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Efficient Powder Process Handling

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Need your powder questions answered? We have an expert for that.

Q: I would like to know if there is an available table or data available for conveying densities (pneumatic conveying) of powder/solid fuels such as coal, biomass (rice husk), woodchips, etc. In designing pipe layout, blowers and feeder valves, this data is important.

A: There are numerous charts and tables available. The primary basis for selection of the type of conveyor is the Geldart Powder Classification Chart. This was published in *Powder Technology* in 1973 on page 285. It has been reproduced extensively. Because of its density and particle size, cement and coal are difficult to convey. In using the Geldart chart, remember that the density is the particle density not the bulk or structural density. This would be especially true for rice husk and wood chips or products that have internal voids.

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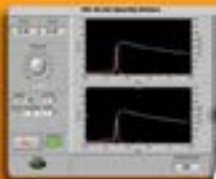
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Optimize Humidity for Efficient Powder Handling

Too much or too little moisture can cause problems during processing and storage

THE INTRODUCTION of even relatively small amounts of moisture may transform a free-flowing powder into something far more difficult to handle. This well-recognized behavior reinforces the tendency to label moisture as always being detrimental to efficient powder handling. However, there are notable occasions when the introduction of water can have a positive effect. For example, in the process of wet granulation, the ability of moisture to promote adhesion between particles is highly beneficial, and leads to the production of free-flowing granules from cohesive fine powders. In certain systems water acts as an interparticle lubricant, thereby improving flow characteristics; in others it enhances conductivity, discharging the electrostatic forces of attraction between particles that otherwise would increase cohesivity.

So, understanding the effect of humidity on the material being handled and stored is essential for developing cost-effective operating strategies. Where moisture is a problem, steps usually can be taken to control it — e.g., maintaining a storage facility at lower humidity or drying a stream exiting a wet unit operation, such as crystallization or wet ball milling, before further processing. However, such strategies incur cost. Optimizing operation depends upon ensuring humidity levels are controlled adequately but not excessively; this, in turn, relies on knowing how easily the powder takes up water and, most importantly, the impact of that moisture on behavior.
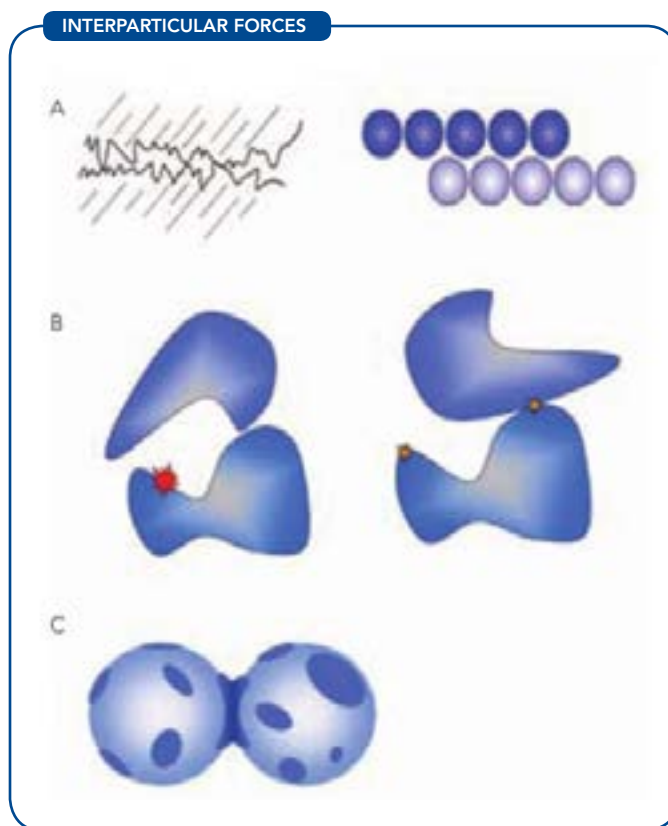
INTERPARTICULAR FORCES

Figure 1. Frictional forces (a), mechanical interlocking (b) and liquid bridging (c) can impact particle movement.

CRUCIAL STARTING POINT

An understanding of powder flow characteristics is essential. They define how easily and reliably material will move through a plant but, beyond this, they directly influence the efficiency of important unit operations such as blending and vial/die filling. In many instances controlling powder flow behavior is the key to achieving manufacturing excellence.

The mechanisms of powder flow are complex. They are influenced by an array of different parameters; some relate to the particles' physical attributes, such as size and shape, and others, such as humidity, to the system itself. Although there is a general understanding of these individual mechanisms, the multitude of interactions that govern the specific behavior of a given powder prevent the prediction of flow properties from first principles. The pragmatic alternative is to measure powder properties that correlate with in-process performance and use knowledge of the mechanisms of powder flow to develop a consistent rationale for these observed behaviors.

When a powder flows the particles within it are moving relative to one another. The ease with which this happens is governed by the strength of interparticular forces that arise from friction, mechanical interlocking, adhesion/liquid bridges, cohesion and gravity. The interaction and relative magnitude of these forces dictate the behavior exhibited by a powder in any specific environment.

Frictional forces inhibit movement, either between particles or between particles and the walls of the confining vessel. Their strength is strongly influenced by surface roughness, with smoother particles and surfaces exerting less resistance to flow, all other factors being equal.

In contrast, mechanical interlocking is more closely correlated with overall particle shape. Irregular particles, if oriented in a certain way, may slot

DYNAMIC TESTING

Figure 2. Powder can be subjected to different stress regimes by rotating the blade upward or downward, and air can be introduced for measuring aerated energy.

together like pieces of a jigsaw puzzle, significantly resisting further movement (Figure 1).

Liquid bridging often accounts for the negative impact that moisture can have on flow behavior. By bridging the gap between particles, or particles and
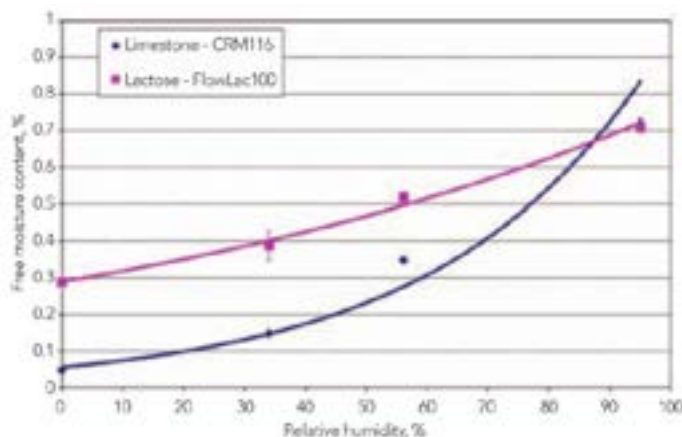
Figure 3. Both test materials take up relatively low levels of water even when exposed to high humidity.

the vessel wall, a liquid can increase adhesive forces and inhibit particle motion.

Cohesive forces, such as van der Waals forces and electrostatics, tend to be especially important in defining the behavior of fine powders. Gravitational forces, on the other hand, have a much greater impact on systems containing large high-mass particles because the force imposed by gravity is function of mass.

POWDER ASSESSMENT

The complexities of powder behavior have led to the development of many alternative testing methods that seek to summarize this behavior in the form of just a single number. The diversity of these techniques underscores that many different approaches can provide some insight into powder behavior. However, processors are increasingly recognizing that reaching the levels of manufacturing performance now demanded requires a focus on methods that:

- are reliable and reproducible;
- generate process-relevant data that correlate with

performance; and
- allow sensitive assessment of the impact of environmental variables such as moisture and degree of aeration.

Three techniques that score highly against these criteria and have proven especially relevant for process-related studies are shear, bulk and dynamic property measurement.

