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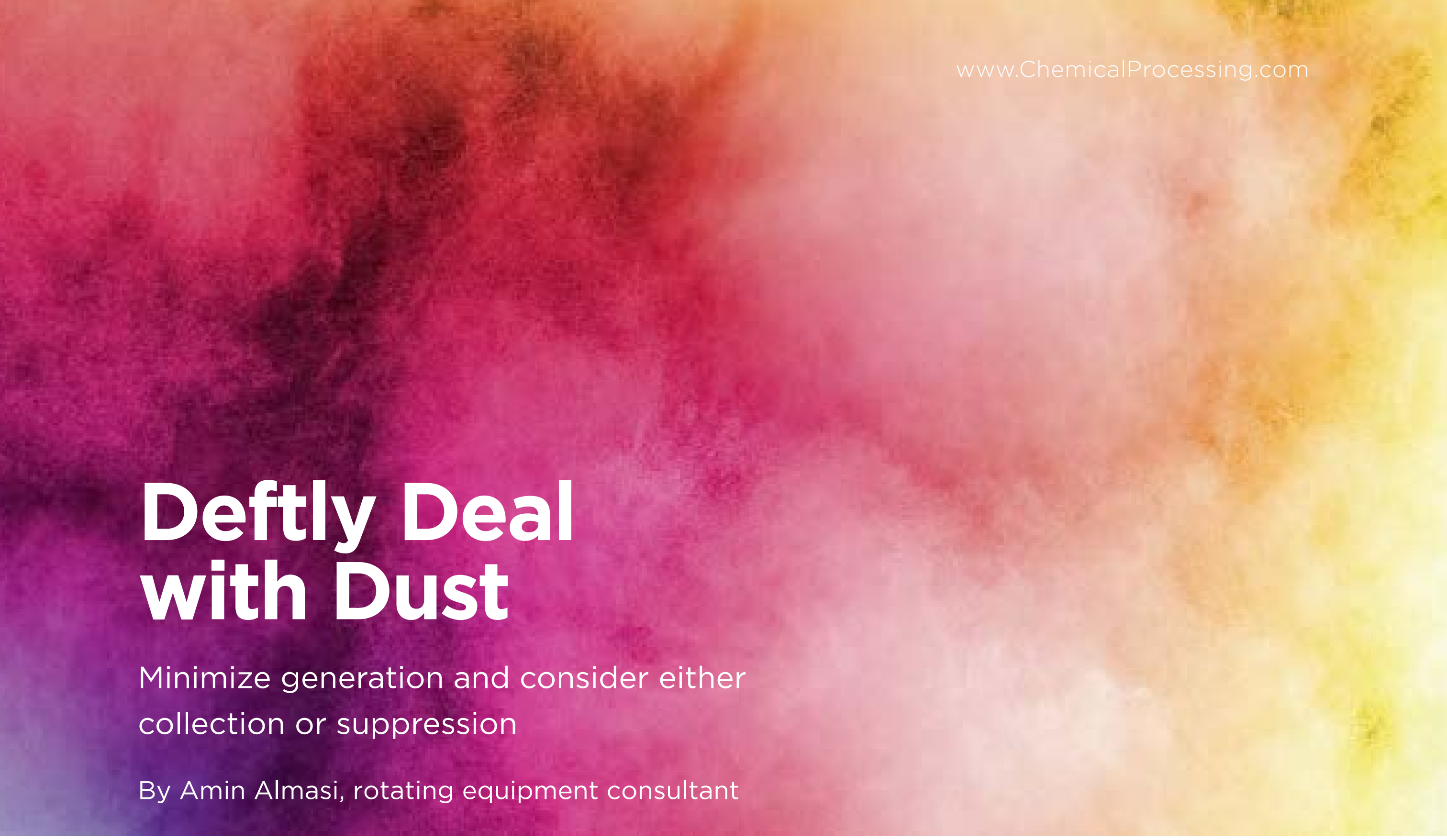

Deftly Deal with Dust

Minimize generation and consider either collection or suppression

By Amin Almasi, rotating equipment consultant

Airborne dust afflicts many plants. Processes such as impaction, disintegration, fracturing, grinding, crushing, etc., generate particulates that then disperse into the air. These particulates come in a wide range of sizes and many remain in the air indefinitely. Such dusts often can harm both people and equipment. So, plants should strive to eliminate or at least minimize dust generation and emission.

Preventing the generation of dust generally is easier, cheaper and more reliable than trying to control and suppress generated dusts. Although total prevention of dust in many plants and during operations such as bulk material handling, conveying, size reduction, etc., is impossible, properly designed facilities and equipment can play an important role in reducing dust generation, emission and dispersion.

However, many facilities must resort to dust control and suppression. So, here, we will look at the two most important methods: dust collection and wet suppression (i.e., using water sprays to reduce the dust generation and capture airborne dusts).

MINIMIZING GENERATION

Facilities often have many potential dust generators. For example, belt conveyors can emit dust from different points. The tail end, where material is received, usually is the main point of dust generation because of the many impacts of materials there. However, dust also can come from the conveyor skirting, the return idlers (due to carryback of fine dust on the return belt), and the head end, where material is discharged. With mills or crushers, the size reduction process itself generates significant amount of dust, which can emerge from any uncovered or unsealed parts of the equipment. In addition, material stockpiles often can create dust.

Some other major areas for dust generation are transfer points, chutes and the discharges of hoppers or bunkers. The amount of dust generated in these places depends upon the specifics of how material is handled, unloaded or loaded. Reducing dust generation often is possible. For example, material being discharged onto a belt conveyor should be loaded onto the center of the belt; the material and the belt should travel in the same direction and at the same speed whenever possible.

