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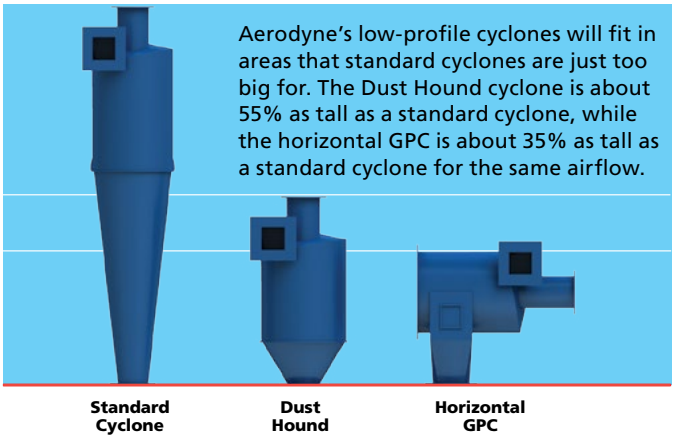

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AD INDEX

Give Vibratory Screens a Fair Shake

Understand the key factors in their selection and use

By Amin Almasi, mechanical consultant

Plants rely on vibrating screens for a variety of duties such as separating, sifting, sorting, dewatering and classifying. Some vibrating screens, if designed properly — i.e., with a full range of adjustments, even can serve as feeders. Today's devices generally boast higher efficiency, lower energy consumption and better reliability than traditional ones, thanks to improved design techniques and accumulated knowledge and know-how. However, success in an application still depends upon proper selection of screens, vibrating mechanisms and auxiliaries.

Many chemical processes require control of the size characteristics of a feed material. The vibrating screen is the most widely used device to split a feed of particulate materials into different grades of coarse and fine materials. Depending upon the degree of material separation and classification required by an application, designs may include two or three decks. In many units, oversize material goes to size reduction equipment for processing to an acceptable size. Even the most efficient vibrating screen will retain some undersize material.

DESIGN, SIZING AND SELECTION

A vibrating screen consists of many different components, e.g., a frame, vibrating mechanism, springs, screen deck(s), liners, etc. Six factors — width, length, screen inclination angle, vibration frequency, vibration amplitude and vibration pattern — are important in the design and operation of vibrating screens. Two parameters — capacity and efficiency — usually define the performance of any vibrating screen.

The crystal phase may be important in drying, transport and storage.

These performance parameters aren't independent; efficiency usually varies inversely with capacity. The screen capacity closely relates to the width. The screen length mainly affects the screening efficiency; the efficiency generally increases with length. The efficiency also depends, to a lesser degree, on the inclination angle, with efficiency declining as the angle gets steeper.

Efficiency could reach up to ≈95% using a screen with large dimensions and the best technologies for everything. This rarely has been attained and requires dedicated and costly tests. In practice, efficiencies of 80–90% are more realistic when using optimized designs. Many modern, properly designed vibrating screens achieve efficiencies of ≈85–88%.

Length-to-width ratio typically is 2.5:1 to 3.5:1. It's not common to achieve efficiencies greater than 80% using a relatively short screen (say, with a ratio of ≤2:1) or angles >30°. Many ordinary and low-cost vibrating screens only attain efficiencies of ≈65–80%, even though their manufacturers claim high efficiencies. Therefore, it's essential to properly evaluate vibrating screen designs and verify claimed performance and parameters.

Inclined screens commonly are used. Many modern vibrating screens rely on an angle between 10° and 25°. In many inclined screens, a single unbalance, rotating on a horizontal axis, generates a simple motion (circular or elliptical) mainly in the vertical plane. This motion imparts little positive movement to particles. Movement mainly stems from the screen inclination and the force of gravity, which cause the particle mass to travel at velocities of ≈0.3–0.6 m/s.

