RELATING POWDER PROPERTY MEASUREMENTS TO EFFICIENT EQUIPMENT SELECTION

Aside from using trial and error and pilot-scale studies, powder and bulk solids manufacturers tend not to have concrete methods of deciding what process equipment works best for their application. Identifying the powder's relevant properties through powder characterization helps to narrow the equipment design focus, as equipment differs in its suitability for different powders. This article describes three case studies where multifaceted powder characterization was critical to determining the right process equipment.

Katrina Brockbank, Freeman Technology

With the possible exception of hopper design protocols established in the 1960s, powder processors have access to few proven models for equipment selection and design. Trial and error and a heavy reliance on pilot-scale studies are the hallmarks of many powder processing industries. Modern powder testing equipment that uses multifaceted powder characterization enables relevant powder property identification and allows protocols to be established that help identify an optimal equipment-selection solution. In this article, we'll explore the value of multifaceted powder characterization via three case studies that illustrate its benefits.

Each of these studies provides insight into how modern powder testers can enable confident specification of equipment that works reliably and efficiently. In each case study, a powder rheometer was used to measure the powders' properties. While this isn't the only equipment that can be used, for the purpose of this article, we'll focus on taking powder property measurements with a rheometer to evaluate its ability to measure multiple powder properties as well as simulate various powder processing conditions.

As you'll see, each company has achieved substantial economic return by investing in a powder rheometer capable of automated dynamic flow, shear, and bulk property measurement. The lessons learned provide practical guidance for anyone looking to improve their ability to select powder processing equipment that's optimally matched to the application.

Case study 1: Choosing a solution for transporting powder

A fluid diaphragm pump is a low-cost option for transporting powder. This positive-displacement-designed pump transfers powder via two valves on either side of two flexible diaphragms, creating a temporary chamber that draws in and expels the powder. Increasing the volume of one of the pump's chambers decreases the pressure, drawing powder in. When the chamber pressure is then increased by decreasing volume, this powder is forced out, and the cycle continues. A diaphragm pump creates an airtight seal between the drive mechanism and the compression chamber, allowing for powder transfer, compression, and evacuation without a lubricant.

A fluid diaphragm pump typically costs around 30 percent (installed) of the costs of a comparable pneumatic conveying system. However, such pumps aren't suitable for all powders, so the challenge is identifying transport equipment that's compatible with the application's material.

Determining what transport equipment works best for the powder being processed has been addressed by engineers working for a leading industrial catalyst manufacturer. The engineers correlated the different powders' dynamic flow, shear, and bulk properties, all measured using a powder rheometer, with their performance in different powder transport systems. This work highlights the value of measuring three particular powder properties:

Compressibility, a bulk property, is the extent to which a powder sample changes in volume, and therefore density, when consolidating stress is applied. Compressibility is determined by testing with a powder rheometer.

Permeability, a bulk property, is the extent to which a powder sample resists the passage of air, determined by measuring the pressure drop across a powder bed as a function of air velocity.

Cohesion, a shear property, quantifies the strength of interparticle forces as determined by shear cell testing.

The company's developed design approach uses compressibility as the primary screening criteria. Cohesive powders typically pack inefficiently, entraining air that can be forced out through the application of a consolidation stress. Higher compressibility is therefore often associated with high cohesivity, which is known to be detrimental to fluid diaphragm pump performance. For this application, compressibility was found to be the most sensitive and relevant indicator of this important characteristic.

If a powder's compressibility is lower than 36 percent, then a fluid diaphragm pump is suitable for transporting that powder, but if compressibility is above 38 percent, then a pneumatic conveying system is required instead. Permeability and cohesion values are both used to differentiate powders with a compressibility between 36 and 38 percent and additional criteria have been defined for selecting a suitable transport system based on these variables. Bulk density values, an additional property generated from compressibility tests, are used to define a system's capacity.

For the catalyst manufacturer in this case study, measuring the handled powder's compressibility, permeability, and cohesion, and, as a result, correctly specifying a fluid diaphragm pump rather than a pneumatic conveying system for multiple installations has already delivered more than $337,000 (£250,000) in savings. This industry case study therefore clearly illustrates how appropriate testing can be used to identify the most cost-effective process solution.

Case study 2: Developing an efficient turnkey packaging plant process

This study addresses the broader problem of which powder properties are most useful to determine when designing a complete, turnkey packaging process for a material such as cocoa, as shown in Figure 1.

