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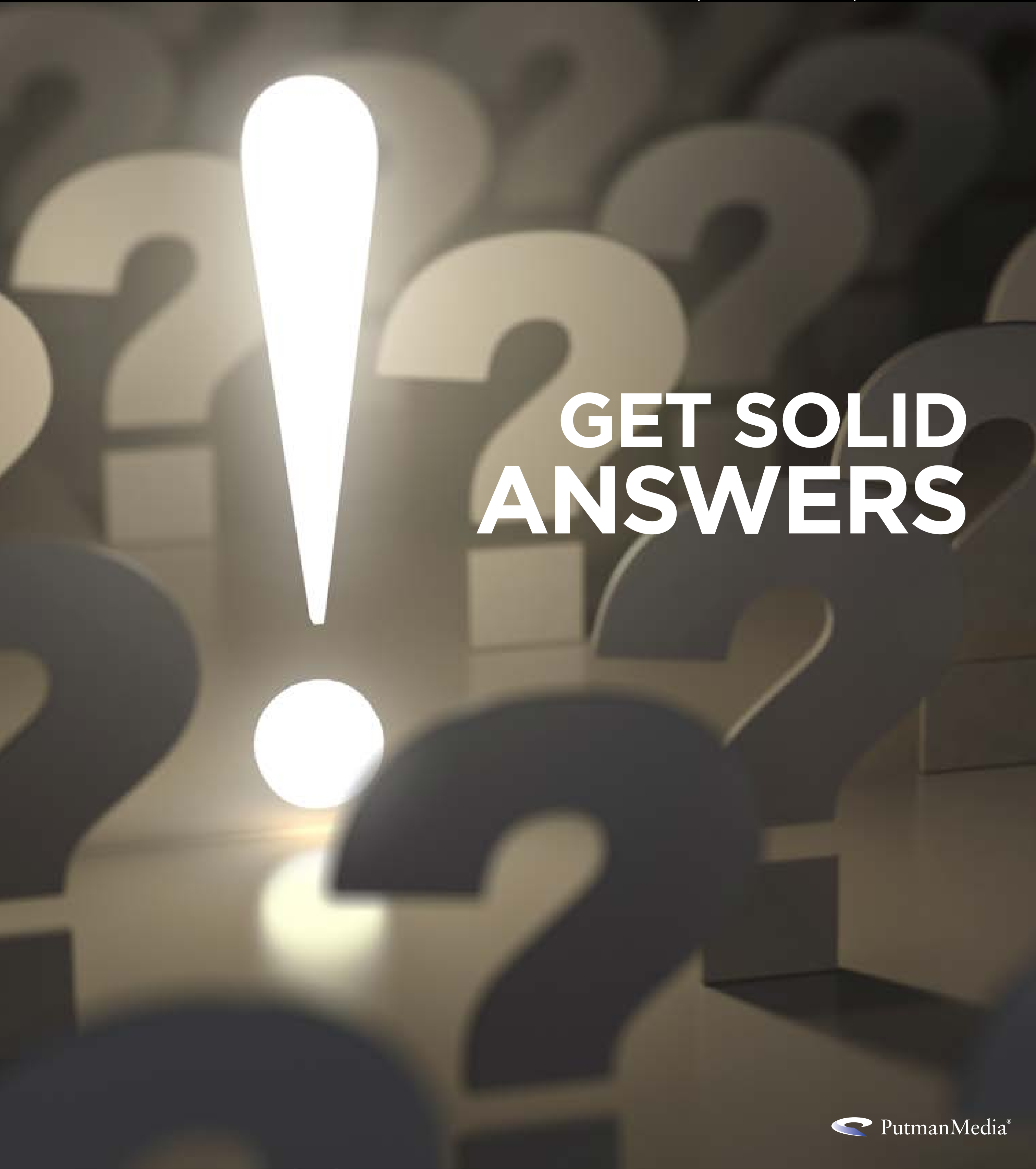

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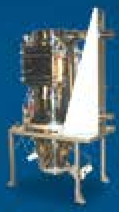