Where and how the material is discharged are important. Design and configuration of discharge locations should minimize the dust generation. Many facilities use devices such as skirt-boards to keep the material on the conveyor after it's received. These skirt-boards usually have flat rubber strips or something similar to provide a dust seal between them and the moving belt. These seals require proper design; otherwise short life and operational issues will ensue.

Running operations at full capacity and equipment fully loaded can boost the amount of dusts due to many effects and issues such as spillage, increased impact, etc. This is particularly true for size reduction processes, separation units, screens and material handling systems. For instance, it's preferable to design a belt conveyor to operate at 75%–80% of its full rated capacity; this reduces spillage, dust emission and wear on different parts such as seals, etc.

Chutes used at transfer points for moving materials from one piece of equipment (such as a conveyor) to another require serious design attention, too. Inadequate designs can result in significant dust generation. The chute should be big enough to avoid jamming of materials. It should be designed so the material falls on the sloping bottom of the chute, not on the subsequent equipment. Wherever possible, materials should fall on a local hard lining rather than on the metal surfaces; this will cut dust and noise generation, lessen wear and abrasion of the chute surfaces, absorb the impact of incoming material and, more importantly, reduce dust emission. When handling fine or abrasive materials, consider welding a number of small steel angles on the chute bottom; the oncoming material slides on the material stored in angles, greatly reducing wear and abrasion of the chute bottom.

DUST CONTROL

In selecting a dust control system, you should consider many factors — e.g., desired air quality, applicable regulations

Figure 1. Skirting on belt conveyor at the loading/impact point (tail end) extends sufficiently to reduce dust propagation.

or standards, interactions with the process and facilities, space or budget limitations, required reliability, etc. Conduct a thorough survey of facilities needing dust control and perform a detailed evaluation before deciding whether to opt for a dust control system, dust suppression or a combination of the two. Place emphasis on the process, operating conditions, characteristics of the equipment, associated dust problems, and the harmfulness or toxicity of the dust. Properly identify major dust emission points and conditions that occur at these points during normal operations; sometimes each point needs a specific solution.

After doing whatever is practical to prevent or reduce the dust generation, the next step is to deal with the dust that is generated. In many applications, plants automatically turn to dust collection rather than water spraying or wet suppression. The common view is that dust collection, theoretically at least, can provide reliable and efficient control over a long period; however, the capital and operating costs are very high. Wet dust suppression systems, particularly water spray systems, are somewhat less efficient, and, thus, theoretically less desirable. Such systems, are less expensive to install and operate, though. Water-spray systems are the simplest and most widely used dust suppression system but they require careful selection and planning to be suitable, effective and reliable.

Let’s now look at collection and water-spray suppression systems in a bit more detail.

COLLECTION

Dust collection systems use ventilation principles to move the dust-filled airstream from the source through ductwork to a collector system. In effect, this exhaust ventilation system works like a household vacuum cleaner. It is one of the most effective ways to control dust and reduce dust emissions. A typical dust-collection system consists of exhaust hoods, ductwork, dust collector and a fan set. A system of exhaust hoods is needed to effectively capture dust emissions at their sources. Proper design of the network of exhaust hoods is crucial for capturing all or a large portion of generated dusts from many different points. Well-designed ductwork also is necessary to transport the captured dust to a dust collector that then removes the dust from the air. A fan system, often with one unit operating and another on standby, usually provides the necessary exhaust volume and energy. Each of these elements is important — poor performance of one component can reduce the effectiveness of the other components. Pressure calculation and a proper airflow are very crucial for any dust collection system. Because the fan set provides the pressure required to start and maintain the airflow, correct sizing of the fans and their operational flexibility are important.

The exhaust hood, which is the point where dust-filled air enters a dust collection system, is one of the most critical parts of such a system but often doesn't receive adequate attention. It should capture dusts efficiently and effectively; otherwise the whole system becomes dysfunctional. Exhaust hoods come in many variants — e.g., local, side, downdraft and canopy hoods. Local hoods, which are available in numerous sizes, shapes and designs, are relatively small units for localized dust collection; they normally are located close to the point of dust generation and capture the dust before it escapes that area. Local hoods usually are efficient and find wide use for many processes and plants. Such applications typically involve a vast network of many local hoods, each positioned near a dust-emitting point. Side, downdraft and canopy hoods are larger versions of local hoods. They cover a greater area or multiple dust generation points and, thus, usually are less efficient than local hoods. There also are large hoods for booths, rooms and enclosures; these sometimes are used for screens, conveyors, etc., but aren't particularly efficient in these applications.

Developing the most-effective exhaust hood system requires sufficient knowledge of the process or operation. Hoods must be installed at the right locations with proper operating parameters. The size and shape of hoods are important to ensure effective capture of the generated dusts. In addition, the airflow through each hood must be set properly; this rate is related to the distance between the hood and the dust source. The duct network needs a careful design as well. To prevent dust from settling and blocking the ductwork, adequate transport velocities are essential; as a rough indication, a velocity range of 16–20 m/s often makes sense. Smooth turbulence-free air flow is important. So, follow good engineering practice

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to minimize turbulence. For instance, all branches should enter the main duct at a proper angle, say, 30°, and, wherever possible, the velocity should match that of the incoming fluid stream.

WATER-SPRAY SUPPRESSION

These techniques use water sprays to wet the material so it generates less dust. Most such systems also rely on a water spray system to capture airborne dusts. The spraying of fine droplets of water on the dust cloud causes droplets and dust particles to collide and form agglomerates that are too heavy to remain airborne. Such a wet system obviously only is suitable for applications that can tolerate adding some water to the materials and where processing isn't seriously affected by such spraying. Many such applications exist. Indeed, finely atomized water sprays are widely used at many facilities and locations such as conveyors, transfer points, etc., for the dust suppression.

