What you should know before selecting size reduction equipment

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Size reduction can be defined as using mechanical forces to split a solid's structure into a collective of pieces without changing the solid's aggregated state. This may sound relatively simple, but there are many types of equipment for reducing dry bulk solid materials. This article reviews what you need to know about your material and available size reduction equipment to choose a size reduction machine for your application.

Most dry bulk solids processes require a size reduction step to improve the final product quality or process the solid material more economically. In fact, about 1 percent of the energy used worldwide drives dry solids size reduction equipment.

Yet simply reducing the material's original size isn't enough in most applications. After initial size reduction, the reduced material often isn't the right size for the intended use or downstream process. For instance, the particle size distribution may be too wide — either with too many fines, which can cause dusting problems during later processing, or too many coarse particles to meet the final spec. Ideally, processors want to produce a *monodisperse material* — that is, a material with a narrow range of particle size and shape — to make the reduced material more suitable for further processing in downstream equipment. A monodisperse material:

- Can be metered more efficiently to other equipment.
- Can help achieve fast, homogeneous reactions and dispersions because of its narrow particle size distribution and large particle surface areas.
- Is easier to handle in applications such as filling and emptying bags, other containers, and storage vessels, because of the material's combination of homogeneous particle size and minimal fines.

Typical size reduction goals and the characteristics they influence are listed for several material examples in Table I. To produce a monodisperse material with the character-

Table I

Size reduction goals and the material characteristics they influence

Goal	Characteristics influenced	Material examples
Enlarging specific surface area of particles	Improved reactivity Better solubility Better release of active ingredients Better digestibility Improved extractability	Salts, sugars, cellulose, legumes, resins, pharmaceuticals
Reducing material's top particle size	Suspension stability with no sedimentation Individual particles undetectable by human tongue or fine palate	Nutrient powders, cocoa powders, chocolate mass
Changing material characteristics	Good flowability Better metering characteristics High bulk density Good blendability Better drying characteristics	Starches, sea salt, chemicals
Improving separation quality	Particle size of one material component is larger than others	Composite materials, paper, plastics

istics to meet your size reduction goals, you must not only choose an appropriate size reduction machine, but correctly preset the machine's parameters (such as the grinding tools' shape, size, and sharpness; the grinding gap; and the screen opening size) and in some cases use further processing steps such as classifying. Such steps may be integrated into the size reduction machine or may require additional equipment and occur after size reduction. [***Editor's note:*** Describing the components and operation of individual size reduction machines is beyond this article's scope; for information about specific machines, see the later section "For further reading."]

Some background for selecting a size reduction machine

Successfully choosing an appropriate size reduction machine requires an in-depth understanding of your material, your application requirements, and the range of available equipment that can achieve your size reduction goals. A good place to start is to consider how your material's hardness and other characteristics affect which size reduction mechanisms are suited to handling the material.

Material hardness. Your material's hardness is one of the most important factors in selecting the right equipment to reduce the material. Material hardness is typically classified from 1 to 10 according to the Mohs scale, which was developed almost 200 years ago by German mineralogist Friedrich Mohs. The scale, as shown in Table II, characterizes the scratch resistance of materials by the ability of a harder material to scratch a softer material. The higher the hardness number, the harder the material. Dry bulk solids processors most commonly reduce materials with a hardness of up to 5 Mohs.

Your material's Mohs hardness number determines whether the material is classified as soft, medium hard, or hard, as shown in Table III. A material with a lower Mohs number — in the soft category — usually produces less wear on the size reduction machine, while a material with a higher number typically increases machine wear. This information not only will help you determine which machines are suited to reducing the material, but can also help you determine how often you'll need to adjust the machine settings — such as the grinding gap — as the material wears the equipment components over time.

Size reduction mechanisms and the material characteristics they handle. Size reduction machines operate by various mechanisms, including compression, impact, cutting, or shearing (or combinations of these). *Compression* applies mechanical energy to compress particles against a surface and fracture them into smaller particles. *Impact* applies high-energy impacts to fracture the particles. *Cutting* uses knives or other cutting tools to cut the material into smaller pieces. *Shearing* (also called *friction*) grinds material by applying two forces that are equal in magnitude and opposite in direction and that act along two parallel lines. Which mechanism (or mechanisms) is appropriate for your material depends on several characteristics, not just the material's Mohs hardness number.