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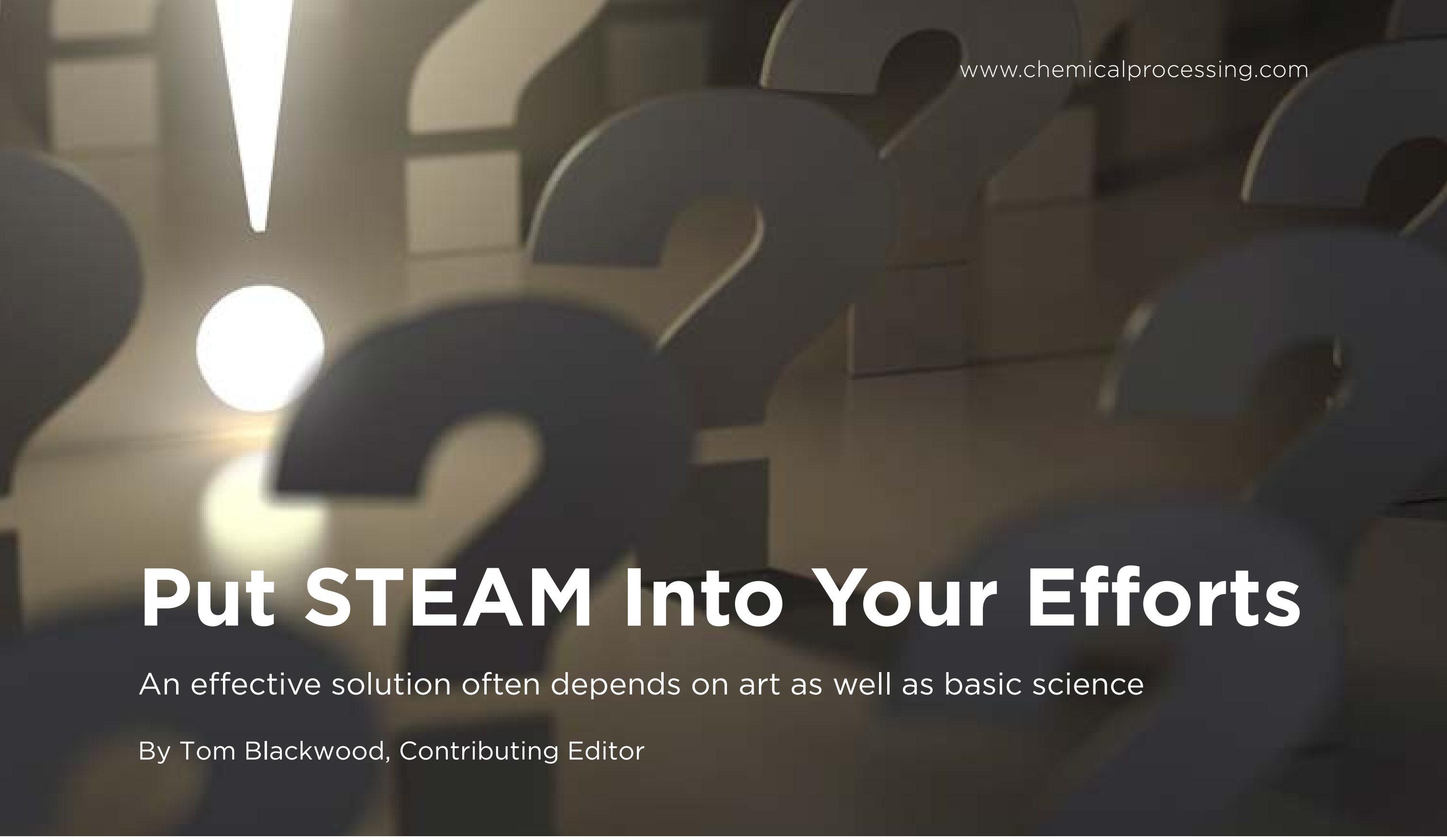

Put STEAM Into Your Efforts

An effective solution often depends on art as well as basic science

By Tom Blackwood, Contributing Editor

Science, technology, engineering and math (STEM) skills underpin the chemical industry. We believe fundamentals beat guessing 100% of the time. Sure, examples that defy initial analysis arise — but we eventually discover a new or misused property to include in future applications. However, until we pinpoint that parameter, part of process design often relies on art — turning STEM into STEAM.

