The New Era In Powder Flow Testing

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In 2003 the Working Party on the Mechanics of Particulate Solids for the European Federation of Chemical Engineers endorsed the idea that a simple and inexpensive instrument to test powders in gravity discharge from hoppers would be of significant benefit to the bulk solids industry. Problems relating to erratic flow behaviour and total stoppage were taking a toll on efficiency of processing operations and, at times, quality and consistency of finished product. Test methods practiced by the industry to evaluate flow behavior were in many cases irrelevant to the underlying causes for why the powders would not flow.

A collaborative initiative starting in 2004, organised by The Wolfson Centre at the University of Greenwich in Chatham Maritime, Kent UK, took aim at this challenge. With funding support from the British government and voluntary participation by four food industry processors and an equipment manufacturer, the objective was to identify a test methodology that would be scientific in principle, simple in practice and sensible in cost. It was important that the solution be affordable to companies of all sizes, with the thought in mind that Quality Control, as well as Research and Development, become practitioners.

Shear cell technology emerged as the test method of choice because it simulated the virtual conditions that powders experience when stored in a bin or silo prior to discharge. The self-weight of the powder causes a settling action, which consolidates the powder. Being able to predict whether this consolidated powder would flow was the heart of the technical issue. The shear cell compacts the powder sample by applying a defined consolidation pressure, then shears the material to determine the failure strength. This measurement approach characterises the force required to overcome the friction between powder particles, thereby allowing them to slide against one another.

Common test methods, like the flow cup or the angle of repose (also known as angle of inclination), do not take into account this fundamental requirement to work with consolidated powder samples. The flow cup, when filled, simply tells whether the loosely consolidated powder will flow out the hole in the bottom. (See *Figure 1*) After the powder flows out the hole, it forms a pile underneath with a measurable slope relative to horizontal. (See *Figure 2*) The angle of repose indicates the internal friction between loosely consolidated powder particles. Ask any plant manager and you will hear that the data from these tests does not show clear correlation with the actual flow behaviour of the powder during processing. The fundamental explanation is that the test sample does not reflect the actual control conditions for the powder in a bin. In any containment vessel the powder at the bottom undergoes consolidation due to the weight of the powder on top of it.

Figure 1. Flow Cup Gives Go/No-go Indication for Loosely Consolidated Powder

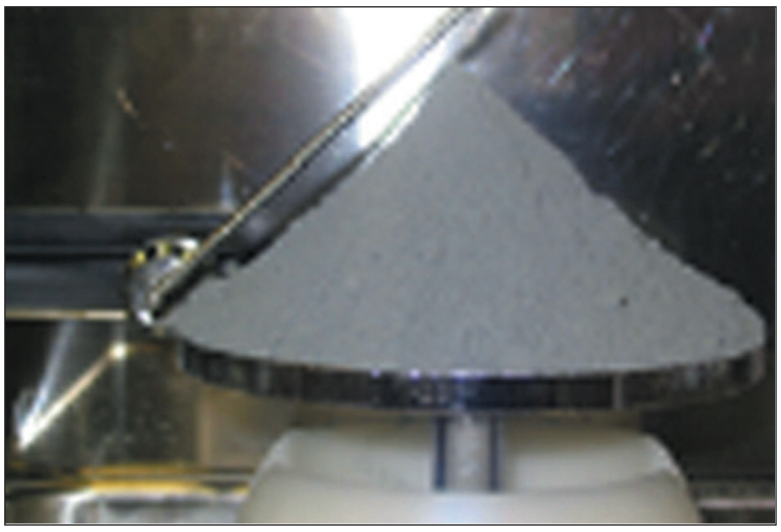

Figure 2: Angle of Repose Test Measures Internal Friction for Loosely Consolidated Powder

The tap density test, which measures the shrinkage in volume of a powder sample through repeated tapping, gives an indication of how density increases as air is removed. The test method requires that a known volume of powder be tapped a fixed number of times and the resulting volume measured for comparison. Mathematical calculations, know as the Hausner Ratio and the Carr Index, provide numerical values which quantify the amount of volume reduction. (See *Figure 3*) While useful in predicting powder cohesiveness, this test still does not get a handle on the failure strength of the consolidated powder.

