Powder Pointers

Summary 2013 Volume 7 No B

Brought to you by: **Material Flow Solutions, Inc.**

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Eliminating Material Hang-up

Background. Two conditions must be satisfied for trouble free process operations using powder materials: the outlet must be large enough to overcome cohesive arching of bulk materials, and the active flow channel must be larger than the critical rathole dimension. But, how large is "large enough," and what is the "critical" dimension which will mitigate rathole formation? All powders have flow properties that can be measured as a function of time and exposure. The properties include unconfined yield strength, wall friction angle, density, and permeability. Both arching and rathole conditions must be overcome to assure reliable flow.

Unconfined yield strength is the major principle stress that will cause material in an unconfined state to fail in shear. It is the primary flow property that governs the development of hang-ups in process equipment. It is used to compute critical arching and rathole dimensions for a given material in a hopper or bin. All hang-ups in process equipment result in the formation of a free surface. By definition, the stress acting normal to any free surface is zero. However, stresses acting along the free surface may not be zero (Figure 1). In a hang-up condition the material on a free surface is supported by stresses that act along the free surface and are equal to the unconfined yield strength of the material.

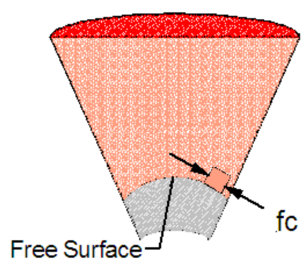

Figure 1. Typical arch in process equipment

Wall friction angle is the angle of slide under normal gravity flow for a given bulk solids against a particular wall surface finish. It is a function of the stress level applied to the wall surface as well as the temperature of the bulk material and wall surface. It is measured by heating material to a given temperature, placing it in a cell on a given wall sample plate, applying a normal pressure to the bulk material, and then inclining the plate until the material slides. The angle measured from the horizontal is the wall friction angle. Because bulk solids obey a columbic frictional behavior against container and process equipment surfaces, wall friction angle is used to determine mass flow / funnel flow behavior in bins and hoppers. Friction angle is also is used to determine velocity profiles in process equipment.

Bulk density is the weight of the particles divided by the combined volume of the particles and the interstitial voids surrounding the particles. It is a function of the stress level and strain history of the material. At Material Flow Solutions we measure bulk density using uniaxial compression

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In This Issue

Upcoming Conferences

Dr. Kerry Johanson will be presenting at upcoming conferences worldwide:

PBE The POWDER SHOW 2013

Powder & Bulk Engineering

Midwest Conference & Powder Show

May 23, 2013: Columbus, Ohio
Thursday morning, 8:00 – 11:00
"Optimizing Product Quality through Particle Size Reduction"

IChemE ADVANCING CHEMICAL ENGINEERING WORLDWIDE

Annual IChemE PTSIG Mtg

Conference on Product Quality in Particle Technology
September 19-20, 2013:
Newcastle, United Kingdom
"Powder Segregation"

AIChE American Institute of Chemical Engineers

Annual Meeting
November 3-8, 2013:
San Francisco, California

Dr. Johanson will chair one session "Aeration Effects on Hopper Flows" and present 3 papers (topics TBA) of a loosely packed bulk material. It is a function of the temperature of the bulk material as well as moisture content and particle size. It is used, along with the permeability characteristics of the bulk material, to determine the limiting rates of particulate materials. It is also used to determine the ability of a given powder to store entrained air. We have identified two distinct density values that are useful in characterizing the behavior of the bulk material. The first density is the density at the hopper outlet (FDI, feed density index). It is the density at low solids contact pressures and describes the density leaving the process equipment it is used to compute mass flow rates from volumetric flow rates. The second density value is the average density of the bulk material within the process equipment (BDI, bin density index). It is measured at higher solids contact pressures and is used to quantify the mass of material stored within the process equipment.