Finding all the factors that predict the desired outcome is time consuming, especially when working with solids. I'm often reminded that it's possible to spend countless hours researching various conditions without ever uncovering the one scenario that causes the specific issue at a plant. Art is selecting different screen sizes for various products that are physically the same size and shape. Art is why we install a device whose operation we can't explain scientifically but which has performed successfully in the past. The inventor may not even know how it works. Whether it's advisable to wait until its technical basis is proven depends on how much time and money are involved.

The practice of medicine is called a "practice" for good reason; so is a portion of solids process engineering. Crystallization primarily is science but do we truly understand nucleation and growth? We recognize that our crystallizer needs to be defrosted. Do we know how long or how to prevent flash-nucleation? Because time is money, we take shortcuts that speed up the process — such as rapping on the crystallizer head at just the right moment during cooling. This is something an operator has discovered over the years and is an art.

Scale formation is a form of undesirable crystallization/precipitation. Magnets have been used to minimize this problem. So, I asked: "What makes them work?" We commissioned a research project to study this type of device and attempted to understand how a magnet placed upstream from where the scale forms could prevent the problem. After several years of study, the researchers found no supporting evidence other than that a magnet seemed to work in several industrial settings but never in the lab. I'm convinced some science can explain this behavior. However, it could be the artist/scientist at work.

Cyclone design is an art. Each manufacturer has its own design, which has proven to work in most cases. However, each design looks different: some are short and wide while others are narrow and tall; some use a volute inlet and others have secondary bottom receivers. Hundreds of articles delve into the advantages of these nuances. A research consortium of industrial leaders developed a universal design program but found that it didn't predict specific particle collection very well. However, cyclones of similar geometry performed in a very predictable manner, which probably is why every manufacturer uses a different shape in its design. Don't get me wrong — designers still look at inlet velocity, space limitations, abrasion issues and a lot of technical aspects of their product to ensure they propose a robust design. When I was in the equipment manufacturing business, my boss always reminded me that we don't buy a bad job, which means keeping any artistic features the same.

While I can offer an explanation for the drop-off in drying rate due to diffusion or capillary action, I end up with a "fudge factor" in the equations for the drying kinetics. When examining a new material, I often feel it between my fingers and relate that back to some other solid to select the best dryer configuration and fudge factor. It's an artistic start in selection of a technology. While I'd like to do all the drying curves, the cost can outweigh the benefit; such art can shorten those studies.

You've probably had similar experiences where some innovation lacked a sound scientific explanation. We're not taking anything away from STEM but rather benefiting from an additional view. As I look around to other engineers and academics, I see a movement that is picking up steam. ■

TOM BLACKWOOD is a *Chemical Processing* Contributing Editor. You can email him at TBlackwood@putman.net

Think Small

Many processes depend on size reduction to improve performance or meet specifications

By J. Peter Clark

The chemical, pharmaceutical, food and mining industries all rely on size reduction. Its uses include grinding polymers for recycling, improving extraction of a valuable constituent from ores, facilitating separation of grain components, boosting the biological availability of medications, and producing particles of an appropriate size for a given use. There are many types of size-reduction equipment, which are often developed empirically to handle specific materials and then are applied in other situations.

Knowing the properties of the material to be processed is essential. Probably the most important characteristic governing size reduction is hardness because almost all size-reduction techniques involve somehow creating new surface area, and this requires adding energy proportional to the bonds holding the feed particles together. A common way of expressing hardness is the Mohs scale, on which talcum is a 1 and diamond is a 10. Also important is whether a material is tough or brittle, with brittle materials being easier to fracture.

Other characteristics include particle-size distribution, bulk density, abrasiveness, moisture content, toxicity, explosiveness and temperature sensitivity. Flow properties can be major factors, too, because many size-reduction processes are continuous, but often have choke points at which bridging and flow interruption can occur. For instance, most size-reduction equipment is fed by chutes, which might constrict flow. Often, the feed flows adequately, but the crushed product will compact and flow with

TYPICAL ADVANTAGES AND DISADVANTAGES		
Type of Equipment	**Pros**	**Cons**
Jaw crusher	Rugged, good for hard materials, common in mining	High wear
Gyratory crusher	Rugged, good for hard materials, common in mining	High wear
Rolls	Narrow size distribution, good for hard materials	Fines
Impact (hammer)	Verstaile, good for tough, fibrous materials	Screen can blind
Jet	Low wear	Energy intensive
Ball, rod, pebble	Very fine particles can be used for wet grinding	Inefficient
Wet	Very fine particles	High wear
Cryogenic	Handles plastics	Cost of cyrogen

Table 1. Ball, pebble and rod mills are capable of producing very fine powders, but are quite enregy inefficient.

difficulty. Intermediate storage bins might aggravate flow issues by causing compaction and bridging.