Shear analysis, which was developed in the 1960s [1], is particularly useful for hopper design and, more generally, for characterizing consolidated, cohesive powders. Modern instrumentation with well-defined methodologies and a high degree of automation has brought enhanced reproducibility and reliability, ensuring the place of shear analysis in the modern powder testing toolkit.

Bulk property measurement, i.e., the determination of bulk density, permeability and compressibility, though well-established, similarly has benefited from instrument refinement. Bulk property data may be used directly in process design calculations and provide a general insight into powder behavior that supports the prediction of performance in
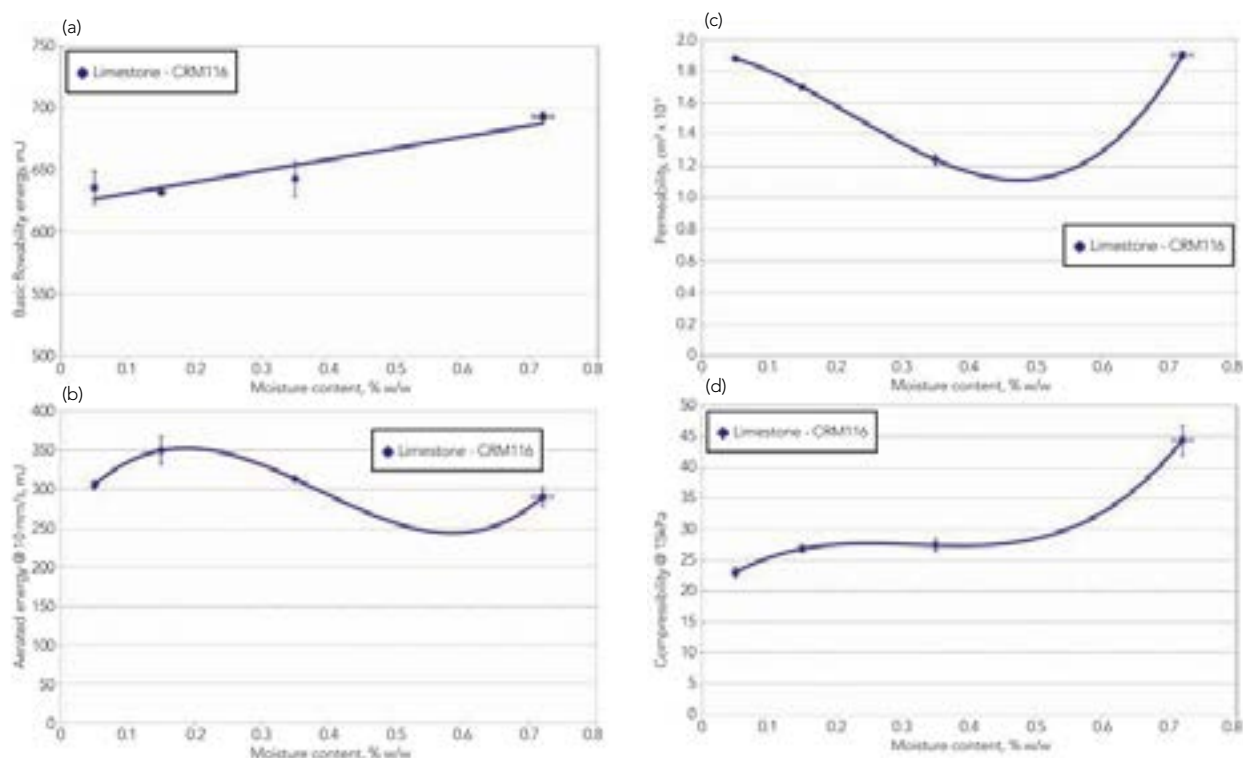
Figure 4. Data demonstrate the impact of moisture on dynamic (BFE and AE) and bulk (permeability and compressibility) properties.

certain processes.

Dynamic powder testing methods, which were developed in the late 1990s, marked a step change in powder characterization, rather than refinement of an existing technique. Dynamic characterization involves measuring the axial and rotational forces acting on a blade as it traverses through a sample along a fixed helical path to generate a value for flow energy (Figure 2). This value directly quantifies powder flowability, i.e., the ease with which the powder flows. The technique is highly sensitive and has the distinct advantage of allowing powders to be characterized in a consolidated, conditioned, aerated or even fluidized state. It can directly measure the response of a powder to the introduction or release of air.

Let's now look at how shear, bulk and dynamic property measurement can provide insights on the impact of humidity on two different, industrially relevant powders.
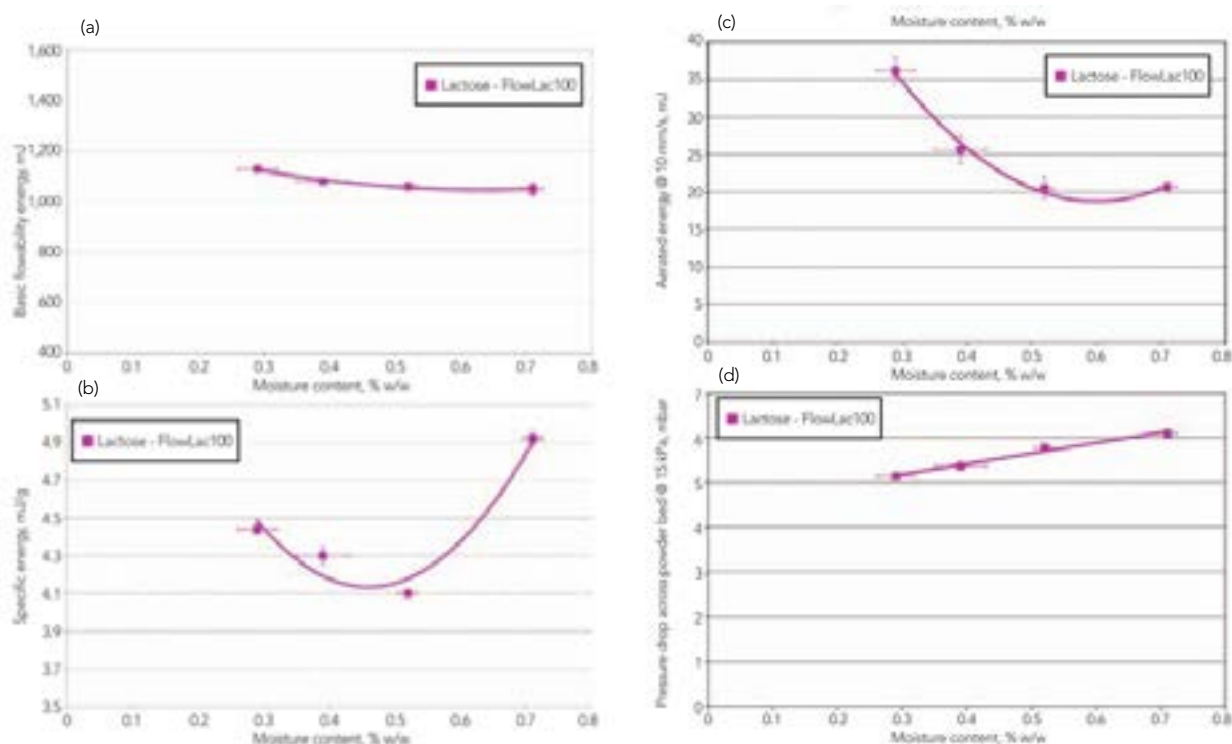
Figure 5. Results show the effect of moisture on dynamic (BFE, SE and AE) and bulk (permeability) properties.

THE IMPACT OF HUMIDITY

We assessed the impact of humidity on limestone (BCR116, a very fine material with a mean particle size of four microns, used as the standard reference powder for shear testing) and lactose (FlowLac100, an example of a widely used pharmaceutical excipient, which has a mean particle size of 140 microns).