Powder packaging is an essential activity for many sectors and calls for the design of integrated equipment tailored to the specific material's properties. Such equipment may include silos and hoppers, filling stations, dosing and weighing systems, and pneumatic conveyors. Companies that specialize in packaging equipment engineering and supplying face the challenge of identifying a reliable solution optimized for each new powder, with consistent powder flow critical to achieving trouble-free operation. Introducing air via aeration jets during packaging, for example, typically enhances material flowability but can also contribute to powder segregation. Minimizing air in the packed material is also crucial to maximizing fill content, so these conflicting requirements highlight the importance of understanding powder flow behavior to come up with a packaging process that works.

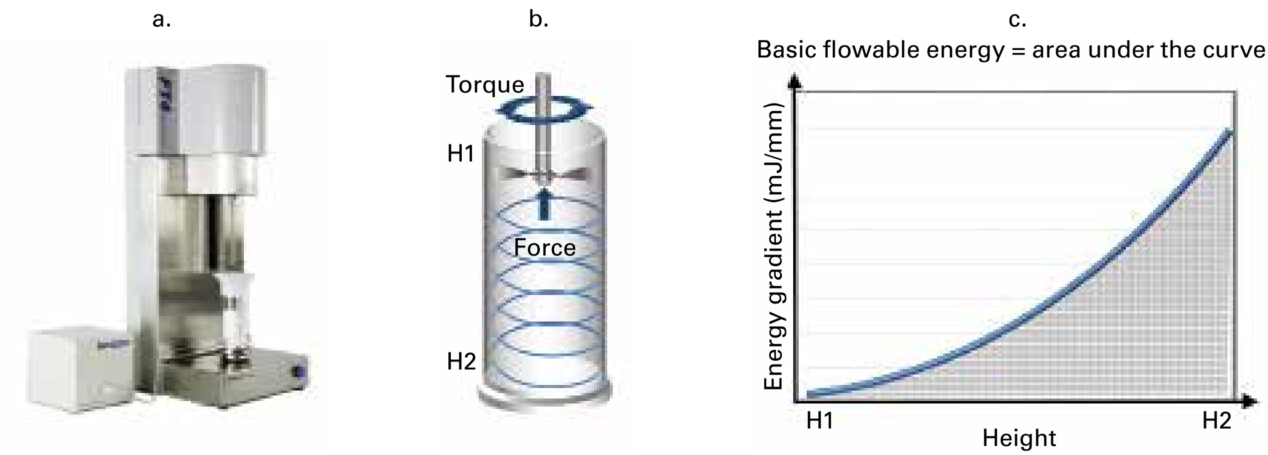
An engineering company specializing in packaging equipment design and supply identified *basic flowability energy* (*BFE*) as a critical parameter when assessing powder and packaging equipment compatibility. BFE is a measure of a powder's dynamic flow properties when the powder is in a loosely packed state. This measurement is determined from a powder rheometer's measurements of the axial and rotational forces acting on a specifically engineered blade as it rotates downward through a powder sample, as shown in Figure 2. Well-defined, automated test protocols ensure high repeatability and the generation of sensitive and differentiating data. Initial investigations into useful powder properties used a shear cell tester, but this technique was considered too time-consuming and the results were heavily dependent on the operator, limiting the company's ability to produce consistent, repeatable results.

FIGURE 1

Cocoa is a good example of a relatively fine powder that can be challenging to package.

FIGURE 2

Dynamic flow testing with a powder rheometer (a.) quantifies flow properties from measurements of the force and torque acting on a blade (b.) as it rotates through the powder sample. The basic flowability energy for the powder is determined from the area under the resulting curve (c.)



BFE measurements were added to the company's routine analytical schedule around 15 years ago. The schedule also includes particle size and shape, density, compaction, moisture, and fat content measurements. The relationship between powder flowability and equipment performance has been extensively researched since the company incorporated BFE measurements into its routine. Subsequently, the company has established a substantial database containing BFE values for a wide range of materials, along with associated equipment designs that have proven optimal for powders with certain flow characteristics. Now, by simply testing a new powder and referencing the database, engineers can rapidly and confidently identify the optimal processing solution. This work has proven crucial to simultaneously minimizing the air input into the process and the risk of powder blockages and downtime, thereby combining maximum filling capacity with high reliability.

For a company that provides hundreds of customized packaging solutions each year, the application of powder testing to refine a core business activity is highly lucrative. Powder testing saves valuable time on each new specification and also boosts the resulting design's quality and reliability, directly enhancing the company's reputation.