For certain material characteristics, some reduction mechanisms are more effective than others and some won't work at all, as shown in Table IV. The following information explains which size reduction mechanisms can reduce materials with various characteristics.

Table II

Mohs hardness scale

Hardness	Material examples	Remarks
1	Talcum	
2	Gypsum	Can be scratched with a fingernail
3	Limestone	Can be scratched with a knife
4	Fluorite	
5	Asbestos	
6	Feldspar	
7	Quartz	
8	Basalt	Scratches window glass
9	Corundum	Produces sparks when hit with steel
10	Diamond	

Table III

Hardness level in relation to Mohs scale

Hardness level	Mohs scale 1	2	3	4	5	6	7	8	9	10
Soft	x	x	x	x						
Medium hard			x	x	x	x				
Hard					x	x	x	x	x	x

Table IV

Size reduction mechanisms for various material characteristics

Material characteristic	Size reduction mechanism: Compression	Impact	Cutting	Shearing
Hard	■	□	□	□
Medium hard	■	■	□	□
Brittle	■	■	□	□
Tough	□	■	■	■
Soft	▣	▣	■	■
Fibrous	□	□	■	■
Elastic	□	▣	■	▣
Heat-sensitive[1]	□	□	■	▣

Key

■ Will probably work successfully
▣ Will work under certain conditions
□ Won't work

[1] *Note:* A heat-sensitive material may also have any of the other characteristics listed in this table, but the material's heat sensitivity is the most important factor in determining which size reduction mechanism is suitable for it.

What every size reduction machine should have:

Basic requirements for reliable, economical performance

No matter what size reduction machine you choose to handle your application, the machine must meet several basic requirements to ensure that it can perform reliably and economically over the long term.

- The machine's grinding tools, machine housing, and drive assembly should have simple, rugged designs to withstand wear from abrasive materials. For instance, for highly abrasive applications, housings and grinding tools such as knives and hammers can be constructed of heavy-duty or special alloy steels.

- The machine should have an operator-friendly design with easy access to the grinding chamber to simplify cleaning and wear parts replacement. For instance, a knife mill with a split housing that can be manually or hydraulically raised and lowered allows easy access to the rotor, knives, and screen.

- The machine should operate reliably to provide efficient 24/7 production and stable operation despite feedrate fluctuations — especially overloading — while providing consistent processing and product quality. For instance, to prevent an overload from increasing the temperature in the machine and potentially damaging your material, the machine should have a safety mechanism that detects an overload and then gradually decreases the feedrate or even brings the machine to a halt.

- The machine should easily handle your material and be easy to monitor so that it doesn't require continuous supervision. For instance, if your material is sticky or has other characteristics that prevent it from flowing freely, the machine may require a liner, a specially designed inlet and discharge, and other features to ensure that the material flows freely inside the machine and from the discharge after grinding. Choosing a size reduction machine equipped with a control system that monitors the machine temperature, amp load on the motor, and the material feedrate will reduce the amount of operator supervision the machine requires. Locating the control system's control panel in your process control room or another central location will also make the machine easy to monitor.

- The machine should have adjustable machine settings or interchangeable grinding tools, or both, so you can adapt the machine to handle various size reduction requirements.

- The machine should consume low specific energy (energy per unit mass, such as Joules per kilogram) to ensure that it can operate economically over the long term.

- The machine's grinding chamber should be designed to prevent material buildup. For instance, if your material is moist or greasy, it can build up inside the grinding chamber and on the grinding tools unless these components are designed with smooth finishes that promote material release.

- The machine's design should comply with the appropriate FDA, good manufacturing practices, and clean-in-place requirements for your application.

- To provide maximum flexibility for handling your future size reduction needs, the machine should be easy to adapt to cryogenic applications and applications that produce combustible dusts. ***—H. Pallmann***

- *Brittle material* is easily reduced by compression and impact. When these forces are applied, the material falls apart without any visible deformation on the material surface. The reduced material usually has a very wide particle size distribution.

- *Tough material* can be reduced by impact, cutting, and shearing. It behaves like a brittle material during high-speed size reduction, but yields a relatively narrow particle size distribution. When deformed slowly, the material tends to break into a few half-moon-shaped pieces.

- *Rubberlike, elastic material* can be reduced by cutting and, under certain conditions, by impact and shearing. The material has very high ductile and tensile strengths, so reducing it typically requires high-energy input. After reduction, it has a very narrow particle size distribution.