First, we allowed samples to equilibrate in environments of varying relative humidity to assess how much water was taken up. For both materials, absorption and adsorption rates are quite low (Figure 3). However, the more interesting question for processors is whether the resulting moisture content of the powder can change behavior. To answer this question, we subjected each sample to shear, bulk and dynamic property testing using the FT4 Powder Rheometer. Reference 2 provides full details of the test methodologies.

Limestone. The dynamic measurements for lime-

The Smartest Distance Between Two Points....

Pneumatic Conveying Systems by VAC-U-MAX

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Pneumatic Conveying Systems * Bulk Bag Unloaders * Bag Dump Stations * Flexible Screw Conveyirs * Aermechanical Conveyors

stone show that basic flowability energy (BFE) — the ease with which the powder flows under forcing, compacting conditions — increases with increasing moisture content (Figure 4a). This behavior may indicate the water acts as a binder, producing liquid bonds that raise the overall cohesivity/adhesivity of the system and promote the formation of loose agglomerates. The variations observed in the aerated energy (AE) data (Figure 4b) at first sight would seem contradictory to the BFE results. However, these are better understood when studied alongside the permeability results (Figure 4c), which are generated by measuring the pressure drop across the powder bed for a given air flow — higher pressure drop equates to lower permeability.

The limestone has very low permeability across all levels of moisture content, largely because of its fine particle size. In general, the strength of interparticle forces increases with decreasing particle size; this is why finer materials tend to have relatively high cohesivity. Strong interparticle forces result in a packing structure that resists the passage of air, causing low permeability. So, with cohesive powders the inclusion of water provides relatively little scope to reduce permeability further. This effect is illustrated clearly here, where increasing moisture content minimally changes permeability in absolute terms.

For analogous reasons, the limestone substantially resists aeration; any upward-flowing air tends to channel through to the surface rather than promoting steady fluidization. Therefore, the introduction of air has a limited and variable impact on flow energy, with the extent and influence of the channelling varying erratically with moisture content.

The compressibility data (Figure 4d) support the hypothesis that increasing cohesivity explains the trend in BFE. Cohesive powders have a tendency to trap air within them, making them relatively easy to compress. In contrast, less cohesive powders

have particles that are efficiently packed together; compression is difficult because there's significantly less air to expel. Therefore, the increase in compressibility as moisture content goes up points to steadily rising cohesivity. The bulk density of the limestone also decreases with increasing moisture content (data not shown), which supports the idea that higher cohesivity leads to more air trapped within the bed.

In this instance, bulk and dynamic property testing identified some significant effects but shear analysis provided little differentiation between the samples. This observation underlines the value of multifaceted powder characterization and the greater sensitivity of certain powder testing techniques for specific applications.

Lactose. The very different behavior of the lactose is immediately obvious from the BFE data (Figure 5). The lactose shows a fall in BFE with increasing moisture levels, suggesting that here the presence of water actually may lubricate interparticular interactions. However, the specific energy (SE) data for lactose show the opposite effect: SE rising with increasing moisture content. This interesting behavior highlights an important, industrially relevant issue — namely, the processing environment strongly influences powder flow behavior. The BFE testing regime subjects the powder to a compacting action that is more representative of the forced-flow conditions that would apply, e.g., during extrusion or the pushing of powder into a partially filled die. In contrast, the upward motion of the blade during SE testing subjects the powder to a gentle, lifting action that produces values that reflect the unconfined flow behavior that would be observed when a powder pours freely from or into a vessel.

As with the limestone, the presence of moisture very likely will produce liquid bridges that would tend to increase the cohesivity of the system. This

fits with the observed trend in SE. However, the BFE data suggest that under forcing conditions this effect is more than offset by a competing lubricating mechanism that makes interparticular movement easier. Therefore, under compacting conditions the net impact of the moisture is beneficial. AE values also decrease with increasing moisture content, suggesting that here too, water reduces the strength of cohesive bonds.

Evaluating bulk properties (Figure 5), the permeability data are perhaps most revealing. The steady rise in pressure drop observed indicates the powder becomes less permeable to the flow of air as moisture content increases. This supports the view that liquid bridges form within the system, inhibiting the passage of air. In contrast, both compressibility and bulk density (data not shown) change very little as a function of moisture content. The variation in bulk density (only 2 to 3 % across the experimental conditions) is particularly noteworthy because it suggests that in this instance bulk density/packing changes aren't responsible for the observed trends in flowability (as quantified by the dynamic test data). This indicates that powder testing methods based on bulk density could easily fail to detect the changes in behavior induced by moisture. Shear analysis is similarly insensitive for the lactose as for the limestone.

BETTER PROCESSING

The effective management of humidity to ensure optimized processing relies on understanding and quantifying the effect of moisture in a way that's relevant to the process. Experimental data presented here for limestone and lactose illustrate the very different responses that moisture can induce and highlight the insight provided by multifaceted powder characterization, most especially incorporating dynamic measurement.

REFERENCES

1. Jenike, A. W., "Storage and Flow of Solids," Bulletin of the Utah Engineering Experiment Station, 123 (November 1964, revised 1980).

2. Freeman R., "Measuring the Flow Properties of Consolidated, Conditioned and Aerated Powders — A Comparative Study Using a Powder Rheometer and a Rotational Shear Cell," Powder Technology, 174, pp. 25–33 (2007).

The results demonstrate that even for materials that exhibit low moisture uptake, exposure to humidity levels typical of an industrial environment can significantly affect performance. Furthermore, they provide evidence dispelling the idea that moisture always degrades powder behavior. For example, under certain conditions moisture improves the flow properties of lactose, a result attributed to the lubrication of interparticular movement.

As many processors already recognize, moisture's effects are neither linear nor predictable. So, it's essential to apply appropriate powder testing strategies to build a secure basis for intelligent decision-making around design and operation. Achieving the highest levels of manufacturing excellence and profitability requires keeping powders just dry enough to ensure optimal processing. Relevant powder testing provides the information needed to achieve this goal. ●

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Select the Right Conveying and Feeding System

Successful bulk handling of calcium carbonate depends on a variety of factors

By Jaime A. Gómez, Ph.D., Coperion K-Tron

CALCIUM CARBONATE ($CaCO_3$) is one of the most popular mineral fillers used in the plastics industry. It is widely available around the world, easy to grind or reduce to a specific particle size, and compatible with a wide range of polymer resins. Plus it's economical.

As an additive in plastic compounds, $CaCO_3$ helps to decrease the surface energy and provide opacity and surface gloss, which improves the surface finish of the finished product. In addition, when the particle size is carefully controlled, $CaCO_3$ helps to increase both the impact strength and flexural modulus (stiffness) of the end product.

Calcium carbonate may be used with a myriad of thermoplastic resins. For example, polypropylene compounds are often filled with calcium carbonate to increase rigidity — an important requirement for operations at high temperatures. In polyvinyl chloride (PVC), calcium carbonate is used to produce compounds for flexible products, such as tubing, wire and cable insulation, latex gloves and trash bags. It's used in compounding rigid products such as extruded pipes, conduits and window profiles.

CONVEYING SYSTEM DESIGN

The design of any feeding or pneumatic conveying system for bulk solids is heavily influenced by the bulk solid's particle shape, size (aspect ratio) and particle-size distribution, as well as the particle's roughness, hardness or abrasiveness, and density.

Material characteristics vary widely for calcium carbonate depending on its source and production process. The sieve analysis (see sidebar, "Calcium Carbonate Sieve Analysis") illustrates the difference in particle shape, particle size and particle-size distribution for two samples of calcium carbonate. The analysis shows the large number of particle interactions that make it impossible to establish a clear correlation between the filler's properties at the particle level and its flow behavior as a bulk solid.