Permeability is the superficial velocity of gas or fluid passing through the bulk material when the pressure drop across the bulk material equals the weight density of the bulk. It can be thought of as an incipient fluidization velocity, except that it is measured as a function of the stress applied to the bulk material. However, the value of the permeability extrapolated to zero stress is identically equal to the incipient fluidization velocity. Permeability data is used to determine the pressure drops in packed bed operation. It is also used to determine the limiting flow rates where the resistance to gas flow is the key limiting factor to solids flow.

Figure 2. Material arch in a funnel-flow hopper

Using the Measured Flow Properties to Prevent Material Hang-up. The cohesive property information (unconfined yield strength) provides the critical arching and rathole dimensions required to prevent hang-up. The wall friction angles provide information required to help specify feed hopper angles that will cause flow along bin and hopper walls. The friction test will also provide information concerning the adhesion of material to equipment and walls. These friction angles and cohesive properties will give an indication of the velocity profiles present in the process equipment. Although bulk density may seem like an intrinsically simple property, it is critical (along with the measured material permeability value) to determine limiting flow rates for process equipment. Permeability information is also used in determining the time required for material to lose entrained air.

Critical conical arching dimension is the smallest span of a conical hopper that will prevent arching of the bulk material. It is a function of the material's unconfined yield strength and storage time in the vessel. The conical hopper must have an outlet at least this big to prevent stable arch formation from occurring. Plane flow hoppers can have hopper widths about ½ as wide and still prevent stable arch formation. The critical arching dimension is also a small function of the bin size and, hence, is usually associated with a calculation basis which represents the approximate size of a given bin geometry.

Critical rathole dimension is the size of the largest flow channel that will result in stable rathole formation in funnel flow bin design. The active flow channels in a funnel flow bin must be greater than this value to prevent stable rathole formation. It is important to note that ratholes cannot form in mass flow hoppers. The critical rathole dimension is a function of the maximum stress level in the bin and, hence, depends on the maximum diameter of the bin.

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Powder Pointers Preview

Coming Next Quarter – Blending Powders for Optimal Performance

Blending of powders occurs because of velocity and velocity profiles in a blender. Any material properties, operation conditions, and/or geometry constraints that modify these velocities and velocity gradients will affect blending, either positively or negatively. Choosing the proper blender for the material is best based on a combination of sound scientific principals, key material flow properties, and the accurate prediction of velocity profiles in the blender. In our next edition of the Powder Pointers Newsletter, we will examine some of these relationships between blending velocity profiles, material flow properties, and process geometry effects.

Future Topics

To put you at the cutting-edge

- Robust product design
- Making the process work for you – optimize your design
- Managing agglomeration

We encourage and welcome your suggestions and special requests for powder flow topics which you would like to see included in future editions of *Powder Pointers.*

Contact: Susan at 352-379-8879

Eliminating Material Hang-up

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Recommended mass flow angle represents the slope angle of the conical hopper measured from the vertical that will produce flow along the walls. Conical hoppers must be steeper than this to cause flow along the walls. Ultimately the recommended mass flow angles are a function of the shape of the bin. Plane flow hoppers converge in one direction at a time and also have a recommended mass flow angle that will produce flow along the walls. However, plane flow angles generally can be about 10 to 12 degrees flatter than corresponding conical angles and still achieve mass flow. It is also important to point out that mass flow does not mean plug flow. Substantial velocity gradients can exist in mass flow bins. The recommended mass flow angle also depends on the solids contact stress in the bin. The stress level in a given bin depends on the position in the bin. We compute the range of pressure expected in a given bin configuration and then use the worse case friction angle in this stress level range to compute the recommended mass flow angle. Generally, the recommended mass flow angles are for flow in a conical hopper.

