repeated impacts at various impact velocities. This figure shows the cumulative increase in particle size for a given maximum particle size limit at various impact velocities between 0 ft/sec and 14 ft/sec. These types of impact velocities may exist in mixing, blending, and drying equipment in typical handling facilities. Notice that the 3200 micron material shows less size degradation than the 2200 micron material. This suggests that the 3200 particles are breaking faster than they are being generated by the breakage of larger particles. The particle size degradation of 1000 micron particles is also less than the 2200 micron

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materials. In this case, the rate of production of 1000 micron particles is slower than the rate of production of 2200 micron particles. We routinely compute the stress and strain levels and impact conditions in typical process equipment. Suppose that the primary process of interest was principally an impact process, such as drying in a rotary drum. This is degradation analysis combined with calculations of impact velocities allows us to estimate the overall process degradation. If the drum is 2-foot in diameter has lifter bars and operates at 20 RPM with a fill rate of 7%, then the expected impact velocities are around 8.6 ft/sec. However, multiple impacts occur after the initial drop onto the pile from the lifter blades. In addition, not all the material drops the full distance. Taking all this into account and assuming about 150 impact events before material exits, the drum leads to an estimated increase in 1000 micron material of about 0.52%. It is important to note that many processes depend on both impact and stress and strain effects and will require performing degradation tests as a function of impact velocity as well as stress/strain effects.

This type of analysis helps with process issues, but does not address the rudimentary cause of particle breakage. Therefore, it is difficult to apply to particle design. However, modifying the degradation test method allows us to determine the mechanisms involved in size reduction. In this case, the test is run at a controlled constant impact or stress/strain condition for various times. This generates a series of particle size distribution curves as a function of the time applied (Figure 3).

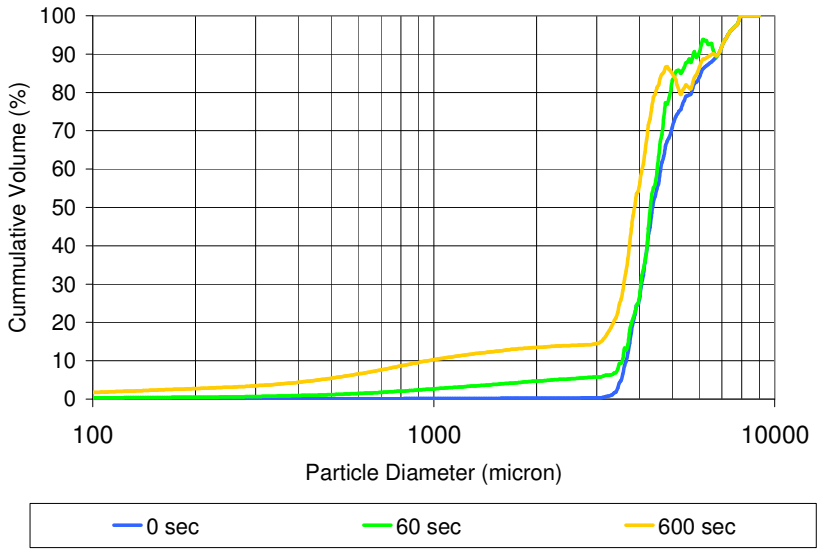

Figure 3. Shift in particle size of bran buds when subjected to repeated impacts at 17.8 ft/sec.

This technique is called population balance modeling. Particle size distribution is broken into individual particle size bins and equations describing the rate of transfer between particle size distribution bins. This series of equations can be solved for both the rate of breakage and the breakage mode. Figure 4 shows the type of breakage that

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occurs. When a given particle size breaks, a series of particles result. If fracture is an important effect, then a large fraction of particles end up in an adjacent particle size bin. If abrasion is occurring, then the fraction transferred directly to fine particles is large. This figure shows the fraction of bin size #1 (6258 micron) that ends up in bin size #2 is only 30%. The remaining material of this size distributes between bin sizes #3 and #4. This suggests that both abrasion and fracture are occurring during impact of (6258 micron) bran buds at this velocity. Conversely, almost all of the material in bin size #3 (1723 microns) ends up in bin Size #4 (904 microns) indicating, 93% fracture of 1723 micron particles. Likewise, the behavior of bin #4 and bin #5 suggest abrasion is the predominant degradation mechanism of particles less than 904 microns.

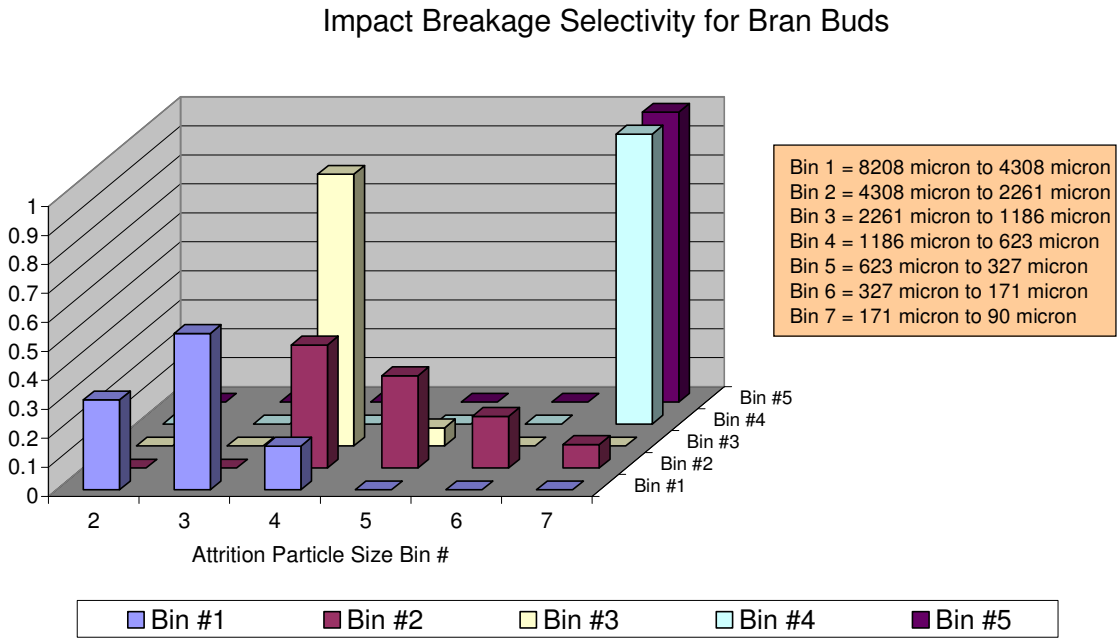

Figure 4. Results of population balance modeling for bran buds after impact at 17.8 ft/sec.

Examining the structure of these bran buds can lead to what may be causing these mechanistic degradation effects. Careful examination of a bran bud indicates that buds are made of a collection of flakes or particles that are roughly 900 microns. These primary particles are librated from the bud particle matrix by an initial breakage event followed by abrasion of the 900 micron primary particles to finer material. Strengthening the binding action between these original particles will help reduce particle size degradation of bran buds. Thus, a population balance degradation study provides a powerful analysis to determine the modifications to the structure of the particles that will lead to a reduction in attrition. At Material Flow Solutions, Inc., we can provide you with a degradation analysis for your process or provide you a population balance model analysis of your product to aid with product design.

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