Angles lower than 10° aren't common in conventional vibrating screens. Some specially designed linear-stroke vibrations can allow placing the vibrating screen at shallow angles (say, <10°). However, conventional screens with a circular or elliptical type of vibratory motion often require >15° angles. Screens set at a shallow angle or near horizontal usually employ a pair of unbalances, rotating in opposite directions on parallel horizontal axes, to generate a (nearly) straight-line reciprocating motion,

inclined to the plane of the screen surface at 40°–50°. Velocities on a horizontal surface typically run ≈0.3–0.5 m/s but can be increased if necessary by inclining the screen downward (say, ≈10–15°). On the other hand, steep angles (>35°) aren't common. Always check that a design allows convenient slope adjustment.

Vibration screens come in standard models as well as custom-engineered versions. In standard models, the frame and other major components are fixed; only the screen and a few other items are tailored for each application. This enables relatively fast delivery. In contrast, custom-engineered units are expensive and incur long lead times, making them sensible only for special situations.

Although vibrating screens have been widely used for many decades, engineers and operators at chemical plants often possess only limited knowledge of their design, installation and operation. Generally, the screening operation is complex. Theoretical models offer little practical utility. So, instead, for design, selection and sizing, users typically rely on empirical curves and formulae provided by manufacturers in conjunction with information on the feed rate, particle sizes, etc., to determine the type of screen deck and details such as the width and length of the screen, screen material, aperture size and percentage open area. Each major manufacturer has developed its own set of curves and formulae. However, many textbooks and handbooks present the curves and formulae from the same well-known manufacturer.

Operational flexibility is important to deal with changes in feed materials or processing conditions as well as emergency situations. For instance, proper operational parameters can enable screening of different feed materials such as sticky and adhesive bulk solids by utilizing automatic and repetitive pulsing vibrations.

Besides classification, another well-known application of vibrating screens is for dewatering. This can involve two different tasks: separating free water and removing surface moisture from the wet materials. The rate of dewatering usually depends on the instantaneous moisture content of wet materials as well as the amplitude of the vibration. In general, a vibrating screen with larger vibration amplitudes provides better dewatering performance.

VIBRATORY MOTION FACTORS

Vibrating screens are characterized by dynamic motions mostly in the vertical plane (although many different patterns have been used for vibration of screens). The acceleration of such movements typically ranges from 3 to 6 g or even more. The lifting and dropping effect expands the effective screening bed. Pure vertical motion gives individual particles limited opportunity for finding and passing through

The performance of a vibrating screen can be optimized for any application by changing the vibration amplitude and frequency.

an opening. Added horizontal motion can resolve this issue and spread materials over the screen. On the other hand, the vertical force component acts to eject near-size particles stuck in the openings, thus resisting progressive blinding, and the turbulent expansion of the material bed prevents packing. Therefore, effective screening usually requires a proper combination of vertical and horizontal vibration.

The performance of a vibrating screen can be optimized for any application by changing the vibration amplitude and frequency. The screening rate and performance respond more to changes in amplitude than frequency, although higher frequencies are useful to increase resistance to near-size blinding, etc. As a general rule, the amplitude should go up if particle size or bed depth increases, with frequency adjusted to maintain peak acceleration in the required range (often, as noted, 3–6 g, and, most commonly, ≈4.5–6 g, for many applications).

As working capacity (feed rate) is increased, the vibration amplitude also should increase. However, the optimum depends on the particular application. Generally, as feed rate goes up, efficiency declines even for optimized designs.

The strength of the screen and equipment imposes limits on vibration amplitude but you generally can vary frequency (say, up to ≈50 Hz). A good recommendation is to use variable speed options for the screen vibratory excitation to better optimize operation. In some very special designs, where the screen is delicate and vibration amplitude is seriously limited, raising the frequency and using a relatively steep inclination angle, say, even 35–40°, may partially compensate.

The mass of material handled by a unit always varies somewhat; this causes a change in vibration characteristic, specifically, natural frequencies and vibration amplitudes. The situation is far more complicated than ones in simplified vibration models. Vibrating screens come in three dynamic categories: pre-resonant, resonant and super-resonant. Many screens in practice operate as pre-resonant or super-resonant systems. An important consideration is to minimize the variation in

the vibration amplitude; considering chaotic changes in mass and other dynamic characteristics that can result in amplitude changes if equipment works at resonance, operation at resonance generally isn't recommended.