For a given feed material, it is important to determine the desired particle-size distribution of the product. In mining, for example, very fine particles can interfere with separation processes, such as froth flotation, and might result in loss of valuable components. In other operations, the objective might be to produce very fine particles. Sometimes, as in sugar grinding, very fine particles are agglomerated to increase the share of larger particles.

Many particle-size distributions can be represented by the Gaudin-Schuhmann equation:

$$y = 100\ (x/x_m)^{\alpha}$$

where y is the cumulative percentage of material that is finer than size x, x_m is the theoretical maximum size, and α is the distribution modulus, which is related to hardness and has lower values for softer materials (0.9 for quartz and 0.3 for gypsum, for instance). The equation indicates that softer materials produce more fines [1].

Nearly all size-reduction techniques result in some degree of fines. So unless producing very fine particles is the objective, it usually is more efficient to perform size reduction in stages, with removal of the desired product after each operation.

HARDWARE OPTIONS

Size-reducing equipment relies on compression or impact. Compression is applied via moving jaws, rolls or a gyratory cone. The maximum discharge size is set by the clearance, which is adjustable. Impact-based equipment commonly uses hammers or media. The pros and cons of several types of size-reduction equipment are shown in Table 1.

Rolls, in particular, can produce very fine particles. Rolls are used in flour milling, where crushing yields different-sized particles, allowing separation of purified flours. Moisture content is important so that, for example, the bran is soft and remains in large pieces, whereas the endosperm is brittle and fractures into small granules. Corn germ can be separated from starch and fiber by roller milling because the germ selectively absorbs water and is made into flakes, whereas the starch fractures.

Impact mills use revolving hammers to strike incoming particles and to break or fling them against the machine case (Figure 1). The hammers might be fixed or, more commonly, pivoted. Typically, the hammers can be reversed to provide added life before they need to be replaced.

In jet mills, particles strike each other as they are transported in a stream of air or steam. For the initial reduction of large materials, a rotating drum propels the feed into the air where the pieces strike each other and fracture.

Ball, pebble and rod mills are rotating cylinders that are partially filled with metal or ceramic balls, flint pebbles or rods. The units are capable of producing very fine powders, such as pigments for inks and paints, but are quite energy inefficient. The crushing mechanism is a combination of impact with the grinding media and shearing between the media and the cylinder walls (Figure 2). A variation is a jar mill, in which relatively small ceramic containers holding some grinding media are rotated on a common machine frame. It is used for small batches of valuable chemicals and in laboratories.

LUMPBREAKER

Figure 1. Such mills can achieve a wide range of particle sizes and are available in sizes from laboratory scale on up. *Source: Schutte-Buffalo Hammermill*

Wet grinding might be appropriate when the fine particles are to be suspended, as in paint or ink, or where an explosion or dust hazard might exist. The fluid might be water, oil or solvent. Water is used to help suppress dust, but complicates the process if drying is then required. Pigments for inks and paints might be ground in the medium in which they are to be suspended. Wet grinding often takes place in ball, pebble or rod mills. The efficiency of wet grinding can be higher than that for dry grinding, but wear of equipment is also higher [2].

Most size-reduction equipment is subject to heavy wear and therefore parts, such as casing liners, hammers and jaws, are designed for relatively easy replacement.

PROCESS FLOW SCHEMES

The basic options for size-reduction flow paths are: simple crusher (no separation); normal order circuit (separation after crushing with recycling of overs, that is, oversized material); reverse-order circuit (separation before crushing with only overs going to the crusher and crusher product going back to separation); and reverse order without recycle (separation before crushing but no recycle) [3].

More complex flow sheets are assembled from combinations of these basic flow schemes. Because the particle-size distribution of the feed and milled product is almost always different, it is often advantageous to remove a desired size range before further milling. The trade-off is that more equipment is required, as is additional material handling. When feasible, a vertical equipment arrangement often is preferred so that many flows are driven by gravity. However, this also means that heavy equipment is located on a frame or on a different floor; so, access for maintenance and stabilization against vibration must be considered.