Dust suppression via a water spray may seem simple but actually is very complex and chaotic in nature. For instance, the collision between dust particles and water drop occurs due to many factors and effects such as impact, interception, electrostatic forces, etc. The optimum droplet size, water usage, relative velocity, and number and location of nozzles depend upon the conditions at individual dust generation locations. System design often reflects a combination of sound engineering practice, vast experience and art.

The spray nozzle is the heart of a water-spray system. Therefore, details and characteristics of the spray are critical. You must carefully

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calculate and evaluate velocities, droplet sizes and pattern, and other operational details. Factors such as droplet size distribution and velocity, spray pattern and angle, and water flow rate and pressure all vary depending upon the nozzle selected. (For more information on types of nozzles, see "Spray Effectively," http://goo.gl/c44ta7.) The nozzle's droplet size distribution is one of the most important variables for proper dust suppression. The droplet size decreases as the operating pressure increases. Moisture addition to the materials should be quite low, typically less than, say, 0.2%–0.3% of the material weight. This generally translates to a low water feed to each nozzle; as an indication, this may amount to somewhere around 30–70 L/h. Some delicate systems add less than 0.1% of the material weight. Another consideration is where and under what conditions and circumstances to spray the water. The system may not be effective either in highly turbulent environments or when the dust dispersion rate is more than 1 m/s.

The effectiveness of wet dust suppression systems depends upon having many small droplets moving at optimum velocities. Many older systems did not pay sufficient attention to this. Today, systems generally use a greater number of smaller nozzles, carefully distributed for better dust suppression. In addition, they provide better control (such as via a control valve) to let the operator optimize water discharge. Airborne dust capture systems may require very fine droplets. These fine droplets usually are generated by fogging nozzles, which may use either compressed air or high pressure water to atomize water in the desired droplet range.

It's best to use nozzles that are adjustable in direction. This will allow operators to alter the path of the water spray, for example during a shutdown or trip, for better dust suppression. You can gain additional operational flexibility by making provision for moving and adjusting nozzle locations.

Hydraulic calculations for water spraying system as a whole need great care; correct sizing and design of the system require properly determining the water necessary for each point in each mode of operation. The spray system for each location or zone must have a control valve to enable flow regulation as well as an on/off valve for isolation. Optimum operation depends upon an operator having the ability to adjust the flow for the dust suppression operation based on actual observation of the dust emission in each point or zone. Higher water flow than needed is harmful and problematic; lower flow than required adversely affects dust suppression. Install pressure and flow gauges to monitor system performance; locate these instruments as close to the point of application as possible.

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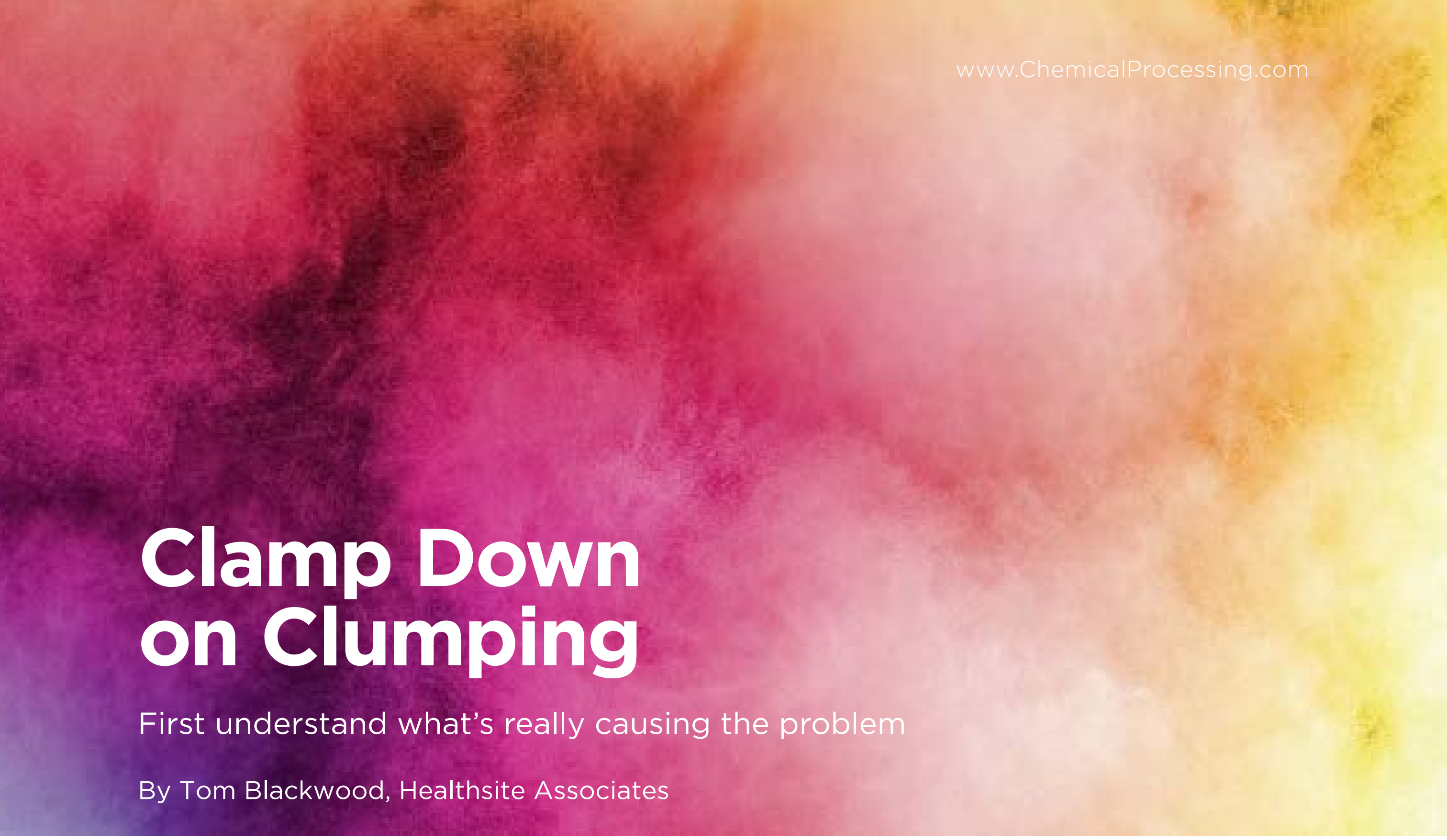