Vibrating screens usually are supported on compression springs, either steel coils, rubber or pneumatic. Fixed at one end, the other end should follow the motion of the vibrating system. The resistance of the spring to displacement in both vertical and horizontal directions determines the amount and direction of force transmitted through the spring to the supporting foundation or framing. The static load supported by each spring is simply the weight of the vibrating system divided by the number of springs; the static deflection is the same weight divided by the total stiffness. Steel coil springs find wide use with vibration screens; they present linear behavior. For reasons of stability, the steel coil springs' maximum static deflection generally is limited to ≈15 mm, with lower values, say, ≤9 mm, most commonly selected. Rubber springs have a nonlinear load/deflection curve, so they only are used in special designs. Pneumatic springs can offer nearly linear behavior but also only suit special applications. Stresses resulting from transmitted vibrations, superimposed on static stresses due to static loading, can cause fatigue failures in the spring system or structural connections.

OPERATION, RELIABILITY AND MAINTENANCE

The basic operation of a vibrating screen is simple. The screen presents a barrier to the passage of oversize material but passes undersize material. Vibration facilitates this process by creating the movement needed to ensure that each particle has opportunities to reach the screen. In fact, each particle should receive several opportunities to pass through the screen. However, the actual screening process isn't quite that simple. It involves many side effects and complicated sub-activities; all of these require very careful review and consideration. For instance, the motion imparted to solid particles during screening can generate dust. It also can result in the particles becoming electrostatically charged. Static charges can lead to screen blinding and significantly reduce the efficiency of the screen. In general, blinding is a major issue with any screen. In addition, static charges can act as an ignition source, which can be a major risk for some applications. All the metal components of the screen system, e.g., screens, frames, etc., require proper grounding and bonding. This will remove the charges from the system itself but a residual charge may persist on the solids. Handling materials such as ignitable particulate solids demands more care. For example, you must limit relative velocities caused by the movement (such as vibration, shaking, oscillation, etc.); as a rough guide, they should be <1 m/s.

Proper bearing selection and sizing is crucial.

Loads on a vibrating screen or hard connections to upstream or downstream equipment can affect the natural frequencies of the system and its vibration. As examples, hoppers with their contents, ducts, other equipment, etc., often are supported by the vibrating screen frame — and can impact system performance.

Vibratory screens frequently use an isolation system or a flexible connection to minimize the forces transmitted to the surrounding equipment and structures. The benefit of flexible connections does come at a price, though, because they are weak points in the system for reliability. Design of flexible connections and evaluation of their reliability and life requires care.

Reliability and maintenance also are important issues for the vibratory screen itself, of course. Along with regular exposure to the erosion, corrosion and other abuses from materials handled, vibrating screens experience high vibration and heavy dynamic loads. Many other adverse effects such as those from dust generation, etc., also can afflict the device. So, not surprisingly, frequent component failures have been reported.

Material and design details of screens need adequate attention. Strong construction is essential; all components subject to particularly severe stresses or dynamic loads require very careful design and fabrication. Bearing issues have been a major problem. Proper bearing selection and sizing is crucial. In addition, the bearing should be installed away from the working areas of the equipment and far from handled materials — and kept dust free.