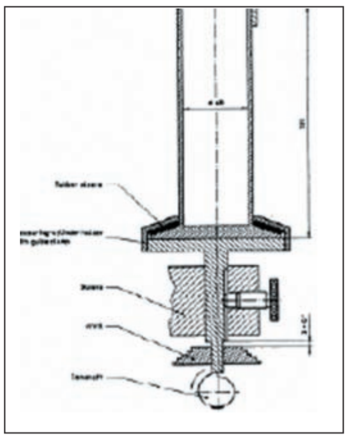

Figure 3: Tap Density Test Measures Reduction in Powder Sample Volume

The minerals industry was the first to use shear cell methodology as early as the 1960s. Commercial instruments evolved over the next three decades. In general, the devices were expensive and mechanically complex, required a trained technician to perform the test, took the better part of a day to run one sample, and needed a scientist to interpret the results. This combination of factors kept the methodology in the R&D world, primarily with major corporations, and in third party test labs that serviced the bulk solids industry. Breakthroughs in all areas were needed if QC were to become a user of shear cells.

Figure 4: Brookfield Powder Flow Tester is Example of Shear Cell Instrument

The electronics industry revolution (fast PCs, applications software which performed the detailed analytical calculations required for powder mechanics) provided new capability to overcome many of the issues. Automatic control of the shear cell was now possible. Voluminous amounts of raw test data could be collected and rapidly converted into Flow Function graphs (which characterise internal powder friction) and Wall Friction graphs (which characterise the friction between powder and hopper wall). The approach to use one sample and test it at repeatedly higher consolidation stresses saved significant test time. (This assumed that degradation of powder particles in the sample would not be significant.) All of these recent developments have combined to allow for a new generation of shear cell testers that can be used by anyone to predict flow behaviour (see *Figure 4*).

The primary test performed by the shear cell is called 'Flow Function'. The method involves preparation of the test sample in a container of known volume. (see *Figure 5*) After the sample is weighed, the shear cell is placed on the instrument. The vane lid (see *Figure 6*) comes down on top of the sample and compresses it. This procedure causes the powder particles to move closer to each other while eliminating air pockets in the sample. The shear cell then rotates slowly and the vane lid rotates with it because the friction between the powder particles is sufficient to cause both pieces of hardware to rotate together. The vane lid is connected to a torque cell that records the buildup in torsional moment as the shear cell rotates. When this torsion load becomes greater than the interparticle friction for the powder, the vane lid holds position while the shear cell continues to rotate.

Figure 5: Sample Preparation of Powder in Shear Cell

This particular event identifies the failure strength of the powder, for example, the friction level at which the powder particles are finally able to slide against each other. This same test methodology is repeated at increasingly higher compression loads applied by the vane lid. The resultant graph from the complete test (see *Figure 7*) shows how the failure strength of the powder changes with increasing consolidation stress.

Pressure buildup in powder stored in a storage vessel is the phemomenon that shear cells are able to simulate. The amount of pressure correlates directly with the height of the powder. The self-weight of the powder bearing down on itself is what causes consolidation in the vessel. The vane lid presses down on the powder sample, simulating the self-weight condition that causes the settling action. This is the key difference in test approach between the shear cell and simpler test devices, which only measure flow behaviour for loosely consolidated powders.