When a material displays this sort of multiple personalities, pneumatic conveying systems can't be purchased off-the-shelf; rather they must be engineered for each individual situation. Both systems' engineering and equipment selection are affected by these differences, and laboratory tests often are necessary to determine a particular material's properties and behavior.

In general, a pneumatic conveying system consists of five basic components: the motive gas, conveying line, dispensing device, material-gas separator and controls.

Conveying Lines. Calcium carbonate powders can cause many problems in conveying systems, as they often stick to the inside surfaces of hoppers, flood while being fed into convey lines, build up inside convey lines, and blind over filter bags and cartridges in receivers.

Rigid pipes may be used as the conveying line for $CaCO_3$ that ranges from highly fluidizable to slightly adhesive. However, if the $CaCO_3$ tends to coat the interior of the convey line, a flexible hose should be
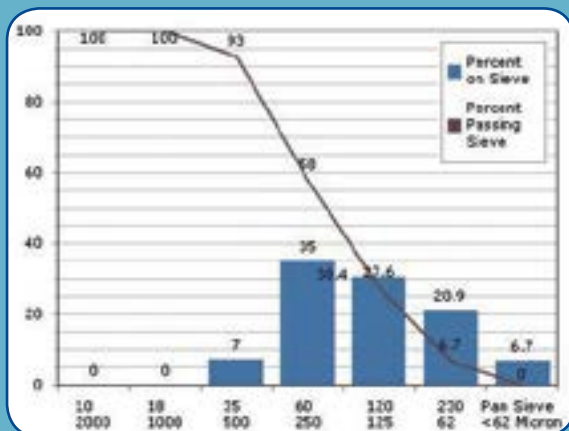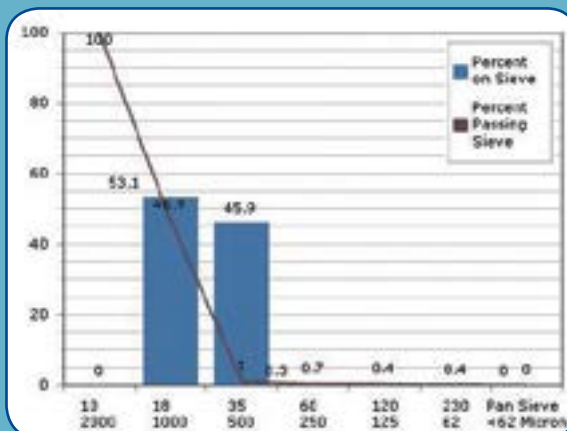
CALCIUM CARBONATE SIEVE ANALYSIS

CaCO$_3$ Sample A
99% pure precipitated calcium carbonate (PCC); bulk density varies from 0.301 kg/dm^3 [18.8 lb/ft^3] loose to 0.398 kg/dm^3 [24.9 lb/ft^3] packed.

GRID: .125" X .125"

CaCO$_3$ Sample B
95% pure granular calcium carbonate; bulk density varies from 1.378 kg/dm^3 [86 lb/ft^3] loose to 1.474 kg/dm^3 [92 lb/ft^3] packed.

Grid: .125" x .125"

considered because the flexing of the line can help to prevent buildup on the walls of the hose.

In vacuum-sequencing systems, it's good practice to use a purge valve to allow the line to clear between conveying sequences. First, a shut-off valve at the pickup of a vacuum system is closed to allow vacuum to build in the line. Then the valve is opened, creating a pressure wave that helps to clean off any coating of material adhering to interior surfaces of the convey line.

Dispensing devices. When selecting a dispensing device, care must be taken with some light and fluidizable grades of CaCO$_3$ that may flood the conveying lines. In such cases, a rotary valve, such as the one shown in Figure 1 should be considered to meter the material into the line. Rotary valves can be used for pickup in either pressure or vacuum pneumatic conveying systems. With adhesive grades of CaCO$_3$, the product will tend to build up and not release from the blades of a drop-through rotary valve. In this case, a blow-through style rotary valve is necessary. In this design, air is blown through each pocket as the valve turns, dislodging material from the blades. The installation of a fluidizing cone in the feed bin is also helpful in controlling the flow of the material.

Material-gas separator. Often CaCO$_3$ will adhere to the filter, causing it to blind over and reduce filter efficiency. For sticky grades of CaCO$_3$ using filter bags instead of pleated filter cartridges might help reduce the tendency of the CaCO$_3$ to stick to the filters. In extreme cases, the use of polytetrafluoroethylene (PTFE) filter media is recommended.

Some calcium carbonate grades might require a

steeper discharge cone in order to allow for complete emptying of the hopper. Flow aids such as vibrators or fluidizing pads inside the receiver hopper will usually help ensure quicker and more complete discharge of the receiver.

APPLICATION EXAMPLE

The sieve analysis shown in the "Particle Interactions" sidebar illustrates the difference in particle shape, particle size and particle-size distribution for two samples of calcium carbonate. Sample A is a precipitated calcium carbonate (PCC) with a relatively low bulk density. Sample B is a granular calcium carbonate with a much higher bulk density.

Figure 2 shows a schematic representation of the pneumatic conveying system required to transfer the calcium carbonate from a storage bin into a feeding system in a compounding operation. In this example, a processor needs to transfer 4.5 tons/h (10,000 lb/h) of calcium carbonate from a storage bin (1), to a filter

Figure 1. When selecting a dispensing device, rotary valves, such as the one shown here, are particularly useful for light, fluidizable solids that may flood the conveying lines.

SAMPLE PNEUMATIC CONVEYING SYSTEM

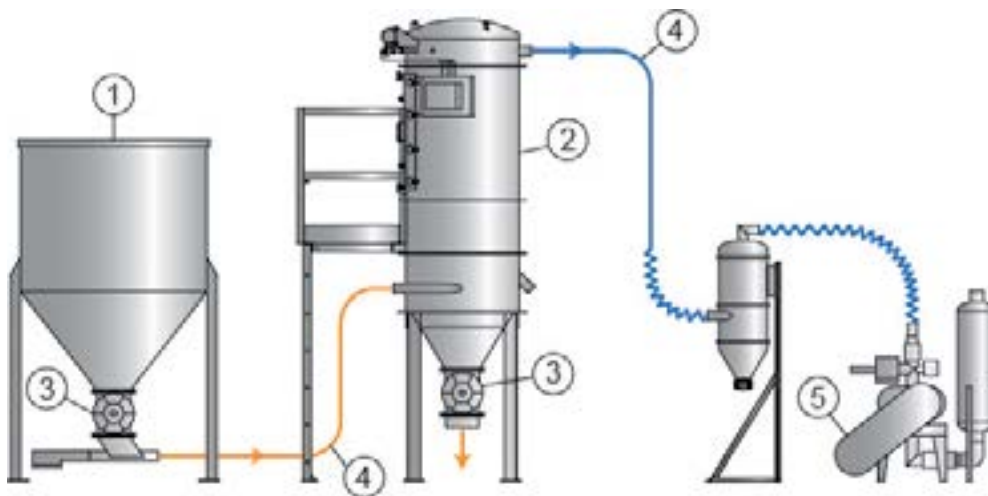Figure 2. In this typical vacuum conveying system, calcium carbonate is conveyed from a storage bin into a feeding system in a compounding operation. 1=storage bin; 2=filter receiver; 3=rotary valve; 4=convey line (orange) and air only line (blue); 5=blower; an inline filter is pictured between the filter receiver (2) and blower (5) to protect the blower from stray particles in the clean air line.

receiver (2), located on top of a rotary valve (3), for the extrusion of polypropylene (PP) and $CaCO_3$ at a plastics-compounding facility. The facility is located at 305 m (1,000 ft) elevation with an average daily temperature of 29.5°C (85°F) during the entire year.