Finally, ensure that screen changing is easy and straightforward, and that deck clamping and tensioning arrangements allow for convenient, reliable and safe screen deck maintenance. Use abrasion-resistant and readily replaceable liner pieces to protect screen structural elements. ●

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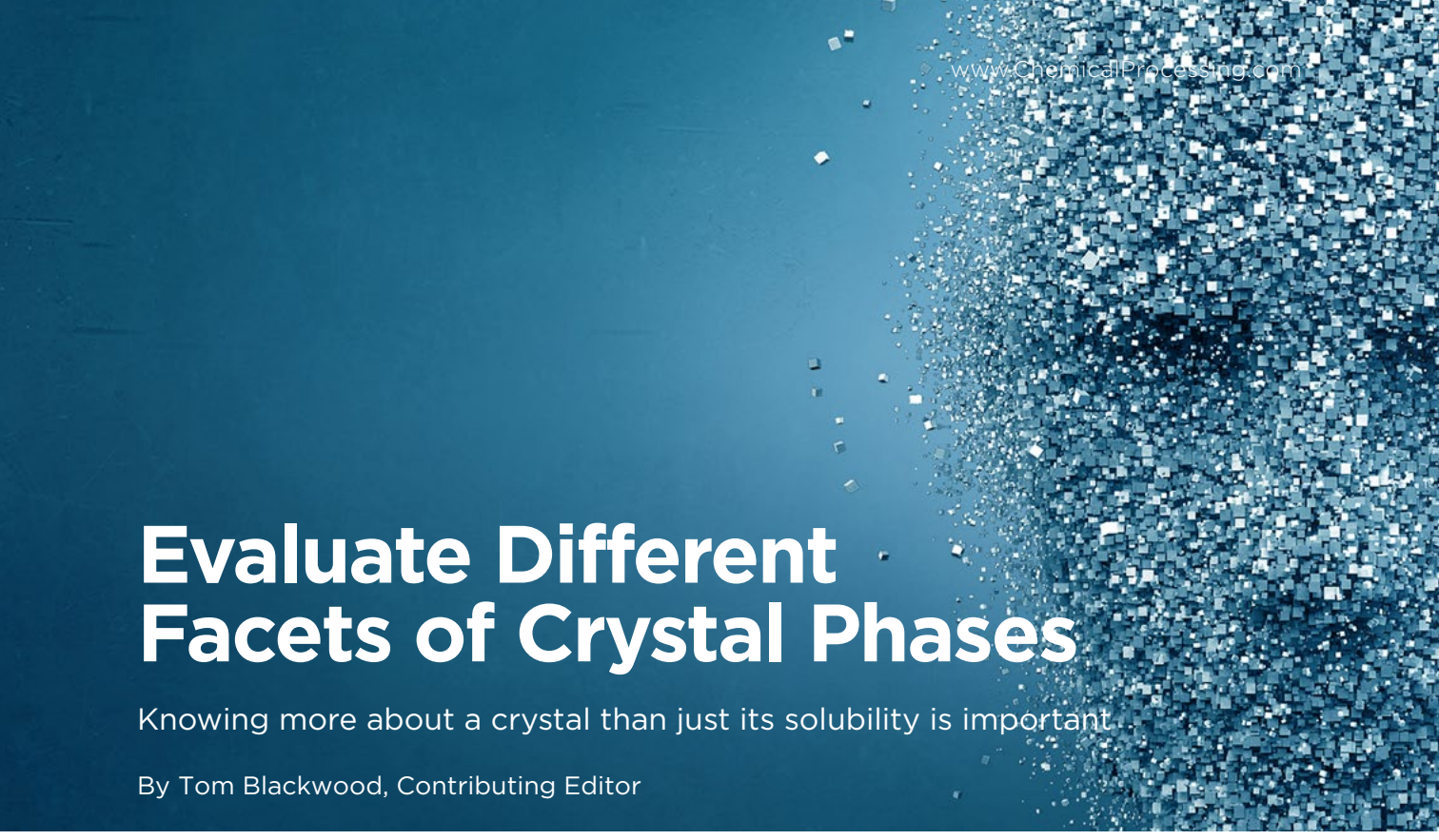

Evaluate Different Facets of Crystal Phases

Knowing more about a crystal than just its solubility is important.

By Tom Blackwood, Contributing Editor

If you have a crystallizer or are planning to install a crystallization process, then you know the importance of solubility curves. Yet, it's amazing how many plants run without such curves or use ones that are ancient, perhaps many decades old. Empirical data underpinned the development of these old-time processes, which probably will run forever without any changes — at least we hope so. However, hope isn't a strategy or a plan. Something such as a raw material will change or customers will want a different particle size distribution.