Clamp Down on Clumping

First understand what's really causing the problem

By Tom Blackwood, Healthsite Associates

Poor flow is one of the most common problems encountered in handling or storing solids. With liquids you open the valve and (hopefully) material runs out. With solids you often have to pray before opening the valve. Wouldn't it be nice to have an inexpensive well-established test method or procedure that would allow you to predict whether a fine powder will flow after a given time interval?

Often test methods take too long and generate results that are qualitative and very subjective. Also, material may be limited and quantitative test procedures are very expensive. If your plant has been working with solids you're probably familiar with this scenario. The basic issue is a balance of cost versus usable results. Clumping is a complicated issue that's difficult to quantify; so it's no surprise that finding a meaningful test is difficult. In most cases, clumping is unpredictable. However, a generalized procedure can be used to solve a clumping problem after it has occurred.

By clumping we really mean unintended agglomeration. While some types of agglomeration are desirable, e.g., to reduce dustiness or make a material easier to handle, most clumping isn't appreciated. The last thing you need in a pharmaceutical plant is for a bulk bag of acetaminophen to come in as a solid block (as has happened). Clumping is such a tricky issue due to its many causes. Before you can select a test method or procedure, you need to determine the root cause of clumping. Sometimes that can identify a solution without further testing.

CAUSES OF CLUMPING

The 10 most common sources of agglomeration in bulk solids are:

1. *Simple dissolution followed by drying of solids without any chemical reaction.* This is the fundamental problem with a lot of storage systems. Bags aren't sealed well enough or a solvent gets into the transport line. Several of the following causes also involve this process but in a roundabout way.
2. *Chemical reaction between particles and gases in voids in the bulk solid.* Most common is formation of hydrates, which changes particle density or creates bridges between particles. Oxidation or reduction of particles is less common but can release gases or yield

CARR INDEX OF FLOWABILITY (ADAPTED FOR CLUMPING)*

Degree of Flowability	Flowability Index	Compressibility		Cohesion	
		%	Index	%	Index
Very Good	91–100	<5	25		
		6–9	24		
		10	22.5		
Fairly Good	81–90	11	22		
		12–14	21		
		15	20		
Good	71–80	16	19.5		
		17–19	18		
		20	17.5		
Normal	61–70	21	17		
		22–24	16		
		25	15	<6	15
Not Good	41–60	26	14.5	6–9	14.5
		27–30	12	10–29	12
		31	10	30	10
Bad	21–40	32	9.5	31	9.5
		33–36	7	32–54	7
		37	5	55	5
Very Bad	0–20	38	4.5	56	4.5
		39–45	2	57–79	2
		>45	0	>79	0

* Note: There are three conditions when the cohesion test should not be used:
1. Mean density (i.e., the average of tapped and aerated density from the Carr bulk density tests) is below 0.4 g/cm^3 and particles are greater than 150 μm;
2. Mean density is between 0.4 and 0.9 g/cm^3 and particles are greater than 75 μm; and
3. Mean density is above 0.9 g/cm^3 and particles are greater than 45 μm.

Table 1. The Flowability Index often can provide important insights.

condensable products that form a sticky film on the solids. Diffusion of soluble gases such as carbon dioxide can soften particles and make them susceptible to shear. In addition, particles can interact with wall material through abrasion, which can act as a catalyst to reduce the potential energy needed for a reaction to occur.

3. *Change of phase.* This is the most difficult problem to diagnose but often is easiest to prevent. Many people don't realize that a polymorph could be present. About one-third of all organics have at least one polymorph [1]; lots of pharmaceuticals rely on chemicals that aren't in their most stable form. While transformation upon storage may take years a small amount of change can result in a big effect on flowability. For crystalline solids the problem usually starts with a very small amount of excess solvent and a temperature change. The unstable form dissolves and then recrystallizes into the stable form with solvent release. The process will repeat as solvent moves from particle to particle. A similar process can occur with amorphous organics because the crystalline form is at a lower potential energy.
4. *Recrystallization of solids during storage.* Often particles can pick up excess energy prior to storage though handling or milling operations. The latter is a very common culprit because attrition raises the surface potential energy of the solids and creates very fine solids, which have a much higher charge-to-mass ratio. It's rare for solid-state transformation to occur but it only takes a small amount of solvent to aid the crystallization process, similar to a polymorphic transformation.
5. *Viscous films on particles.* Interstitial solvent can prompt formation of such films. Heating or cooling solids can cause solvent to migrate and collect in one location. As the solvent partially evaporates, it leaves behind a sticky surface on the particle that can lead to bridging.
6. *Impurities in solids.* These can induce stresses in the particles, which can hasten chemical reaction, phase changes and recrystallization. Impurities can act as catalysts in a reaction

Testing Device

Figure 1. This apparatus provides qualitative data on solid's flow through orifices. *Source: Hanson Research.*

or interact with wall materials to initiate one of the causes previously cited. Localized change in density due to an impurity can prevent normal transfer of shear force from particle to particle and put more stress on an individual particle, resulting in breakage. Location of the impurity — whether on the surface or interior of the particle — may even be critical and cause some batches of solids to behave much differently than others.