The selected calcium carbonate sample would need to be pneumatically conveyed over 30 meters (100 ft) horizontal distance, and 15 meters (50 ft) vertical distance with four 90-degree angle elbows

(4) present in the system. The blower (5) would be located in such a way that the air line would be 15 meters (50 ft) long (when combining horizontal and vertical distances) with no more than two elbows.

Material testing showed significant particle characteristic differences between the two $CaCO_3$ samples, which require different equipment components, and different sizing considerations for the entire system. For instance, a higher blower horsepower

PARTICLE INTERACTIONS

Three distinctive relationships affect the flow behavior of mineral fillers in pneumatic conveying and feeding systems: Particle-particle, particle-equipment, and particle-environment interactions.

PARTICLE-PARTICLE INTERACTIONS

Particle-particle interactions are directly related to the filler's chemical composition and physical characteristics (rather than its bulk properties). The most important parti-

cle-particle forces are the electrostatic or van der Waals forces of attraction between molecules. As the separation between particles increases, the van der Waals forces decrease, explaining why the addition of small particles to cohesive powders can help to improve the powder's flowability. Other particle-particle forces include capillary forces, which are responsible for the formation of liquid bridges, and sintering forces, which are responsible for the formation of solid bridges. Capillary forces develop in the presence of water vapor in the gas phase, whereas sintering forces develop when material migrates due to diffusion or viscous flow. Interparticle forces contribute to the cohesive characteristics of fine powders and their tendency to form aggregates or agglomerates.

PARTICLE-EQUIPMENT INTERACTIONS

The flow of solid particles inside a vessel or a pipe is a function of two important characteristics — wall friction and shear strength. Wall friction relates to how particles slip on a contact surface, while shear strength is the resistance that the powder bulk offers to deformation, and influences how particles slip relative to each other.

PARTICLE-ENVIRONMENT INTERACTIONS

Particle-environment interactions deal with external forces (such as temperature, relative humidity, vibration, gravity, aeration and so on) that are exerted over the aggregate of particles. The air relative humidity (RH) and the filler's hygroscopic nature often are coupled with increased cohesiveness because of interparticle liquid bridges. Temperature affects the particle's crystallinity behavior, thereby promoting "caking," while pressure increases the contact points between particles, thereby causing "compaction" or an increase in inter-particle adhesion.

(5) is required for sample B to provide the increased system airflow and vacuum necessary to maintain dilute-phase conveying at the required rate.

Similarly, differences in the bulk density and particle characteristics determine the adjusted rotary valve (3) throughput to maintain the desired rate. To this end, for the much denser material B, the volumetric throughput is significantly lower than sample A.

The diameter of the filter housing is determined by the can velocity (sometimes written as CAN velocity). The upward velocity or can velocity is a function of the container's cross-section (the smaller the container diameter the higher the can velocity), but it varies depending on the characteristics of the material being conveyed.

Maximum can velocity is defined as the largest vertical velocity through the filter housing that will allow the majority of material to fall out of the airstream. The filter cloth area for each material is based upon the filtering characteristics of each sample.

Particle size plays a large role in determining the necessary filter cloth area required to accommodate the material. The larger the particle size, the easier it will be to separate from the airstream; therefore, less filter cloth is required. Table 1 summarizes some of the different equipment requirements for the two samples of $CaCO_3$ described here.

FEED SYSTEM SELECTION

The selection of the appropriate feeding system for each of the illustrated $CaCO_3$ samples is determined by two main variables: the characteristics of the mineral filler (for instance, the particle size and shape, gas permeability, bulk density and angle of repose) and the required feedrate. Table 2 shows an example of ideal feeding systems for the two $CaCO_3$ samples described here.

Loss-in-weight (LIW) feeders, such as the one shown in Figure 3, provide total containment of the raw material and dust and optimal feedrate perfor-

DIFFERENCES IN CONVEYING EQUIPMENT SELECTION

Equipment	Sample A	Sample B
Blower size	16 kW [20 hp]	20 kW [25 hp]
Rotary valve throughput	15 m³/hr [531 ft³/hr]	3.6 m³/hr [123 ft³/hr]
Rotary valve efficiency	84%	92%
Adjusted RV throughput	17.9 m³/hr [632 ft³/hr]	3.9 m³/hr [139 ft³/hr]
Filter housing diameter	1.4 m [54 in]	0.9 m [36 in]
Filter cloth area throughput	17.7 m² [191 ft²]	7.5 m² [81ft²]
Maxium can velocity	21.3 m/min [70 ft/min]	No restriction

Table 1. Significant particle characteristic differences between two $CaCO_3$ samples require selection of different equipment components, and different sizing considerations for the entire system.

DIFFERENCES IN FEEDING EQUIPMENT SELECTION

Equipment	Sample A	Sample B
Feeder model	K2-ML-T60	K2-ML-D5-T35 or -S60
Hopper size	180 dm³	50 dm³
Agitation	ActiFlow or Arch-breaker	None
Feeding device	Twin concave screws	Single auger screw/twin auger or spiral screws
Weighbridge	3 load cells	D5 platform scale

Table 2. This shows an example of ideal feeding systems for the two $CaCO_3$ samples.

assure overall end product quality. LIW feeders are available in a variety of configurations, so that the hopper size, feeding device and weighbridge can be tailored to the specific material characteristics, flow properties and flowrates for the material to be fed.

The weighing system or weighbridge used for the loss-in-weight feeding system can range from small-capacity platform scales to larger, three-point

suspension scale systems. Today's patented, digital weighing technology (K-Tron) provides weighing resolution of 1:4,000,000 in 80 ms resolution, and is designed to reduce vibration and temperature drift during operation.

Most feeders may be categorized as volumetric or gravimetric. Volumetric feeders operate by delivering a certain volume of material per unit time and are typically the feeding solution with the lowest capital cost. However, volumetric screw feeders can't detect or adjust to variations in a material's bulk density during operation. As a result, these feeders are typically most effective with relatively free-flowing materials that have consistent bulk density, such as pellets, and in applications where guaranteed feeding accuracy isn't crucial to the operation.

During gravimetric feeding, dry bulk material is fed into a process at a constant weight per unit of time. Gravimetric feeding provides better monitoring of the feeding process by providing a feedback loop that measures weight and speed. This helps to determine the actual weight of material being fed on a second-to-second basis.

HOPPER SELECTION

Once the size and type of feeder is established, a hopper of the appropriate shape and size must be selected to contain the right amount of filler required for the continuous plastics-compounding operation. Hoppers are available in cylindrical, asymmetrical and symmetrical shapes, and in sizes ranging from one liter to several hundred liters.

A feeder hopper is sized based upon the refill requirements of the feeder and the physical space available at the site. A general rule-of-thumb for calculating the appropriate size is 12 hopper refills per hour, with the maximum fill level in the hopper at 80% of the hopper volume. A large hopper might not be desired because of incremental cost, space requirements, and the possibility of material compaction due to particle interactions.
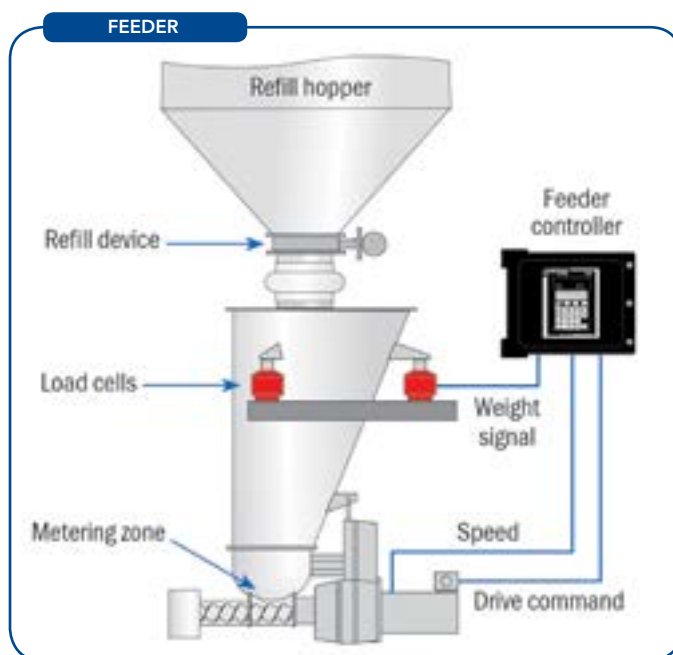

Figure 3. Loss-in-weight feeders dispense dry bulk materials into the process at a constant weight per unit of time. A feedback loop measures weight and adjusts motor speed to ensure that the actual weight of material being fed is exactly what the recipe calls for.