Table 1: Technical Data Sheet for a Pulverized Powder

Technical Data Sheet for Powder					
Effective density leaving process (Feed density index FDI) Density leaving a process is a function of the solids contact pressure at the outlet (Dout).					
Outlet Diameter			Dout = 0.5 ft	Dout = 0.8 ft	Dout = 1.0 ft
Bulk Density FDI (pcf)			54.845	56.493	57.806
Effective density in process equipment (Bin density index BDI) Density in process equipment is a function of the maximum size of the bin (Db). Bin density index (BDI) is computed assuming a standard cylindrical bin with a 2:1 height-to-diameter ratio.					
Bin/Equipment Diameter	Db = 2.0 ft	Db = 4.0 ft	Db = 6.0 ft	Db = 8.0 ft	Db = 10.0 ft
Average Bulk Density BDI (pcf)	66.59	71.26	74.18	76.34	78.06
Critical Rathole Dimension (RI) in process equipment in (ft) Critical rathole dimension is a function of the maximum size of the bin (Db). Rathole index (RI) is computed assuming a standard cylindrical bin with a 2:1 height-to-diameter ratio.					
Storage Time in (hr)	Db = 2.0 ft	Db = 4.0 ft	Db = 6.0 ft	Db = 8.0 ft	Db = 10.0 ft
0	1.07	1.38	1.65	1.91	2.15
2	1.22	1.54	1.82	2.09	2.34
16	1.69	1.93	2.16	2.39	2.60
Critical Arching Dimension (AI) in process equipment in (ft)					
Storage Time in (hr)			Dout = 1.0 ft		
0			0.60		
2			0.69		
16			1.01		
Limiting Flow Rates for Powder Limiting flow rate is a function of both the maximum consolidation stress and the stress value at the outlet. Limiting flow rates computed here are based on the maximum size of a typical mass flow bin (D_b) and the outlet sizes specified (D_o). Limiting flow rate is computed assuming a standard cylindrical bin with a 2:1 height-to-diameter ratio.					
	Limiting Flow rate in (ton/hr) for max bin diameter of				
	Db = 2.0 ft	Db = 4.0 ft	Db = 6.0 ft	Db = 8.0 ft	Db = 10.0 ft
Dout = 0.5 ft	0.13	0.10	0.09	0.08	0.08
Dout = 0.8 ft	0.27	0.20	0.17	0.16	0.15
Dout = 1.0 ft	0.47	0.33	0.28	0.26	0.24
General Comments	Limiting flow rate may be a problem if the process flow rate is greater than flow rates listed above				
Approximate Settlement time in 10.0 ft diameter bin that is 20.0 ft tall. Settlement time in (min)			113.57 (min) High flooding and flushing potential		

Limiting Flow Rate. Permeability and bulk density are used to compute the limiting flow rates of a given material in a particular hopper geometry. Two things limit the flow of a bulk material through a hopper subject to gravity feed conditions. The converging nature of the hopper will cause an increase in velocity which can not cause accelerations greater than gravitational accelerations. This limiting flow rate is typically high and characteristic of flow of coarse granular materials. Fine powders pose another potential flow rate limit. Fine materials consolidate as they flow through a bin. If consolidation occurs slowly, then the gas found in the interstitial voids of the bulk material leaves the material through the top surface. As this compressed and de-aerated material approaches the hopper outlet, it must expand to flow from the outlet. This expansion results in a negative gas pressure formation near the hopper outlet. Gas attempts to rush in to equalize this negative gauge pressure. If the permeability is low, this process takes time. The negative gas pressure gradient persists, resulting in partial support of material flowing from the outlet and creating a very slow flow rate through the hopper. Both the compressibility and the permeability of the bulk material are required to compute the value of this rate limitation. Generally, this problem occurs with fine powders, but it can also happen in granular material subject to adverse gas pressure gradients during processing. Table 1 contains calculated dimensions for a process of bins and hoppers that will successfully handle the bulk material free of hang-ups. Table 2 is a summary of the material flow properties for the measured material, including flow rate, hang-up and hopper angle indices. From these calculations, system parameters can be determined.

- The measured wall friction angles indicate that rough steel mill finish conical hoppers must be steeper than 10 degrees to achieve flow along the walls and smoother stainless steel walls must be 16.5 degrees to achieve the same acceptable flow (Table 2).