- *Fibrous material* can be reduced by cutting and shearing. How much it can be reduced depends on the material's moisture content and the direction of stress and impact during size reduction. The reduced material typically yields fiber bundles, but can sometimes produce single fibers.

- *Soft material* (with Mohs hardness from 1 to 4) can be reduced by cutting and shearing and, under certain conditions, by compression and impact. Such a material typically behaves like a tough liquid during size reduction, which disperses material agglomerates, opens the material's inner cell structures, and homogenizes the material.

- *Heterogeneous material* contains multiple components with different hardnesses and other characteristics, and all the components behave differently during size reduction. The mechanism (or combination of mechanisms) best suited to reducing this material depends on the components' characteristics and the desired final results. Size reduction can separate each component from the others, as well as reduce the particles in each component.

Size reduction mechanisms and the machines that provide them. The size reduction mechanisms provided by several common size reduction machines are listed in Table V. For each machine, the table also lists the rotor's peripheral (rotational) speed range and typical applications.

Selecting a size reduction machine

Several common machines for reducing solid materials to coarse to fine particle sizes are illustrated in Figure 1. Like all size reduction machines, these machines share several features, with many variations from unit to unit, including:

- *Rotor:* The machine can have one rotor or two; with two, the rotors can be parallel or coaxial.
- *Rotor axle direction:* The rotor axles can be horizontal, vertical, or angled inside the machine.

Table V

Size reduction mechanisms and machines that provide them

Size reduction mechanism	Size reduction machine	Peripheral rotor speed	Typical applications[1]
Cutting	Knife mill granulator	15 to 70 fps (5 to 20 m/s)	Cutting and disintegrating tea leaves; cheese; asparagus; leaf-, bark-, and root-based drugs; succus blocks; resin blocks; rubber bales
Impacting	Pin mill, stud mill	30 to 650 fps (10 to 200 m/s)	Grinding and pulverizing starch, sugar, caffeine, legumes, yeast, potato flakes, milk powder, spices, saccarose, urea, pigments, hard waxes
	Hammermill	130 to 170 fps (40 to 50 m/s)	Pulverizing and fiberizing or crushing and disintegrating paper, wood shavings, cellulose, root-based drugs, tough and fibrous materials, shellac, chalk, dry adhesives, salt, china clay
	Double-stream mill	230 to 400 fps (70 to 120 m/s)	Pulverizing and micronizing gelatin, legumes, cocoa chips, wood shavings, cellulose, lead oxide red, anhydride, ammonium nitrate, sodium metaphosphate
	Impact mill with pendulum hammers	230 to 300 fps (70 to 90 m/s)	Crushing and grinding salt, spices, gypsum, glass, resins
	Screen-basket mill with hammer rotor	250 to 330 fps (80 to 100 m/s)	Grinding and pulverizing tobacco, herbs, tough and fibrous plant parts
Impacting, shearing, cutting	Turbo mill	250 to 400 fps (80 to 120 m/s)	Grinding and pulverizing or fiberizing and disintegrating oil seeds, fat, nuts, milk powder, flax meal, corn, cacao beans, salt, paper, organic and inorganic pigments
	Counter-rotating mill	230 to 400 fps (70 to 120 m/s)	Grinding and pulverizing fish meal, bone meal, cellulose ether, cellulose derivatives
Impacting, shearing	Screen basket mill	170 to 230 fps (50 to 70 m/s)	Grinding and disintegrating glucose, salt, asbestos, talcum phosphate, alkali salt, mirabilite
	Beater mill	230 to 300 fps (70 to 90 m/s)	Crushing and grinding or disintegrating agglomerates, activated carbon, carbon black, synthetic resins
Shearing	Tooth disc mill	15 to 70 fps (5 to 20 m/s)	Disintegrating and fiberizing, including degerming corn, continuously mixing dry powders, moistening dry powders, fiberizing leather waste
Compression, shearing	Double-shaft breaker	3 to 26 fps (1 to 8 m/s)	Breaking hard, brittle materials, such as sea salt, to coarse particle sizes

[1] *Note:* The size reduction methods described here are derived from the mechanisms compression, impact, cutting, and shearing.

• *Material inlet:* The material inlet can direct the feed into the machine center or periphery.

• *Material flow:* Inside the machine, the material can flow in a radial direction (outward from the machine's center), axial direction (along the machine's axis), or peripheral direction (around the machine's perimeter).