Thus, hopper size selection is initially guided using the following theoretical calculation: *Hopper capacity = Flowrate / (Bulk density × 0.8 × 12)*

Precipitated $CaCO_3$ tends to compact in hoppers and may cause the formation of flow-stopping ratholes and bridges. Flow-aid devices that work by inducing particle-particle vibrations should be considered to ensure predictable flow by preventing the formation of highly dense material zones inside the hopper. In addition, this approach can help to reduce headroom requirements and eliminate cleaning concerns because there's no need to use mechanical agitators inside the hopper. For extremely cohesive materials alternative mechanical agitators are available.

FEEDING DEVICES

Feeding devices vary depending on the bulk material

to be fed: single screw or Bulk Solids Pump (a patented product by K-Tron) for free-flowing powders and granulates, twin-screw feeders for difficult powders (Figure 4), vibratory trays for fibers and friable materials.

While a single-screw feeder may work with free-flowing grades of $CaCO_3$, a twin-screw feeder is generally recommended to achieve a reliable result. A variety of screw designs are available according to the flowrate and characteristics of the mineral filler (Figure 5). The most common screw profiles are concave, auger, spiral and double spiral. The objective of the screws is to discharge the bulk solids uniformly into the plastics compounding process. Screws also serve to stop the material flow when the screw feeder is stopped, and to prevent flooding effects with fluidizing bulk solids.

Calcium carbonate's tendency to compact also occurs on metal surfaces like the feeder's screws. For this reason, two intermeshing, co-rotating self-wiping screws are needed to keep the screw surfaces clean and free of material buildup.

DESIGN MATTERS

Because $CaCO_3$ is so widely used in plastics-compounding operations, it's important to appreciate how much the success of the overall operation depends on its bulk material handling systems. Correct design of pneumatic conveying and feeding systems for $CaCO_3$ isn't a trivial proposition. A number of variables affect the flow of this often-difficult powder, and the return on investment (ROI) of a plastics-compounding plant is directly impacted by the proper selection of the most cost-effective pneumatic conveying and feeding system. Particle characteristics, as well as material flow behavior (governed by, among other things, particle interactions with other particles, and particle interactions with the equipment and the environment) will influence the selection of equipment and system design. ●

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FLOOD PREVENTION

Figure 4. To prevent flooding with free-flowing grades of $CaCO_3$, twin-screw feeders are recommended.

SCREW DESIGNS

Figure 5. These intermeshing twin screws can prevent flooding of fluidized material. A variety of feeder screw designs are available, depending on the flow rate and characteristics of the mineral filler.

Suppress Explosions for Process Protection

A properly designed and engineered suppression system offers many advantages

By Jef Snoeys, Fike Corp.

CONSIDER A variety of reasons for applying explosion protection: OSHA and EPA compliance issues, corporate safety directives, pressure from insurance companies, process changes, technology improvements and more. But the most important reason is a bit more basic: doing the right thing to provide for the safety of employees and the facility in which they work.

For years, explosion venting has been the primary strategy for explosion protection. However, improved protection technologies, increasing public awareness and stiffer regulations from EPA, OSHA and NFPA all point to considering alternative, or additional, protection strategies and systems.

Explosion suppression is a technique whereby combustion of an explosive atmosphere in a closed, or essentially closed volume, is detected and arrested during incipient stages, thereby restricting development of damaging pressures. Explosion suppression offers many advantages as a protection method. First, suppression stops the deflagration before developing pressure can damage the process equipment. In addition, it controls any ensuing fire and reduces the propagation of the flame front to other process equipment. Because explosion suppression doesn't vent flame or other material, it's the solution of choice when toxic materials are being handled, equipment is located indoors, or venting exposes personnel to discharge of pressure and flame. Explosion suppression systems utilize electrical and mechanical components that can be adapted easily to most processes and are maintained in an active condition with continuous electrical supervision of components.

USING EXPLOSION SUPPRESSION TO PROTECT YOUR PROCESS

A properly designed and engineered explosion suppression system offers a variety of distinct advantages:

- Extinguishes the flame within the equipment, preventing fire damage
- Helps prevent pressure piling and secondary explosions with interconnected equipment (especially when used in conjunction with explosion isolation systems)
- Complies with NFPA regulation barring venting of explosions indoors. (Explosion vents must be discharged to a safe location. Indoor applications are difficult to vent — even with discharge ducts.)
- Retains toxic or valuable materials within the process equipment
- Integrates with the process controls to enable other protection devices, process shutdown and remote annunciation devices
- Suppresses Class ST III dust hazards, the highest level of industrial explosion
- Greater latitude in protection strategies, and process operations

HOW EXPLOSION SUPPRESSION WORKS

In many ways, explosion suppression systems function like automatic fire suppression systems, although much faster. An explosion suppression system is comprised of explosion detectors, explosion suppressors and a central control and annunciation system. Following detection of the incipient explosion, the suppressant agent is released from a pressurized vessel and distributed quickly and evenly throughout the vessel to be protected. Because the suppressant agent creates an atmosphere that will no longer allow explosion propagation, the damaging pressures from the explosion will not develop. This suppression sequence is illustrated in Figure 1.

In explosion venting, the reduced explosion pressures are designated as P_{red}. For suppression, the final pressure within the protected equipment is designated as TSP or Total Suppressed Pressure. In both cases, the equipment strength must be above these levels in order to avoid damage from an explosion.

An explosion is regarded as suppressed when the total suppressed pressure is lowered to a maximum reduced (suppressed) explosion overpressure $P_{red,max}$ or TSP of typically between 3 to 7 PSIG (20 to 50 kPa). For most practical applications of explosion suppression the worst case maximum TSP that can result is predicted by calculation. Provided that this suppressed explosion pressure is lower than the process equipment design strength, effective explosion suppression can be assured.