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- Pulverized powder has significant limiting flow rates. It will also hold onto entrained air for long periods of time, and will have a significant tendency to cause flooding and flushing in bins and hoppers. Air injection systems will be needed to maintain consistent flow rate control of this material (Table 1).
- Pulverized powder will likely arch over 1-foot conical outlets and mass flow hopper such as a Diamondback® hopper will be required to help prevent arching of this material (Table 1).
- This material will also be moderately sensitive to rathole formation and mass flow should be used up to about 2.6-feet in diameter in bins that are about 10-feet in diameter (Table 1).

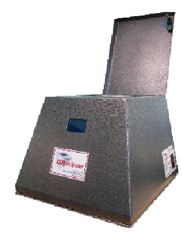
Table 2: Summary of Material Flow Properties for a Pulverized Powder

Flow Rate Indices Indices Basis : Dbin =10.00 ft Dout = 1.00 ft			
Bin Density Index BDI	Feed Density Index FDI	Flow Rate Index FRI	Settlement Index SI
(pcf)	(pcf)	(ton/hr)	(min)
78.06	57.81	0.24	113.57
Hang-up Indices Indices Basis : Dbin =10.00 ft Dout = 1.00 ft			
Temperature in	Storage Time in	Arching Index AI	Rathole Index RI
(deg F)	(hr)	(ft)	(ft)
70	0.0	0.60	2.15
70	2.0	0.69	2.34
70	16.0	1.01	2.60
Hopper Indices Indices Basis : Dbin =10.00 ft Dout = 1.00 ft			
Temperature in	Wall Material		Hopper Index in
(deg F)			(deg)
70	304 - 2B SS		16.5
70	304 - #1 SS		10.0

The analysis described above is for typical bin and hopper flow with gravity feed. A similar analysis can be done for conditions where gas is injected into the bulk material, situations where internal mechanical devices are present, or external vibration is induced. Thus, this set of properties also applies to semi-fluidized packed bed, reactor vessels, mixers, blenders, blow pots, pneumatic receiving vessels, leaching vessels, feeders and agglomeration units.

For additional information, please contact: Kerry Johanson at 352-303-9123

A Comparison of Strength Testing Apparatus



The *SSSpinTester* applies the science of centrifugal force to the measurement of unconfined yield strength of fine powders by first consolidating material using centrifugal force and then causing the compacted material to yield using that same centrifugal force. This is why the tester requires such a small material sample – and why the measurement can, with accuracy, be run at such low operating pressures.

Testing Parameter	*SSSpinTester*	Brookfield PFT	Freeman FT4	Hang-up Indicizer	Peschle	Schulze	Sigma Scan
Material required to run test	0.06 gram	300 gram	10 gram	50 gram	200 gram	300-600 gram	300 gram
Test runs required for one strength measurement	1	5	5	1	5	5	5
TOTAL MATERIAL NEEDED	0.06 gram	1500 gram	50 gram	50 gram	1000 gram	1500-3000 gram	1500 gram
Consolidation pressure range (based on BCR limestone)	0.01 – 45 Kpa	1 Kpa +	0.5 Kpa +	1 Kpa +	1 Kpa +	1 Kpa +	1 Kpa +
COST (estimated)	$36,000	$22,000+	$75,000	$33,000	$55,000+	$65,000+	$50,000

Reactive centrifugal force is the reaction force to centripetal force. A mass undergoing curved motion, such as a circular motion, constantly accelerates **toward** the axis of rotation. This centripetal acceleration is provided by a centripetal force, which is exerted on the mass by some other object. In accordance with Newton's third Law of Motion, the mass exerts an equal and opposite force on the object. This equal, but opposite, force is the reactive centrifugal force. It is directed **away** from the center of rotation, and is exerted *by* the rotating mass *on* the object that originates the centripetal acceleration. The concept of reactive centrifugal force, as used in mechanics and engineering, is referred to as just "*centrifugal force*."