This is when I show up asking for data such as a solubility curve, and pose a lot of questions about the crystals and the process. Even plants that have a curve are stymied when I ask about potential crystal phases such as polymorphs or solvates. The concern I have for crystal phase isn't limited to the crystallization process; this physical property may be important in drying, transport and storage of the chemical.

I can't emphasize enough the need to look very hard for the existence of these phases along with any temperature sensitivity. Any heat flux that shows up during temperature changes is a concern. We were developing a new pharmaceutical and in the final stages of getting U.S. Food and Drug Administration approval when the solubility of a batch changed dramatically; we even saw a slight shift in the x-ray pattern. When I asked about polymorphs, the team responded that it didn't think any existed. However, one chemist said she may have seen one. Molecular modeling identified six potential polymorphs; two were robust. The

The crystal phase may be important in drying, transport and storage.

problem was resolved by avoiding a temperature region that allowed one of these polymorphs to form.

I've mentioned phase in previous columns (for example, see, "Get a Solubility Curve," http://bit.ly/2JR2P5M). Here, let's look at some tools for identifying polymorphs and solvates to help you avoid or address production problems, or allow you to produce a more desirable product:

Molecular modeling. This is a theoretical method and computational technique that attempts to mimic the behavior of molecules. Many advances have occurred in this technology. Hand calculations can define simple systems. The common feature of molecular modeling is the atomic level description of the molecule. You can treat atoms using molecular mechanics or by explicitly modeling electrons using a quantum chemistry approach. I ran some rather crude computer programs over 20 years ago to identify the polymorphs in the pharmaceutical problem cited above.

X-ray diffraction. This method will identify structural differences of a material. By measuring the angles and intensities of a diffracted beam, a chemist can produce a three-dimensional picture of the crystal. It's important to look at material produced under different conditions to identify the most stable crystal form and any polymorphs.

Differential scanning calorimetry. Many variations of this technique exist but the basic idea is to identify phase changes as a sample is heated. The amount of energy absorbed or released may indicate a polymorph or solvate.

Raman and infrared spectroscopy. Raman spectroscopy is a technique to observe vibrational, rotational and other low-frequency modes of a chemical. It can identify molecules that have a slight variation in structure. Infrared is another method that can serve for quantitative analyses of unknown substances or to determine the structural properties of known substances.

The most important conclusion you can reach is the identification of the most stable form of the chemical.

Microscopy. It's amazing what you can learn from looking at your product under an optical microscope. However, a scanning electron microscope or a transmission electron microscope will reveal differences in the surface or composition of the sample and help identify structural distinctions that indicate the presence of different chemicals.

Drying rate or critical moisture. Often solvates or polymorphs dry differently due to altered heat capacity caused by their distinct structure.

The most important conclusion you can reach by using these methods is the identification of the most stable form of the chemical. If that form is the most effective product (e.g., the drug that works the best), the additional information about when an unstable form occurs will allow you to always make the desired product. If an unstable form is more effective, then these data will allow you to tailor your process to avoid the stable product.

TOM BLACKWOOD, Contributing Editor

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Get a Handle on Solids' Flow

Some simple parameters often provide a good sense of flowability

By Don McGlinchey, Glasgow Caledonian University

Properly accounting for how bulk solids actually will flow in a vessel or overall process can be crucial for successful operations. So, in this article (see sidebar), we will look at two parameters — the Compressibility Index and the angle of repose — that can help. While neither provides definitive answers about "flowability," they do give rough guidance about how a material is likely to behave.