7. *Particle size and width of the particle size distribution (PSD).* These attributes often can't be changed but contribute to clumping. Finer particles have higher specific surface area and more particle/particle contact, resulting in higher shear forces. In addition, the van der Waals' forces increase rapidly with finer particles. The wider the PSD, the more likely voids around larger particles will fill in with fine particles and boost cohesion. While this is a major factor in clumping, it's very easy to identify in advance of a problem.
8. *Attrition.* This is more of a contributing factor for the previously mentioned sources of clumping. Breakage of particles releases energy that's confined

TEN SOLUTIONS TO CLUMPING

	CAUSE	POTENTIAL SOLUTIONS
1	Simple dissolution	Shrink-wrapping pallets of bags can help. Choosing the correct liner or using multi-liner bags is another solution. Ensure that convey lines are dry and operators know how to properly store the material (i.e., good education on the product). Clamp down on procedures.
2	Chemical reaction	The material safety data sheet should provide an indication of potential reactivity of the solids. If not, this needs to be spelled out in the specification for the material. Consider potential chemical reactions before selecting a packaging method or container. If the material forms a hydrate, purge particles with dry gas prior to packaging. Also, don't package solids hot as this can speed up a reaction.
3	Change of phase	Know if the material has polymorphs. Molecular models can suggest and a DSC can verify that the material is the most stable form. Ensure there's no free solvent. In some cases a desiccant can be put into the container to pick up excess solvent. When an unstable material has to be packaged, use conditioned transport to minimize temperature changes.
4	Recrystallization	Avoid packing freshly milled solids unless there are no polymorphs — or minimize the intensity of the milling (i.e., use multiple millings rather than a single pass).
5	Viscous films	Avoid packaging solids when hot as this can drive solvent to voids in the top of the container where they can condense. Also, control humidity in the packaging area.
6	Impurities	These can be critical in promoting chemical reaction. They aren't a common source of clumping but can cause problems. When an impurity doesn't affect end use, improve product purity to remove it.
7	Particle size	This is the most difficult problem. When the customer wants a fine particle or a wide distribution, a problem is likely. Maybe a different specification can be used to make the particle larger and the distribution narrower.
8	Attrition	Design filling and handling equipment properly to limit attrition. Use an extended chute to minimize dropping distance. If the material is sensitive to attrition, use dense-phase conveyors.
9	Mechanical deformation	Consider not stacking bags or limiting the depth in a drum (use separators or sleeves). If a material has a poor initial strength, it's likely to deform and then clump. Design packages to limit the amount of compression by restricting the height of solids or inducing motion during transport.
10	Vibration	Vibration can work for or against clumping. Use specialized containers that limit transmission of motion to minimize the effect — or air-ride shipping methods.

Stop Solvent Snags

Solvents — gases as well as liquids — cause many clumping problems; understanding the nature of the solvent can be crucial in coming up with a solution. The solvents fall in four major categories (with the relevant one often related to how solids are dried):

1. *Free or surface.* These are easily removed by drying. However, in a production facility time may be limited or heat not uniformly distributed to solids. Most dryers are run based on contact time or exit temperature. While a longer time will give a dryer product that extra time may alter product color, taste or effectiveness.
2. *Bound.* Cohesive or electrostatic forces can cause physical or chemical adsorption of solvent onto particles. Some types of dryers are better at removing bound solvent but this can a difficult source to quantify.
3. *Inherent.* Solvent molecules trapped inside crevices of crystals or micropores of amorphous powders come into play when particles break. These molecules usually can't be removed by drying but you can minimize their effect, especially after a milling process. Solvents of hydration or crystallization are part of this group — but they're a stable form of the chemical that only would be released by a phase change or chemical reaction.
4. *Interstitial.* Vapor that fills voids in bulk material may total only a very small amount of solvent but can play an important role in caking mechanisms. When this source is identified as part of the problem it's fairly easy to fix by purging or fluidizing with dry gas.

Total solvent is the sum of all of the above.

In evaluating clumping it's important to know where solvent comes from so you can understand the clumping and propose the correct solution to the problem. There are eight common methods for determining the solvent in a particulate solid. Some are specific to the most common solvent, water. Each one can give a slightly different result because of the technique. The methods are:

1. *Karl Fischer* — for free and bound moisture (note other chemicals can be used to titrate solid for presence of other solvents);
2. *Loss on drying (LOD)* — for free or surface solvent and a major portion of bound solvent (for moisture, the test usually takes place at 90°C for 6 hours);
3. *Infrared* — for surface moisture, which is a close approximation to free moisture;
4. *Radio frequency* — for inherent (sometimes), bound and free moisture;
5. *Microwave* — for total and interstitial moisture (using different wavelengths);
6. *Loss on ignition* — for total solvent (can be done following LOD to get solvent of crystallization). Often this test is carried out in temperature steps to observe crystallization solvent as well as other volatile components or decomposition;
7. *Thermo-gravimetric analysis* — for total solvent loss with time (differential thermal analysis is more precise for solvent flux and can be combined with gas chromatography/mass spectroscopy to identify chemicals in a multi-component solvent system); and
8. *DSC* — for heat flow with time (which is especially useful in multi-component solvent systems).

to the solids' surface. In addition, finer solids will have poorer flowability and higher electrostatic charge. The increase in fines makes the PSD wider and solids easier to bridge.

