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Simple Physics of Powder Density in Gravity Discharge

Powder at rest can be deceiving. Spread out on a horizontal surface, the particles may look perfectly flowable because they move easily to the touch. Put the powder into a container and its behavior in gravity discharge out the bottom may be something very different. Why?

Powder particles unconstrained on a horizontal surface have plenty of open space between one another. They move freely at the slightest touch. When placed in a container, the self-weight of the particles on top pushes down on those below. Air between the particles is gradually squeezed out. Settling takes place as spacing between the particles moves closer. Consolidation causes bulk density to increase over time relative to the "loose-fill" condition when the powder was poured into the container.

Note that powder consolidation in a container is a time dependent phenomenon. Some powders, like nasal sprays, may collapse very quickly to a small fraction of their initial volume. Others, like BCR Limestone, may change gradually from their "loose fill" density condition and consolidate to half the original volume. Sugar crystals at the other extreme will hold volume and exhibit relatively little change in density.

One general observation is that powders which compress to less than half their original volume are prime candidates to have flow behavior issues during processing. Is there a way to identify problem powders using this criterion? It's one way to begin, but cannot be the sole test basis for making final judgement.

Simple tools for assessing compressibility have existed for many years. The Wolfson Centre for Bulk Solids Handling Technology at University of Greenwich in England makes a simple Demonstration Kit for this purpose. Powder is placed into a cylinder so that it completely fills up. The powder is then removed and weighed. "Loose fill" density is easily calculated by dividing cylinder volume into the recorded weight for the powder sample. Individual iron weights of known value are then placed atop the cylinder full of powder. *See Figure 1*. As more weight is added, the height of the powder column reduces and the corresponding density increase is easily calculated.

Figure 1: Wolfson Centre Powder Demonstration Kit

A tool called the Tap Tester is widely used in the pharmaceutical industry. This instrument physically shakes a column of powder to cause entrapped air to escape. As the number of shakes increases, the height of the powder column reduces. The resulting density value depends on the total number of shakes which are typically on the order of 100 or 150. Mathematical calculations using established formulae known as Carr Index and Hausner Ratio provide numerical values for the final test result. *See Figure 2*.

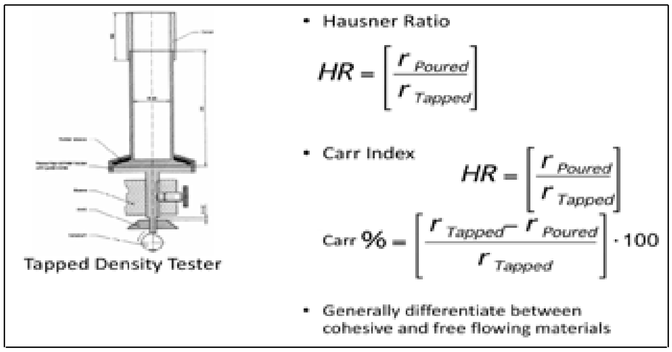

Figure 2: Carr Index and Hausner Ratio

Annular shear cells are gaining in popularity for density measurement because they physically simulate what happens to powder when placed in a containment vessel. The cell loaded with powder (*Figure 3*) is placed on the instrument. A compression plate affixed with a specially designed flat-face lid makes contact with the sample and consolidates the powder to a defined pressure. This action simulates the weight that a container of powder filled to a defined height applies to the material located at the bottom. As the pressure applied by the lid is increased, higher consolidation is achieved and the bulk powder density climbs in value. At test conclusion, the density curve may look like the graph in *Figure 4*. For reference, the Tap Test described above will very likely report a value that lies somewhere on the density curve as shown.

Figure 3: Shear Cell with Powder Sample

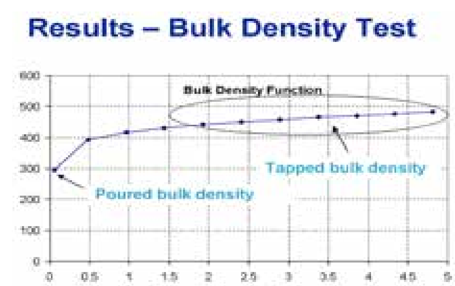

Figure 4: Density Curve From Shear Cell Test

The shear cell test demonstrates how consolidation affects powder bulk density. Useful calculations called "Compressibility Index" and "Compressibility Ratio" (similar to Carr Index and Hausner Ratio) are automatically reported from the shear cell test and define how much volume reduction has occurred. The advantage of using this approach is that the method simulates what happens to a powder in a containment vessel as air is squeezed out. The resulting consolidation increases the powder bulk density. If the increase is substantial, i.e. > 35%, then the possibility of flow behavior problems is real.

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