However, before we discuss these parameters, it is important to understand bulk density. It is probably one of the most common and widely used of the bulk characteristics. It is employed to determine wall loading in hopper design, to size volumetric feeders, such as screws and rotary valves, to estimate "flowability," and in many other ways. It is rather unfortunate then that such a useful characteristic is not a constant for a given material. The bulk density of a material is simply the mass of material divided by the volume that it occupies. The density of the particles themselves can be taken as constant; however, the complication arises because the amount of "space" between the particles depends upon how the material has been handled before the measurement. The volume that a unit mass of product can occupy can differ by 50% between the material being in a compressed and a very loose state. Cement, for example, has a compacted bulk density of 1,400 kg/m^3 and an aerated bulk density of 1,000 kg/m^3. It is obviously important that the correct bulk density value is selected for any calculation.

MATERIAL	TAPPED BULK DENSITY, KG/M³	POURED BULK DENSITY, KG/M³	PARTICLE DENSITY, KG/M³
Iron powder	3,410	3,360	7,200
Aluminum powder	1,220	1,095	2,650
Cement	1,400	1,100	2,700
Nylon pellets	680	680	1,140

TYPICAL BULK DENSITIES
Table 1. Poured and tapped bulk densities may differ significantly for some materials.

MATERIAL	SHAPE	POURED ANGLE, DEGREES	DRAINED ANGLE, DEGREES	DYNAMIC ANGLE, DEGREES
Tapioca	Spherical	30	37.5	32
Sand	Angular	37	39	36.5
Coal	Angular	37.5	41	34

ANGLES OF REPOSE
Table 2. As with most materials, these three provide different results in each test method. (Data from Ref. 2.)

BULK DENSITY

The full expression for bulk density is:

$$\rho_b = \frac{Mass_{solids} + Mass_{spaces}}{Volume_{solids} + Volume_{spaces}} \quad (1)$$

For dry bulk solids, the void spaces would usually contain air or some other gas, the density of which can be taken as negligible compared to the density of the solid particles; so, we can approximate:

$$\rho_b = \frac{Mass_{solids}}{Volume_{total}} \quad (2)$$

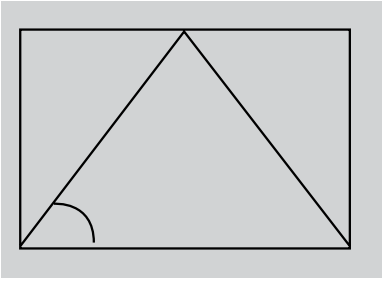
We can relate this to another common characteristic, voidage or void fraction, which is the percentage of the total volume not occupied by particles:

$$\varepsilon = \frac{Volume_{spaces}}{Volume_{total}} \quad (3)$$

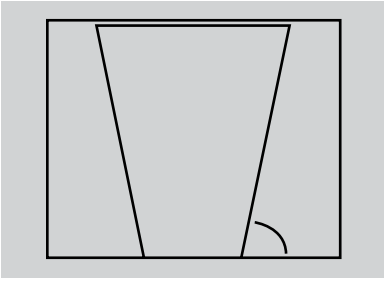
Again, assuming air or gas in the void spaces and taking particle density as rp, we can write:

$$\rho_b = \rho_p(1-\varepsilon) \quad (4)$$

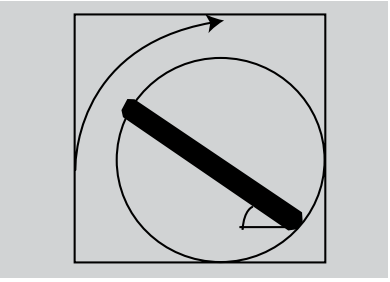
To illustrate the range of values that voidage can take, consider a static heap of mono-sized spheres. If the spheres are in a regular hexagonal packing (the classic "cannon ball" stack), the voidage would be 26%. In contrast, if they were in regular cubic packing, the voidage would increase to 48%. However, even this does not represent the loosest packing possible for large smooth identical spheres. The cannon ball stack gives each ball six contact points, but simple static mechanics requires only two contact points below the center of gravity of the ball for equilibrium. Therefore, it is



POURED ANGLE OF REPOSE
Figure 1. Angle is measured from a heap formed by pouring material onto a flat horizontal surface.