MEDIA MILL

Figure 2. This mill uses 0.1-mm media to product nano-sized particles. *Source: Premier Mill*

Usually, some form of separation follows size reduction. The most common is simple screening, in which the screen openings are selected to pass the desired size range and retain material that is too large. Because particles rarely are symmetrical, it is important to understand which size characteristics matter. Screens are subject to blinding by particles large enough to enter a hole, but not able to pass through. High-moisture solids can also cause blinding by agglomeration. Most screens are moved by vibration or regular motion to facilitate passage and to remove overs.

Air aspiration is often used, especially in jet mills, to remove fine particles by entrainment while retaining larger particles. Hammer, ball and rod mills frequently have screens on their discharge to retain large particles and media while passing fine particles.

Other separation techniques include froth flotation, in which the difference in surface chemistry between a desired material and waste is exploited to float fine particles attached to air bubbles. The fine particles might be the product or the waste. The remaining material is either enriched or depleted.

Centrifuges or hydroclones, which rely on differences in density and particle size, are also used to separate materials after size reduction. Corn wet mills use both devices to remove starch from protein and fiber.

Sometimes fine particles require agglomeration to provide an appropriate size distribution — such as for successful compression of powders into tablets for confections or medications. This process is called granulation and is accomplished by mixing the fines with small amounts of water, solvent or syrup; it might occur with simultaneous drying, heating or cooling.

SPECIAL OPTIONS

Some of the more difficult materials to mechanically process are plastics, rubbers and fibers because they deform, but do not fracture, when struck. One solution is cryogenic milling, in which liquid nitrogen or carbon dioxide is injected with the feed to a hammer mill. The extreme cold makes plastic materials brittle enough to fracture easily. For much the same reason, meat usually is ground at a temperature just above freezing.

A completely different approach to size reduction involves dissolving a material in a solvent and then separating it. One example is spray-drying of fortified dairy beverage mixes. Many chemicals are produced as powders by crystallization. Another example is the use of supercritical carbon dioxide. Upon depressurization, the supercritical fluid loses its high solvent power and precipitates a very fine powder. This approach can be used for heat-sensitive pharmaceuticals and fine chemicals that would be damaged by conventional milling.

NO SMALL MATTER

There are many choices for a size-reduction process, depending upon the feed material, the desired product, hazards, costs and common practices in the given industry. Size-reduction equipment can range from very large and rugged jaw crushers, capable of reducing boulders to sand, to very precise cutting mills. Integration of the correct separation equipment with size-reduction units and attention to solids-flow and material-handling issues are critical to successful design and operation of a size-reduction process. ■

J. PETER CLARK is an Oak Park, Ill.-based consultant who specializes in process development, including size reduction.

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Reduce Particle Segregation

Consider these practical steps to improve product quality

By Diamondback Technology

Particle segregation is a common problem in many bulk storage systems and its presence creates serious quality control problems. Segregation creates inconsistent batches that can cause dosage variations in pharmaceuticals, significant weight and flavor variations in packaged foods and gas flow problems in chemical reactors.

There are more than a dozen easily identifiable segregation mechanisms that result in out-of-spec product, but the five most common segregation mechanisms — sifting, angle of repose, fines fluidization, air currents and chute trajectory — are responsible for more than 80% of segregation problems in solids handling and storage systems.

Sifting segregation is mostly likely in a mixture containing free-flowing particles of significant size variation, usually three or greater in the mean diameter. As process equipment imposes interparticle motion, usually through vibration, the finer component can sift through coarse components. All bins, batch blenders and chutes have the potential for sifting segregation problems.

Angle of repose segregation occurs whenever solids with greater angles of repose form a steep pile under the deposit point, allowing solids with lesser angles of repose to slide or roll to the head of the pile. A mixture containing components that are cohesive or rough-surfaced are particularly prone to angle-of-repose segregation.

Rotating shell-type blenders, stock piles and bins are susceptible to this mechanism.

Fluidization segregation results when a mixture contains a large portion of light or fluffy free-flowing, fine component, enough to form a layer, and smaller portion of a relatively coarse, heavier component. The larger component easily penetrates the fluidized fines, pushing the fines layer to the top of the bin or vessel. Fluidization is especially active in air blenders, high-speed ribbon blenders, bins and piles.