Case study 3: Optimizing multifaceted powder testing's full potential

This final case study similarly highlights the value of BFE data for designing a powder handling process but also provides evidence of the significant value of other dynamic flow, shear, and bulk properties.

With a product portfolio including hoppers and silos, a specialist provider of bulk powder handling equipment routinely used shear cell, angle of repose, and tapped density testing to characterize incoming powders. The aim was to test powders in the lab to identify potential process solutions ahead of an in-house full-scale trial. However, all three test techniques proved inadequate. Shear cell analysis was lengthy and operator-dependent, while the more traditional tests (angle of repose and tapped density) suffered from poor repeatability. None of the tests could provide information relevant to processes such as pneumatic conveying, in which powders are handled in low-stress or fluidized states.

To address this issue, the company began testing powders using a modern, automated powder rheometer that had the capability for dynamic flow, shear, and bulk powder property testing. Though higher in cost than the other testers, this instrument delivered multiple benefits including:

Automated shear testing, which reduced measurement times by a factor of 4 and eliminated operator variability.

Dynamic flow testing, which measured BFE and other parameters for the secure prediction of powder performance under different process conditions, such as consolidation, aeration, or varying shear stress levels.

Aerated powder characterization, which supported the design of storage, discharge, and pneumatic conveying solutions.

Please note that not all powder flow testers deliver these benefits. When you're in the market for one or dealing with a powder testing company, make sure you specify your needs and expectations of what capabilities you want a powder tester to have.

Measuring BFE using a powder rheometer takes less than 20 minutes and is now the company's most frequently measured parameter when specifying powder handling equipment for a new powder. BFE has proven to be such a sensitive, reliable, and valuable differentiator of powder behavior that the company also now offers BFE testing as a supplementary customer support service for batch-to-batch variability assessment and supply chain management.

Shear testing within the company is still routine with easier, automated measurements now shared across the company's broad range of operators. A powder's wall friction data is used to assess new construction coatings or materials, and powders' shear properties are generated for the design of silos and hoppers. However, additional test data including aeration and deaeration and permeability measurements are also now applied in silo and hopper design. For example, for highly cohesive powders such as titanium dioxide, certain hopper design methods don't work because efficient discharge isn't feasible simply through the manipulation of hopper dimensions. Measuring complementary powder properties using a powder rheometer directly informs decisions on the use of mechanical aids, such as vibrating devices or air injection systems, to address discharge issues. In addition, dynamic flow testing is used to investigate powder consolidation behavior with these results guiding operating practices, such as hopper emptying frequency and any requirements for powder recirculation.

The ability of dynamic flow testing to characterize powders in an aerated state is also used to elucidate processes that subject a powder to aerating conditions. Measuring BFE with air flowing through the sample at a defined velocity generates values of *aerated energy* (the powder's measured resistance to flow when aerated). This technique is used to assess a powder's suitability for processes such as pneumatic conveying, which is significantly influenced by powder aeration and fluidization characteristics. Engineers at the company are now using a powder's dynamic flow and bulk properties in combination to establish design criteria for pneumatic conveyors, identifying correlations that allow for them to determine the material throughput and pressure drop calculations required for process design.

In addition, in combination with permeability measurements, aerated flow testing is used to support the selection of discharge solutions, such as rotary valves and dosing screws. Selecting the right discharge solution is important because powder flooding is a possibility, depending on the powder's response to air. Choosing a discharge solution that avoids powder flooding is highly desirable.

The bulk powder handling equipment company in this final study handles up to 500 new materials in any given year, so the ability to quickly identify the best powder processing design based on streamlined powder properties testing is extremely valuable. Furthermore, this effective testing reduces the reliance on expensive, material-consuming plant trials, reducing the overall process development cost while more easily meeting customer requirements. **PBE**

For further reading

Find more information on this topic in articles listed under "Particle/powder analysis" in the article archive on *PBE*'s website, www.powderbulk.com.

Katrina Brockbank (katrina.brockbank@freemantech.co.uk, +44-0-1684-851-551) is head of laboratory and powder technologist at Freeman's Gloucester, England, location. She received a PhD in powder flow characterization from the University of Bradford. She's been with the company since 2012 and is experienced in solid state characterization methods.

Freeman Technology
Norcross, GA
770-662-3636
www.freemantech.co.uk