DRAINED ANGLE OF REPOSE
Figure 2. Angle is measured on the internal conical face formed by discharge of a material through an orifice.



DYNAMIC ANGLE OF REPOSE
Figure 3. This is the angle to the horizontal of the free surface of material in a slowly rotating drum.

possible to have a stable structure with far fewer contact points and a resulting increase in voidage [2]. If the particles are irregular in shape, have a size distribution and in some way cohere to one another, the packing arrangement can be very loose and so the voidage can be very large.

Measurement of bulk density is, in theory, quite simple; it only requires a knowledge of material mass and volume and is generally based on one of two techniques.

The first is to weigh out a quantity of material using a simple balance and put this into a calibrated cylinder in much the same way as you would a liquid. If the particulate material is poured into the cylinder, the volume taken up would be of the material in a loose or poured state; the associated bulk density is commonly described as "poured bulk density." If this same cylinder is then tapped or dropped from a small height onto the bench several times, the volume would likely decrease and the new value is called the "tapped bulk density." Similar techniques can be used to determine aerated bulk density from a fluidizing column or compacted bulk density from a material placed under load.

The second technique is to fix the volume of the bulk material by filling a cup-like vessel to overflowing and then leveling it with a straight edge. The vessel then is weighed on a balance and the bulk density calculated. This approach gets around some of the problems of trying to estimate the actual level of powder in a cylinder with a surface that typically is anything but flat and seeing through a glass that has become coated in powder. Table 1 lists typical bulk density values for a few common materials.

One possible complication with bulk density measurements is the effect of the porosity of the particles themselves; so, to avoid ambiguity, it is worthwhile stating whether

These relatively quick and easy measurements can be effective in giving some indication as to how powders will likely behave.

the bulk density value is inclusive or exclusive of closed pores. Confusion could arise if the method of determining particle density does not take account of internal voids. (Using a helium pycnometer, which determines particle density by a measure of displaced gas, may be advisable when porosity is a factor. The gas generally can penetrate open pores as long as these are not comparable in size to the gas molecule but obviously cannot penetrate closed pores.) These differences become important if, for example, we are concerned with surface area available for reaction or the total solids' fraction available for reaction.

FLOWABILITY BASED ON BULK DENSITY

Bulk density measurements have been used to give some qualitative prediction of the flowability or "handlability" of a bulk solid — that is, some estimate of the likely ease or difficulty in dealing with these materials. One such predictor is the often-quoted Hausner ratio:

$$H = \frac{\rho_b tapped}{\rho_b aerated} \quad (5)$$

Another close relative is Carr's Compressibility Index:

$$CI\ [\%] = \frac{\rho_b tapped - \rho_b aerated}{\rho_b aerated} \times 100 \quad (6)$$

The percentages provide a means to rank materials:

5-15%	free-flowing to excellent flow — granules
12-16%	free-flowing to good flow — powders
18-21%	fair to passable powdered granule flow
23-28%	easily fluidizable powders — poor flow
28-35%	cohesive powders — poor flow
33-38%	cohesive powders — very poor flow
>40%	cohesive powders — very very poor flow

These relatively quick and easy measurements can be effective in giving some indication as to how powders will likely behave but are by no means

comprehensive; exercise some caution if relying only on this information.

ANGLE OF REPOSE

Another parameter that is used to determine flowability is the angle of repose, which is defined as the angle of the free surface of a heap of particulate material to the horizontal plane. Unfortunately, we are faced with the same problem that we were with bulk density — the angle of repose is not a constant for a given material and depends upon the method of heap formation. There again are two measurements commonly quoted: the poured angle of repose and the drained angle of repose. The poured angle of repose is the angle measured from a heap formed by pouring material on to a flat horizontal surface (Figure 1). The drained angle of repose is the angle measured on the internal conical face that has been formed when material is drained from a orifice on the flat horizontal bottom of a container (Figure 2). A third angle of repose that you may come across is the dynamic angle of repose, which is the angle to the horizontal of the free surface formed in a relatively slowly rotating drum (Figure 3).

