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What exactly is powder flowability?

Powder flow affects solids dosage operations through material handling problems, segregation, tablet/capsule uniformity, and fill control. But when we say a powder has good or poor flowability, what are we really saying?

To answer that question, imagine filling one cup with water and another cup with sand and packing it. Invert each cup. The water flows away, while the sand forms a tower. What do we learn? That powders are not fluids, and that bulk powders, as solids, can withstand pressure and stress without flowing (or more correctly, yielding).

So powders have a yield strength—just as a solid has—and that yield strength is a function of the history of compaction stress and the currently applied stress. This is the powder's flow function. Bulk powders do not have a viscosity, except possibly in a fluidized state or under very rapid granular shear. When discussing powders, simply forget most of what you know about fluids. It rarely applies to powders.

Now let's think about measurements. Can we use a torque rheometer that measures fluid viscosity to measure powder flow, too? First, consider some of the key requirements for using the rheometer: The fluid must not slip on the torque surfaces; the strain-rate field must be defined; and the material functions of the fluid must be known.

Absent any of these, you cannot determine a viscosity. Instead, you'd measure torque for an ill-defined stress field, which is useful for telling you the torque required to shear *that* fluid in *that* vessel with *that* geometry. You're unlikely to learn anything about shear forces or flow in an actual process of differing geometry, pressure, or scale of operation. But to comply with the FDA's PAT initiative, that's exactly the kind of data you need.

As solids, bulk powders exhibit anisotropic stress, elastic deformation, and yield strength. They don't flow like a fluid. Instead, they fail along slip planes, often don't exhibit shear gradients, can slip on wall surfaces, and are less sensitive to strain rate. In most cases, their flow properties are best measured by shear cells originally developed from the study of soil mechanics. A powder flows when the stresses in the process exceed its yield strength, and it can be shown that this yield strength is closely connected to how readily the powder over-compacts with overpressure. That's where shear cells come in.

Shear cells determine simple flow indices, which are measures of the forces required to initiate flow (defined as powder failure) based on measurements of bulk density, cohesive strength, powder friction, and wall friction. With such information, you can estimate the likelihood of powder arching or ratholing, mass discharge or feed rates, blend segregation, powder caking, stress transmission in tabletting and encapsulation, and a host of other solid-like behaviors.

This should not be news to pharmaceutical researchers. After all, the study of powder flow properties dates back to Reynolds (1885), Prandlt (1921), Coulomb (1773), and Mohr (1882). Collin (1846) was among the first to record using direct shear cells. And the relationship between stress and bulk density during powder failure was pioneered by Hvorslev (1937) and Roscoe et al. (1958). Jenike (1964), Carr and Walker (1967), and Peschl and Colijn (1976) further refined the use of translational, annular, and split rotational cells, respectively.

Designs for all such devices now have ASTM methods and can be validated against shear cell standards (e.g. BCR 116 limestone). Advances in automation have drastically improved reproducibility, ease of use, and operator independence. Furthermore, with modern simulation codes, it is possible to simulate stress and bulk density evolution in complicated die geometries, based on property measurements of a *prior* material. This knowledge base generally resides in the fields of materials and geotechnical engineering. It's unfortunate that the knowledge has been slow to creep into pharmaceutical processing. *T&C*

Further reading

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