9. *Mechanical deformation of solids.* This usually isn't the primary cause of agglomeration. The normal stresses in a bulk bag or fiber drum are fairly low. However, the ultimate formation of agglomerates often appears as a mechanical failure. Because a solid is defined as something that can support its own weight, most failures stem from shear forces that exceed the solid's strength. Many of the previous sources of clumping induce a failure that allows for compression of solids to form agglomerate.
10. *Vibration.* This often is overlooked as a cause of finer solids sifting into voids and increasing compression of bulk solids. When combined with temperature changes, vibration can make solids soften or plasticize, resulting in physical deformation and clumping. However, sometimes vibration can help to prevent mechanical deformation during transport.

As the above highlights, one major factor that repeatedly enters the equation is the presence of excess solvent or solvent vapor. If either afflicts solids, you must focus attention on the solvent source. Water is the most common solvent; moisture causes many clumping problems. Four major types of solvent in bulk solids contribute to clumping (see sidebar). No single test can detect all four; methods for determining the amount of solvent may not give a clear indication of the type.

USEFUL TESTS

Many bulk solids' tests focus on setting parameters for design of a bin or chute to keep product moving or to induce flow. Clumping is an afterthought of these methods. The tests can show how a material gains strength upon storage but can't predict outside of testing conditions (time or temperature) future increase in strength. In many cases the rise may be limited, at least to a solid block of solids. In addition, most methods require specialized and costly equipment, which is the major reason plants don't conduct such tests prior to experiencing a problem. However, these tests, by determining the time-dependent unconfined yield strength, are some of the best ways to determine when there'll be a problem.

The three major contenders for test equipment for this property are the Schultze (ASTM D6773) and Jenike (ASTM D6128) shear cells and the Johanson Indicizer. In addition, other devices have been developed for specialized industries. Some of these methods can use samples as small as 20g — but several runs may be needed to account for product variability. These tests' major limitation is that, to be assured that material won't exceed a given strength in the future, trials must cover a wide range of temperature and humidity over the expected storage time. This may not be practical for solids kept in a bag or drum for many months and for replicating shipping conditions.

Carr [2-4] developed several tests in an attempt to determine the flowability and compressibility of bulk solids. His methods give indices that have had mixed reviews over the last 40 years. Many companies have devised their own internal methods and have published these for others to use — but they're often subjective and depend on the operator's scrutiny. Examples are observation of flow though different orifice sizes, lumping and compression as well as frangibility and friability tests.

Here's a highspotting of the pros and cons of the most common qualitative tests for evaluating clumping potential:

- *Carr Flowability Index* (ASTM-D6393) [5] — is quick and easy to do (simple equipment) and used extensively, gives a relative indication of how much a powder will compact and the strength of cohesive material, but can't provide quantitative results and isn't useful for time and temperature effects on solids;
- *BASF lumping and compression tests* (BASF Bulletin TPU 0402) [6] — uses small amount of material (10–15 g) to get qualitative results, but provides limited ability to study the effect of storage time and temperature on flow;
- *Flow though an orifice or down a surface* — offers qualitative results on how big an orifice needs to be for 50% of solids to flow out of a container (commercial instruments are available (Figure 1); however, many companies have constructed their own devices) or the necessary angle of slide (specific to wall material), but can't give the effect of storage time on flow; and
- *Frangibility* (sometimes called friability) tests — indicate relative strength of agglomerates, can be used to estimate crushing strength or how easily a clump can be broken, which may eliminate the need to solve a clumping problem, but use non-standard equipment (large balls are placed on the upper screen of a sieve stack and vibrated; amount of solids that pass to the pan is compared to the amount that goes to the pan without the balls).

In general, these tests will give an indication of the potential for clumping to occur upon storage when starting particulate solids are cohesive or flow poorly, i.e., Carr flowability index of less than 50 (see Table 1). However, initial good flowability doesn't predict lack of clumping upon storage. So, when facing a problem, it's important to look at the 10 most common sources of agglomeration to ascertain the likely culprit(s). In that respect the following techniques are useful in determining potential for phase change and can identify chemical components that are the cause of the problem:

- *Raman spectroscopy* — can find polymorphs;
- *Differential scanning calorimetry* (DSC) — can identify changes in structure and presence of unstable chemical forms or polymorphs;
- *Scanning electron microscopy* — can see formation of bridges (this can be combined with a probe to look at specific elements);
- *Transmission electron microscopy* — can detect bridge composition and impurities (but has limited application unless sample is very strong because it must be thin); and
- *Atomic force microscopy* — can observe real-time agglomeration (this technique is evolving rapidly and eventually may be able to see atomic-level changes).

CLUMPING SOLUTIONS

Is it possible to predict cohesion? Probably not. No one test is appropriate but many qualitative tests can help define the potential. So, what do you do to minimize clumping?

The solution to many prospective causes of clumping centers on minimizing solvent contact with solids, controlling particle size, limiting attrition sources and avoiding putting excess energy into solids, especially prior to packaging. The sidebar on page 16 highlights some specific suggestions for the ten common causes of clumping. For each there's often a first line of defense. However, many of the solutions can treat other related causes. For example, filling a drum from an excessive height can increase attrition, mechanical deformation and solvent vapor trapped (by boosting the amount of voids). Also, packaging a hot material can promote chemical reaction, phase change, recrystallization and formation of viscous films. As a last resort you can modify solids through agglomeration or addition of flow aids such as silica. But that's another subject.