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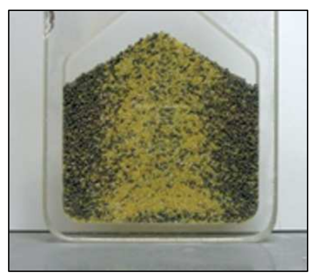
Points to Ponder: From Pharmaceuticals to Catalysts

- All drugs must be "packaged" somehow with excipients in order to be marketable. Material bulk properties **must** be measured at some point in the development process to quantify drug formulations for use in tablet press, tablet fill, and segregation modeling. The *SSSpinTester* can be used to measure bulk properties of pharmaceutical powder at **formulation** time. This will speed time to market by at least six to eight months. Why? Because, in the formulation step of drug development only a few grams of material are created due to very high cost of production. The *SSSpinTester* is the only testing unit that can measure material bulk properties (strength) during the formulation step in drug development – the amount of sample required by other testers prohibits measuring these properties until much later in the process. Having this data sooner rather than later narrows the R&D path – and cuts the time necessary to get a new product to market.
- Catalysts are used in fluid beds to assure good gas contact. The life of a catalyst is directly related to the amount of fines and the ability to fluidize material without channeling. Cohesive properties are a strong function of the amount of fines. Solids contact pressures in a fluid bed are very low. Thus, if you can measure the strength of catalyst material at low consolidation pressures, you can use the data to determine if a catalyst will channel or not – and correlate this with the life of the catalyst in the fluid bed. The *SSSpinTester* measures the cohesiveness of the catalyst powder at actual process operating conditions, thereby avoiding messy manual extrapolation which is inherently inaccurate and time consuming. The *SSSpinTester* accurately measures material strength of fine powders at pressures as low as 30pa up to 50Kpa. With this information, scientists and engineers can accurately predict the effective catalyst life.

Learning the Trade – Mechanisms of Segregation

Knowing and understanding key material properties is power to characterize bulk material flow behavior. We will empower you quarterly as we discuss one of these fundamental flow properties and its industrial application.

Segregation occurs through several mechanisms. Identification of the segregation cause and pattern produced through handling is critical to prevent de-mixing during handling and packaging. Any property difference between materials can cause separation of critical material components, although there are five common causes of segregation problems in typical handling systems. In this Newsletter, we will discuss one of the primary causes of segregation as well as best practices to eliminate or mitigate the condition. Subsequent issues will discuss other mechanisms and their prevention.



Sifting segregation

Sifting Segregation. In a mixture of multiple components, fines may sift through a matrix of coarse particles during handling. Sifting segregation that void space between adjacent particles be large enough to permit fine particle to pass through (a particle size difference of about 3:1). Inter-particle motion is required to provide a means of exposing empty void spaces to fine particles and fines must be free flowing enough to prevent arching between adjacent particles. In general, this sifting segregation produces a radial pattern as material forms a pile in process equipment. Fines accumulate near the pile charge point and decrease in concentration toward the pile edge. In each case, components separate due to differences in particle scale properties. Understanding the relationship between particle scale properties and segregation potential leads to development of models which relate the properties to segregation behavior.

To develop these models, the component segregation patterns and magnitudes caused by typical process behavior must be measured. Additional material flow properties such as moisture content, surface tensions, particle size, particle shape, bulk strength, repose angles, and particle roughness must also be measured. These segregation and material flow measurements can be coupled with modeling to describe process segregation behavior and particle scale laws relating segregation driving forces to segregation magnitudes (i.e. how bad is the segregation). Knowing how fine and coarse particles interact in your mixture to cause sifting segregation, and how that material reacts within your specialized process parameters, decisions can be made for product modification to eliminate or greatly reduce segregation. Ascertaining that sifting segregation is indeed the primary mechanism is the first step. Determining which component(s) is "bad-acting," and how the components interact with one another, is the second step. Product modification based on this data is the third step. Sometimes simply changing the size of one or more mixture component achieves the desired goal. However, making decisions based on measured material properties and sound scientific principles takes the guess-work out of the process and speeds time to market.