It's important to note that the pressure time relationship as shown in Figure 2 is fuel specific and knowing the explosibility characteristics of the potential dust, gas or hybrid fuel is necessary to design an effective explosion suppression system. The parameters of interest are the maximum explosion pressure (P_{max}), and maximum explosion pressure rate of rise (dP/dt or K_{ST}). These values are obtained from standardized laboratory tests.
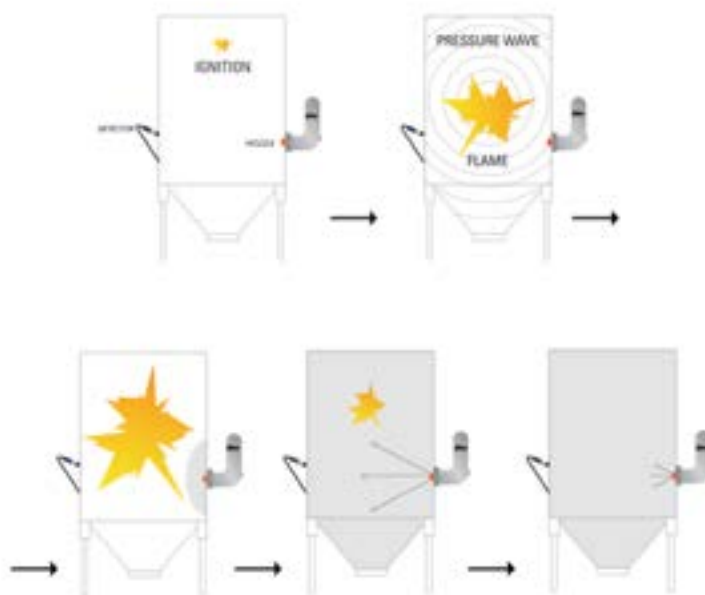
Figure 1. A typical explosion suppression device prevents developing pressure from damaging process equipment.
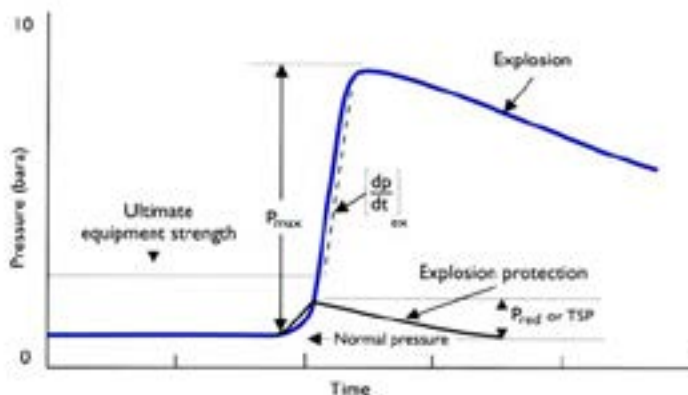
Figure 2. When designing an effective explosion suppression system, it's important to know the typical pressure time history of a suppressed explosion.

SYSTEM DESIGN

Explosion suppression can be used on many different types of process equipment such as dust collectors, cyclones, driers, mixers, pulverisers and shredders. The dimensions of the protected equipment can range from 0.5 to 1,000 m^3.

Explosion system design should be performed by qualified professionals trained to understand how to relate relevant explosion and process characteristics to the suppression systems performance, in order to apply this knowledge and design the protection system solutions. Besides selecting the type and number of suppressors and the suppressant agent, the most appropriate means of detection and hardware to warrant effective distribution will have to be selected.

Detection. Any physical characteristic that will give evidence of an explosion in its early stages, can be detected. Absolute values or rate of pressure or temperature rise have been used, in addition to the detection of infrared (IR) and ultraviolet (UV) radiation levels. Although optical detectors are extremely fast and sensitive, they are an in-line-of-sight system, and multiple detectors would have to be used to see all of the locations where an explosion might occur. The most universally applied detectors are those relying on pressure, and ceramic diaphragms are preferred because of their mechanical and chemical resistance. Typical pressure detector activation pressures for applications that operate at or near atmospheric pressure, range from 0.5 PSIG (3.5 kPa) to 1.5 PSIG (10 kPa). Where pressure fluctuations are expected, or where the normal operating pressure is above atmospheric, a pressure rate-of-rise unit may be required.

Suppressant. The effectiveness of the suppressant used and the compatibility of the suppressant with the process must also be considered. Testing determines the effectiveness and perfor-

Figure 3. Pressure detectors with ceramic diaphragms are preferred because of their mechanical and chemical resistance.

mance of the suppressant, which then quantifies the applicability of a particular type of suppressant. Other important considerations include food compatibility of the suppressant, ease of removing the suppressant from the process and the suppressant's temperature stability.

Water and carbon dioxide, two popular materials for extinguishing fires, are not generally utilized for explosions. Aside from a possible reactivity with the chemicals in question, relatively large quantities of water would be necessary to limit reactions. Carbon dioxide has a low effectiveness–weight ratio and would require large storage units. Materials have also been known to reignite after having been extinguished by CO_2. Halogenated compounds, mostly methane derivatives, are popular suppressants but pose environmental issues and may chemically react with the hazard.

The most commonly used suppressants are dry inert suppressant powders such as sodi-

umbicarbonate (SBC), and mono-ammonium phosphate (MAP). Figure 4 shows a dataset of experiments conducted with cornstarch. The inertant dusts used were sodium bicarbonate (SBC), mono-ammonium phosphate (MAP) and rock dust (RD). Note the outspoken form of the SBC suppressant curve which resembles a classical flammability curve, clearly showing the superior suppressant efficiency of SBC against the hazard of cornstarch.

Suppressors. Suppressors or extinguishers are typically available in a range of volumes from 2.5 to 50 L and are mounted outside of the equipment on a flange. They are usually pressurized with nitrogen to 900 PSIG (6,200 kPa) and are fitted with a rupture disc or diaphragm that's opened by a contained explosive charge (see Figure 5).

Suppressors have been reported which use an electromagnetic means of opening, typically releasing a flap instead of breaking a disc. Due to the high speed at which the pressure rises during an explosion and to the relatively long time needed to obtain full opening of such valves, it's believed that they are too slow to protect against moderate- to fast-developing explosions.
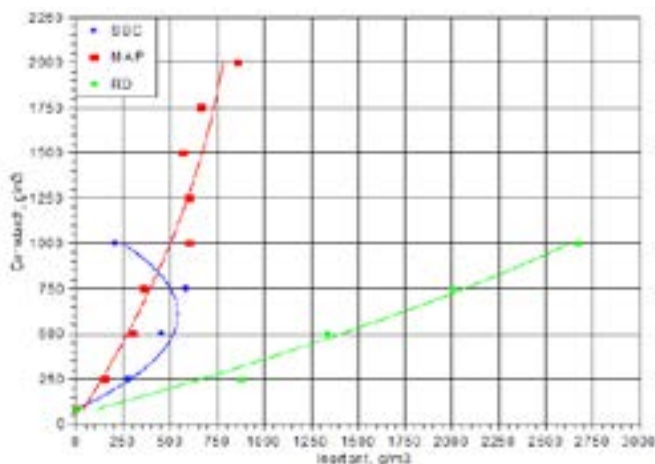
Figure 4. Each Application of hazard must be defined as to the minimum inerting concentration (of fuel and suppressant) below which explosions are possible and above which they are not (example shown: cornstarch in a 1m³ explosion chamber).

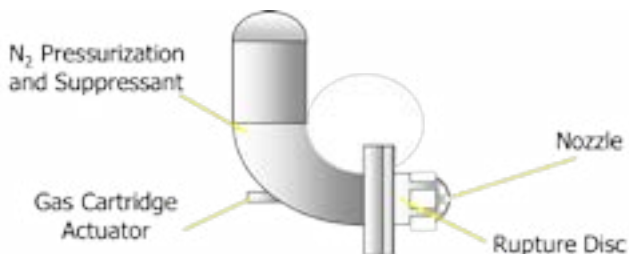Figure 5. Suppressors are pressurized with nitrogen and fitted with a rupture disc or diaphragm that's opened by a contained explosive charge.

Figure 6. Gas cartridge actuators use explosive detonators to initiate the opening of the rupture disc.

A fairly recent development is the use of gas cartridge actuators instead of explosive detonators to initiate the opening of the rupture disc (see Figure 6). These self-contained gas generators have proven to be as fast as detonator-operated valves but are less hazardous and easier to transport and handle.

Nozzles. To ensure a uniform suppressant distribution in the vessel to be protected, dispersion nozzles, fitted with protected caps are mounted to extend into the vessel (see Figure 7). Traditional suppression systems used "pepperpot" style nozzles which aren't very suitable for powder-based suppression systems. Instead, nozzles with large openings in the top and sides have been developed to ensure a hemispherical, fast and uniform distribution of the suppressant (see Figure 8).