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Install Pneumatic Conveyors Correctly

Follow 10 steps to prevent a variety of common problems

By Thomas R. Blackwood, Healthsite Associates

Pneumatic conveying is one of the most versatile ways to move solids over moderate distances. So, not surprisingly, *Chemical Processing* over the years has published a number of articles (e.g., Ref. 1) on the design, installation and operation of dense- and dilute-phase pneumatic conveyors. Several models and a whole host of data from research groups also are available. However, even the best model and data can only go so far. Actual performance depends upon mechanical accuracy. For instance, a small unnoticed leak can kill the performance of a pneumatic conveyor — so much for having a good model. Additional problems may result from non-uniformity of the flow or local changes in the solids-to-air ratio.

The reality of most plant environments is that the quest to keep costs low can dictate design considerations and spell trouble, particularly when using old equipment for a new project.

However, you can take a number of steps to prevent problems.

Poor Layout

Figure 1. Sometimes no detailed analysis is needed to spot a bad layout.

TOP 10 TIPS

I have found the following pointers useful both for planning new systems and modifying existing ones.

1. *Put lifts before horizontal runs.* In most conveyors the feed point has the lowest gas velocity and particles may fall out of suspension. This can be offset by line size changes but standard line sizes can force you to push the velocity higher than desired, especially near the end of the line. As the pressure along the line goes down, the velocity goes up. By raising the conveyor in front of horizontal runs instead of at the end, particles have a chance to accelerate toward the gas velocity and gain momentum, mainly because the choking velocity is generally lower than the saltation velocity. The downside is cost. Unless you are going over a building, the extra support can be expensive.
2. *Minimize elbows and angled runs.* Pressure drop and attrition are highest in elbows (for the effective distance solids travel). Most of the wear and maintenance seen in pneumatic conveyors is due to the elbows; so it often is best not to use too many. The major exception to minimizing the number of elbows in a system is for a line that needs to go up and then horizontal. While an angled run offers the shortest distance between two points, it does not have lowest pressure drop. Indeed, a convey line going up at a 45° angle has much higher pressure drop than a horizontal and vertical line with three elbows. Putting elbows too close together is another major mistake, due to acceleration effects. Many models just count the amount of elbows — but placement in the layout is more important. The lowest number of elbows is not always optimum.
3. *Calculate velocity every 10 to 20 feet on the line.*Don't rely only on measurements of the pickup velocity or the maximum and minimum velocities in the system. The velocity of the gas and particulates should be determined along the entire length of the line, to ensure that the correct density is used to determine the choking and saltation velocities. This makes the design a trial-and-error calculation. Shortcut design methods often overlook this critical step.
4. *Check acceleration lengths at feeders and around elbows.* It takes time for a particle

Valve Venting

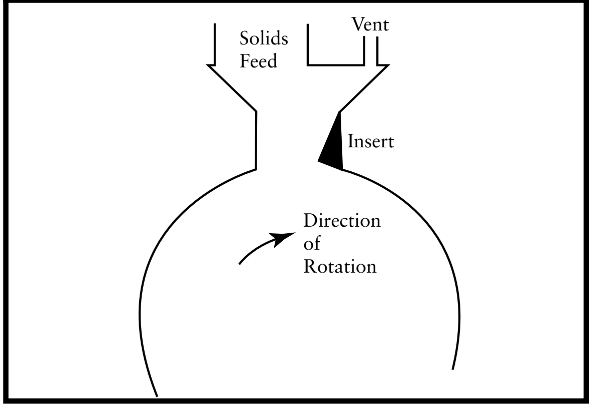

Figure 2. This modification enables venting if a valve lacks a vent port.

Running a Convey Test

One of the most important parts of putting in a new conveying line is correct testing, especially on a new product or long layout. Most equipment manufacturers will perform a test for a nominal fee that seldom covers its real cost. Remember vendors are not clairvoyant and usually don't understand your overall process as well as you do. Some engineers arrive at a test expecting the manufacturer to guide them through the testing process and to point out what the buyer needs to do. That approach doesn't sell a lot of pneumatic conveyors, which after all is the vendor's objective. Most manufacturers' test setups are not research systems but demonstration devices. So, it is best to have a test plan that you and the vendor agreed upon beforehand. This may mean bringing in additional testing resources at your cost to supplement what is provided.

Pointers

1. *Look at particle attrition.* Conduct particle sizing tests and examine the particles under a microscope.
2. *Attempt to find the choking and saltation velocities*. Compare these to calculated values. Design the system at 1.5 times the maximum value but plan to reduce this velocity after installation (by reducing the blower flow rate).
3. *Run at both twice and half of the expected design velocity.*
4. *Ensure the solids-to-air ratio is constant during the test.*
5. *Calculate velocity along the line.* This requires data on pressure and temperature.
6. *Roughly determine the particle-to-gas velocity along a straight section of pipe.*
7. *Get the layout close to what is expected in the plant.* Try to match elbows and lift location.
8. *Make some of your own measurements.* This keeps the vendor honest.
9. *Inspect the piping.* Pay attention to the type of joints, construction material, elbow R/D, feeder and collector details.
10. *Run a "power failure" test.* Deliberately stop the gas flow and let the line sit overnight, if possible. Failures happen. The best place to find out their consequences is in the lab.