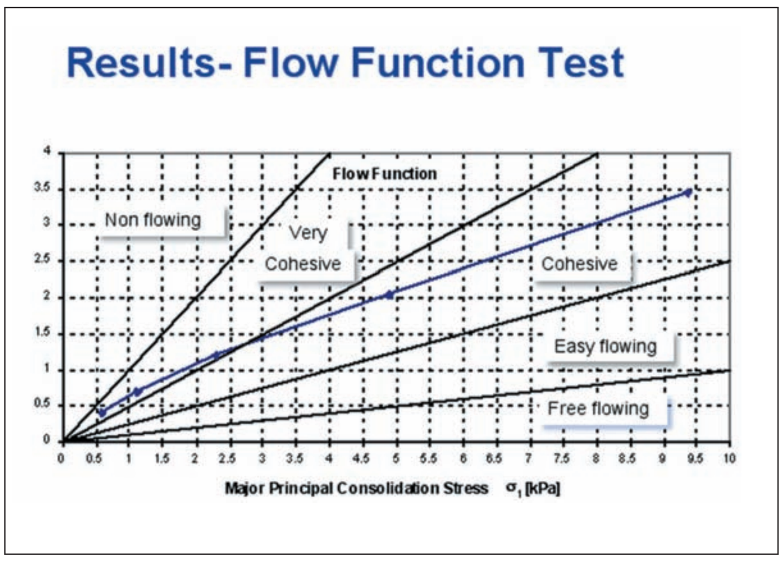

Figure 7: Flow Function Graph for Multiple Powder Samples

One important piece of data that is generated by the shear cell along with the Flow Function is the density graph for the powder. As the consolidation pressure in the sample increases, the density of the powder goes up as well. *Figure 8* shows a typical density curve for a powder sample. The increase in density is most noticeable at the beginning of the consolidation process. Compressibility of the powder is a characteristic that indicates potential for flow behaviour problems. Typically, powders that are compressible to 50% of their original loose-fill volume will experience flow behaviour issues. The data points on the density graph at the highest consolidation stress values may be correlatde with the data from another test discussed earlier, the Tap Density Test, as can be seen in *Figure 8*. The advantage of the shear cell test is that repeatability is more predictable.

Figure 6: Vane Lid Used to Compress and Shear Powder Sample

One of the food processors in the development project organised by The Wolfson Centre actively tested a variety of flavourings with the new generation shear cell instruments. The results turned out to be especially promising for a number of reasons. Small batches of powder for new formulations (different tastes, slight changes in ingredients) could now be tested for flowability before delivery to the customer for evaluation. Scale up to production quantities could be investigated and qualified using a lab instrument to verify whether modifications would impact processibility. The obvious gain from these developments is the reduce cycle time for launching new products.

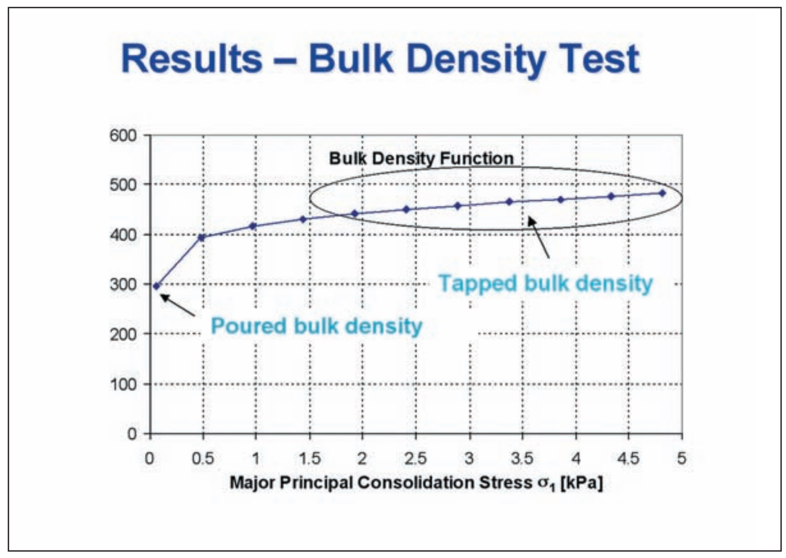

Figure 8: Density graph for Powder Sample

Challenges facing the bulk solids industry today still include the unforeseen jams and stoppages that can bring operations to a halt. Key to a major step forward is the real need for education in order to deliver companies from the simpler, but traditional, practices of flow cups, angle of repose, and tap density.

The new era of powder processing demands a test method that truly models the flow conditions for powder stored in any type of container, whether a large silo, a small feed device, or stacked sacks of final product in shipment.

Shear cell technology is the new solution for today's processors because the test conditions correctly simulate what happens to powders.