Be aware of several things when using angles of repose: First, the angle formed will depend upon the details of the formation process. For example, the fall height for the poured angle or the orifice size for the drained angle will influence the angle. Therefore, the angle measured is not independent of the measuring apparatus. Second, the same material tested using the three techniques will give a different angle for each (Table 2). The measurements only can be reliably made when using powders that are free-flowing to slightly cohesive and are fairly homogenous. Materials that are a mixture of components or that have a wide size distribution will give angles that are difficult to determine and suffer low repeatability. There also are some uncertainties based on the fundamental physics of the problem, relating to stress history and avalanche behavior [2, 3].

Despite these difficulties, the angle of repose in whatever form can be a useful tool to rank materials. As a rough guide, the relationship between the angle of repose and flowability often follows the structure below:

Angle of repose, degrees	Flowability
25-30	very free-flowing
30-38	free-flowing
38-45	fair flowing
45-55	cohesive
>55	very cohesive

This classification allows us to make some judgment on the likely flow behavior of a material but has very limited value for equipment selection and design. In particular, it is a mistake to use the angle of repose in an estimate of the wall angle required for the converging section of a hopper.

There is no obvious benefit in combining both test results into a single index value.

However, the angle of repose can serve in some cases to estimate the surcharge (the material at the top of a hopper which forms a "heap") in a storage vessel or the ground area requirements when forming a stockpile.

ROUGH GUIDANCE

The Compressibility Index and angle of repose both give some indication of flowability under different flow conditions, although the applied stresses in both cases can be considered to be relatively low. There is no obvious benefit in combining both test results into a single index value; both may be usefully applied separately to benchmark or rank materials based on known plant performance. For example, if you have experience that a material with a particular flowability value passes through a chute or indeed an entire process without difficultly, then you may expect that a different material with the same flowability value also will not cause problems. (Most times, you will be correct.) However, a material with a worse flowability value needs be treated with more caution. Plants suffering from poor performance require more detailed testing to establish the cause(s) of the flow difficulties or product hangups.

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EHANDBOOKS

Check out our vast library of past eHandbooks that offer a wealth of information on a single topic, aimed at providing best practices, key trends, developments and successful applications to help make your facilities as efficient, safe, environmentally friendly and economically competitive as possible.

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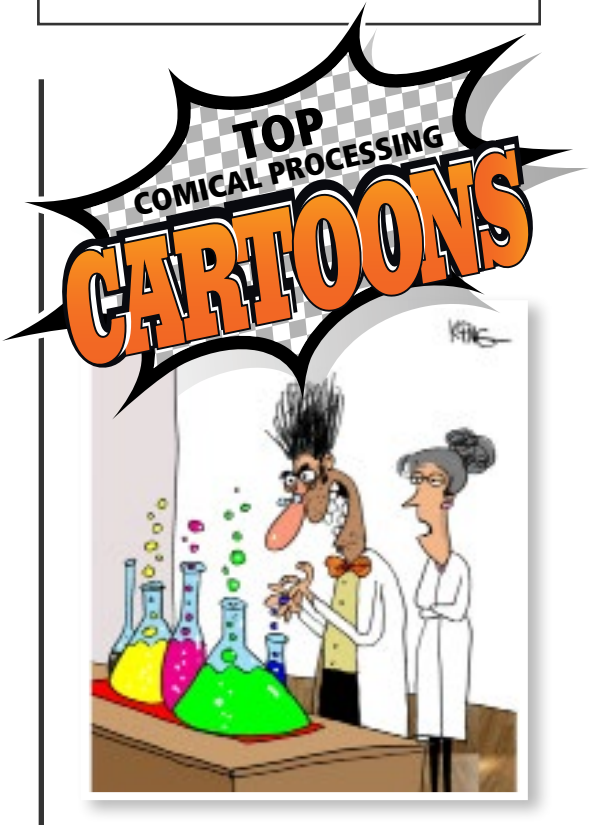

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