While following the test and designing the conveyor, enjoy the process of understanding your material. Imagine yourself running around inside the pipe. Pneumatic conveyors are powerful and the solids convey considerable force. I was reminded of that one time when every few hours we heard a clanking noise in a vertical section on a recirculation pneumatic conveying blender. We shut down the conveyor and removed the bottom elbow to find a 6-in.-long, 1-in.-diameter bolt that had made several trips through the system. Oh well!

to reach its slip velocity (effective velocity below the gas velocity). Particles also must be dispersed across the convey line so the solids-to-air ratio is uniform — otherwise the saltation effects will be drastically different. You could have high localized solids-to-air ratios that would throw a dilute-phase conveyor into dense phase and slug flow. The acceleration length can be determined using the graphic technique of Rose and Duckworth [2] or the Jotaki and Tomita method [3]. For a quick estimate of the optimal spacing of elbows or feeders from each other, use a value between the square root and the cube root of the stopping distance for the particle in feet:

$$X_s = (V_g\, d_p^2\, r_s)/(18\, \mu_g)$$

where V_g is gas velocity, ft/s; d_p is particle diameter, ft; r_s is effective particle density, lb/ft^3; and μ_g is gas viscosity, lb/ft-s. Sometimes it is obvious by looking at a conveying line that the elbows are too close together and the layout was not well planned (e.g., Figure 1).

5. *Be careful with pipe joints.* Piping should be carefully aligned during installation. The use of slip-couplings can allow for gaps or pinched gaskets, even with tie-bars. Even welded pipe can be improperly fabricated at the flange due to misalignment and “cat teeth” from the welds. When joining pipe, specialized welding methods can prevent slag inside the pipe.
6. *Slow the particles down before the collector.* Particle-to-particle impact is the biggest source of attrition. Even discharge into a bin can result in a significant amount of attrition as the particles strike the pile. Bag collectors increase the particle-to-particle contact unless there is a cyclonic inlet or an expansion of the line prior to the collector. The acceleration velocity can be used to judge the length of any deceleration spool piece, generally about 25% of the acceleration length, or the optimal distance between elbows, as described in Tip 4.
7. *Watch for leaks.* Small leaks can cripple operation by reducing or increasing the difference between the gas and saltation velocity. High velocities lead to high pressure drop and attrition; low velocities lead to transitional flow (dilute to dense). The obvious location of a leak is at the feeder. When several feeders are on the same convey line, check for leakage at each one. Diverters and misaligned pipe also can contribute to the problem. In vacuum systems, the area around the collector, including the discharge valve, can be a major leak source.
8. *Match the type of compressor to your convey line.* On most dilute conveyors the pressure rises rapidly during the feeding of solids and usually falls off after leaks and the compressor slip have stabilized. A large surge tank can help but adds cost to the system. Volumetric

feeders are just that — the solids-to-air ratio will vary over a conveying cycle. As the compressor heats up, the gas velocity can increase in small or light-weight compressors, leading to attrition of the solids. When a conveying system is used continuously, this usually is not a problem, except maybe during start-up. Oversized compressors that run at low speeds can be sluggish and unable to keep up with leaks or sudden changes in solids-to-air ratio. This is especially true when spare equipment is being re-used.

9. *Vent the feeder valves and factor the amount lost into the design.* If there is one thing that can upset a pneumatic conveyor it's sudden changes in solids-to-air ratio. An unvented solids feeder prevents the pockets from filling uniformly and can fluidize the solids in the tank or bin above the feeder. The solids can flood the valve, prompting over-consolidation and bridging. Not only does the solids-to-air ratio change but particles also can be pinched in the feeder and break. Figure 2 shows a way to vent the valve in the absence of a vent port supplied by the manufacturer. Note in particular in the figure the use of an insert to prevent particles being pinched between the housing and rotor.

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10. *Look for frictional differences between products.* Sometimes after conveying one material and either making a change to the ingredients or trying to convey a different material we forget that the particles may not behave the same. While basic physical properties can be helpful in predicting a problem you can't go wrong with a few tests. Frictional changes can be subtle. Even the same product can have different shear rates and pickup velocities. In addition, don't forget to check the characteristics of an existing material after conveying a new material. A fine coating or change in surface may alter the pressure drop in the system.

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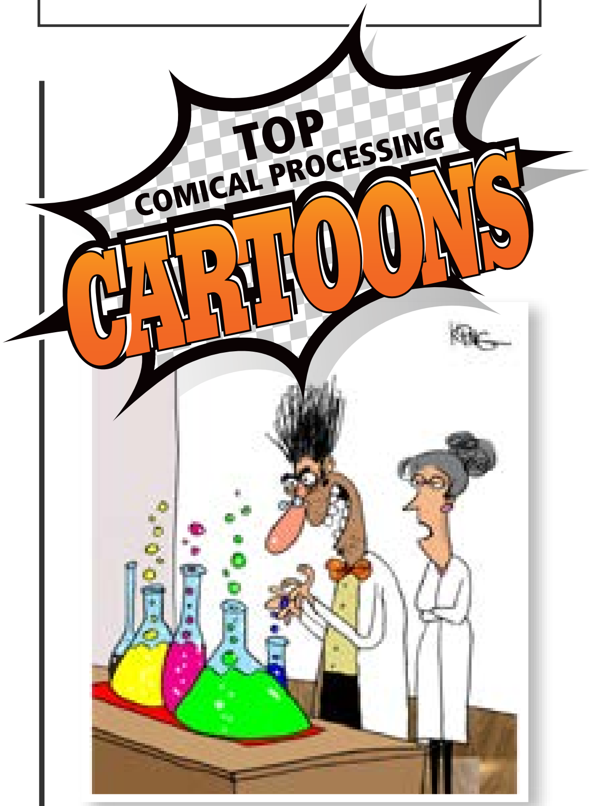

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