Air current segregation occurs when fine particles become airborne as bimodal material enters a bin. These very fine particles migrate to the vessel walls or toward a dust collection system. If the fines are a minor component of the mixture or are cohesive, migration can be significant.

Chute trajectory segregation results from particles with different friction coefficients. High friction coefficient materials usually contain fine particles and slide more slowly down a chute than low friction materials. This results in different discharge trajectories. Particles with high friction angles dribble off the end close to the chute, while particles with low friction angles accelerate and are thrown further away from the chute.

There are simple, practical steps to reduce these segregation mechanisms.

- **DO** use a bin with tall cylindrical section that provides flow at the walls.
- **DO** use a mixing device at the center for charging a multiple-outlet bin. This will create uniform, symmetric segregation.
- **DO** proportion and mix badly segregated materials just before processing using as little surge capacity as possible.
- **DO** use a tangential entry for pneumatically conveyed fluidizable solids or install a cyclone at the bin top that uses a deflection plate.
- **DO** use inclined open chutes to decrease air entrainment in ascending solids. This not only reduces fluidization entrainment, it also reduces dusting.
- **DO** premix liquid with coarser particles before adding finer components if sifting or repose segregation are present.
- **DO** use blenders that remix top-to-bottom during hopper discharge or use static stream blenders below belt discharge points to remix segregated solids.

- **DON'T** split material from a belt conveyor into various bins since the belt may segregate the materials.
- **DON'T** use a non-symmetrical, multiple-outlet bin.
- **DON'T** use a uniform velocity mass-flow bin to cure fluidization-type segregation. It will only make it worse.
- **DON'T** use freefall chutes to transfer materials with different friction angles unless there is a mixing device downstream.
- **DON'T** charge a mixture of fine fluidizable powder and non-fluidizable coarse particles from a pneumatic conveying line using a vertical downspout.

Segregation problems created by these mechanisms can be solved by modifying equipment or operating procedures, both of which often do not require large capital expenditures.

For information on solving segregation problems, contact Diamondback Technology at info@diamondback-technology.com

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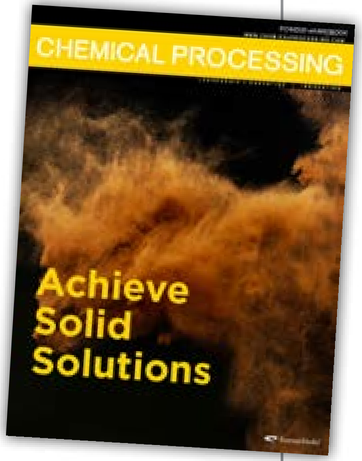

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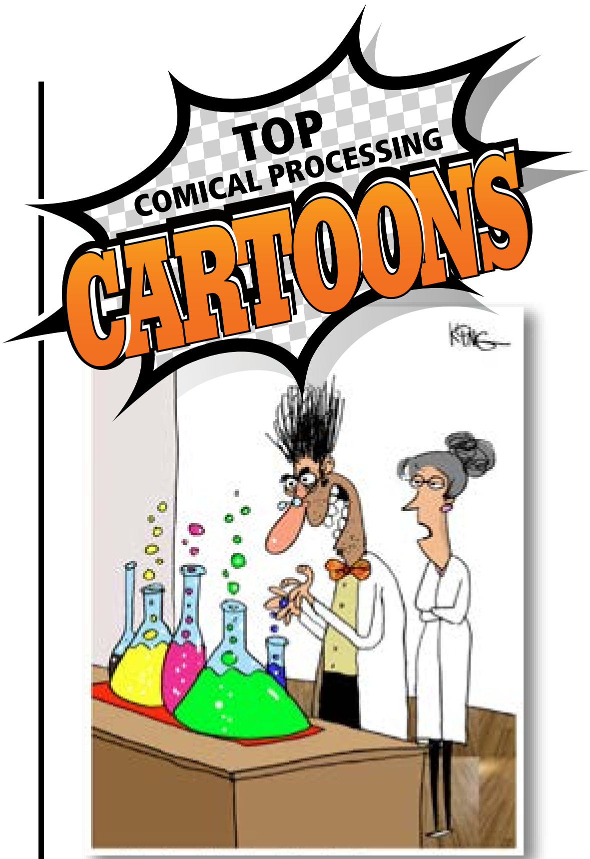

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