Many processes, particularly in the food and pharmaceutical industries, require the use of hardware that prevents the buildup of material. This provides optimum processing and easier cleaning of the equipment (CIP). To address these needs, telescopic nozzle arrangements have been developed which are flush mounted and typically use a silicone, Teflon or stainless steel nozzle cover. The nozzle functions by moving from the flush position to a position inside the protected area when the system is activated.

LARGE-SCALE TESTING

Understanding the explosibility characteristics of a particular process media, or other explosion hazard, is typically the first step toward obtaining effective protection. However, large-scale testing is required to validate the interaction between the dynamics of explosion propagation and the suppression system hardware to achieve TSP within the strength limitations of the equipment.

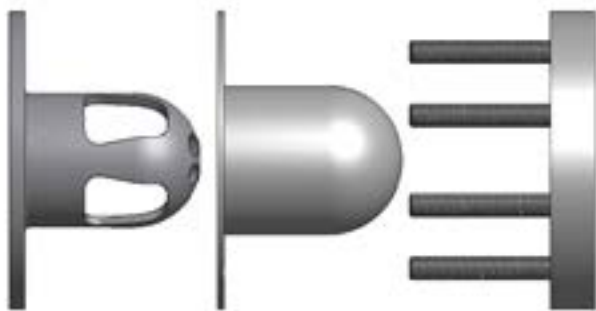Large-scale tests are conducted with test chamber

NOZZLES

Figure 7. Dispersion nozzles fitted with protected caps are mounted to extend into the vessel to ensure uniform suppressant distribution.
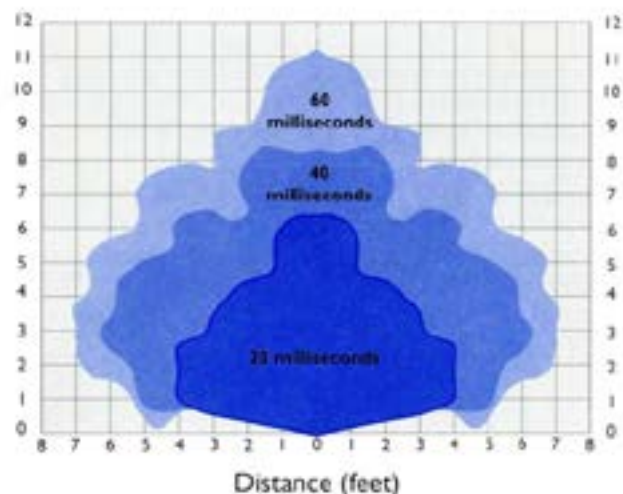

POWDER DISTRIBUTION

Figure 8. Hemispherical suppressant powder distribution is attained when using nozzles with large openings in the top and sides.

volumes that are similar to the volumes of industrial equipment (Figure 9). Explosion chambers with volumes from 0.5 to 250m³ have been used to validate large-volume suppression. In these chambers, explosions with K_{ST} values of up to 550 bar.m/s are generated and the explosion suppression system is allowed to react independently to these explosions. Experimental parameters of importance are volume, K_{ST}, Pact and size and number of suppressant discharge containers used. Figure 10 shows a dataset obtained by varying the number of containers used to suppress a K_{ST} 300 bar.m/s hazard in a 25 m³ vessel.

From the experimental data, the minimum number of HRD-suppressors, N_S, required to effectively suppress an explosion of a defined explosion violence using the ISO method of dust distribution in a given volume, V, can be determined using following equation: $N_S = N_o . V^{2/3}$.

When selecting an explosion suppression supplier, check the availability of efficiency numbers to ensure that large-scale-suppression testing has been performed and that the protection requirements are met. It's advised to work with your selected explosion protection provider to relate relevant explosion and process characteristics to the suppression systems performance. It's common practice to use CAD software tools to solve complex problems and design the optimum suppression system.

SAFETY IN SPEED

With any explosion protection system, speed is paramount. Detection, control and releasing functions must be completed within a few milliseconds. With proper system design and a response in milliseconds, a suppressed explosion is limited to a typical pressure increase in the range of 3 to 7 PSIG. The reduced pressure

Figure 9. A 250-m³ explosion test chamber fitted with Fike 50 L suppressors (white colored containers) is used for large-scale testing.
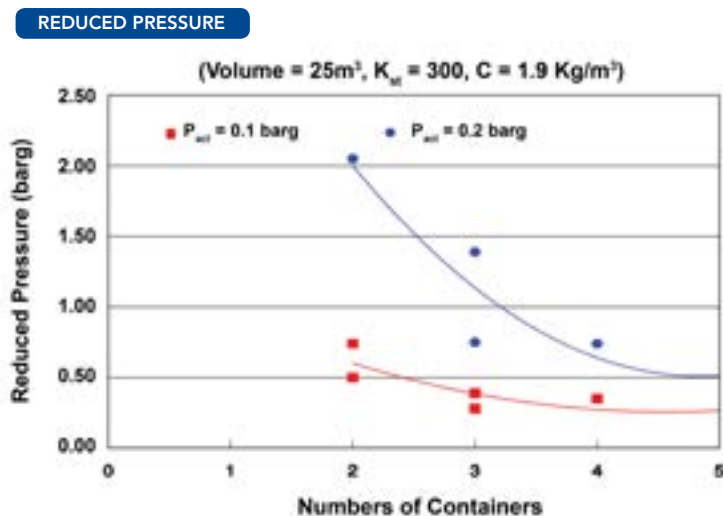
Figure 10. Containers used to suppress a K_{ST} 300 bar.m/s hazard in a 25 m³ vessel.

EXPLOSION ISOLATION

Explosion isolation systems are designed to work in conjunction with both venting and suppression protection methods, by preventing the deflagration from reaching other areas through interconnected process pipes or ducts — placing the connected equipment and facilities at risk for secondary explosions. These secondary explosions are often the cause of the most severe damage and loss of life. Explosion isolation systems prevent the propagation of flame through the use of fast-acting valves or chemical barriers, effectively eliminating secondary explosions.

Mechanical explosion isolation involves the use of uniquely designed mechanical valves which provide an actual physical barrier to prevent the spread of an explosion through connecting pipework.

Chemical explosion isolation is achieved through a rapid discharge of a chemical explosion suppressant to prevent the flame from continuing through to other areas of a process system. An explosion detector initiates the release of the extinguishing agent when it detects a deflagration pressure or flame front, preventing the propagation of flame and burning materials.

Regardless of other protection measures, explosions must be prevented from propagating to other locations within the facility.

EXPERIMENTAL DATA

D of outlet	101.4 mm (4")				152.4 mm (6")	
K_{max} (m.bar.s-1)	5 l HRD	10 l HRD	20 l HRD	30 l HRD	25 l HRD	50 l HRD
200	0.99	0.49	0.27	0.23	0.19	0.15
300	0.99	0.57	0.35	0.31	0.26	0.22
D = Diameter						

Figure 11. Values of the constants N_o for the Fike explosion suppression system using HRD-suppressors with 4-in. (101.4-mm) and 6-in. (152.4-mm) outlets (dry powder suppressant; Ps = 62 bar; V = 1-1000m³).

limit brought about by suppression is very short in duration and minimizes equipment damage while optimizing personnel safety. Additional advantages are seen when toxic materials are being handled, equipment is located indoors, or venting exposes personnel to discharge of pressure and flame. However, the increased cost over a passive (venting) solution, is incremental and maintenance is required to ensure overall system readiness and reliability throughout the lifecycle of the suppression system.

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BIBLIOGRAPHY

Instrument and Automation Engineers' Handbook (IAEH). 4th Edition

Chatrathi, K. ; Going, J. *Dust Deflagration Extinction*, AIChE 2000

Chatrathi, K. ; Safety and Technology News, Fike, Volume 7 issue