• *Grinding tools:* These can be items such as hammers (fixed or movable), pins, plates, knives, cams, or grinding segments.

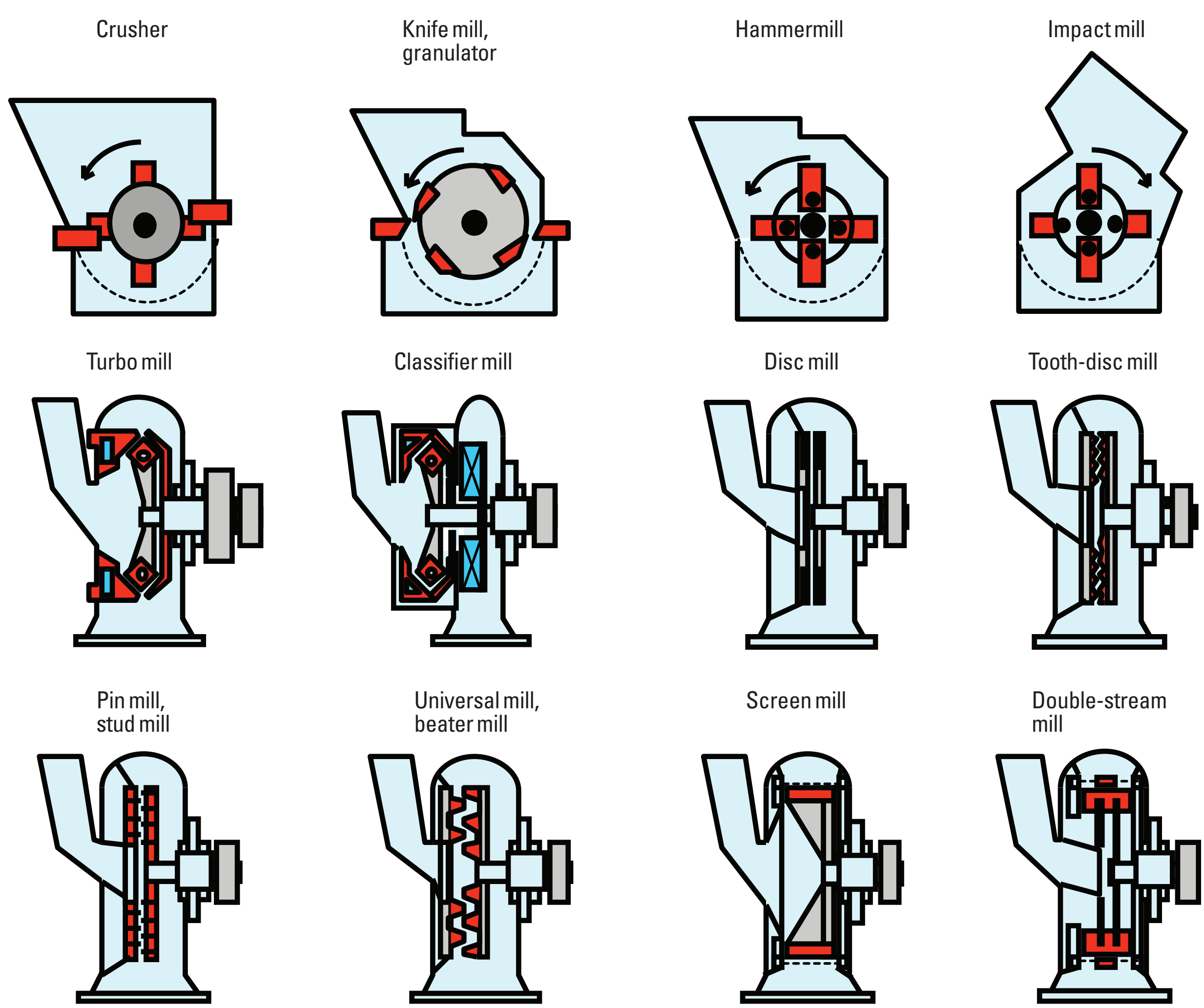
• *Fineness control components:* The machine can have internal or external components for controlling the final particle fineness, including an adjustable grinding gap between the rotor and stator or a grate, screen, or classifier.

To determine which size reduction machine has the right combination of features for your application, you must consider your material characteristics and desired grinding results along with factors such as the material's concentration in the grinding chamber, the temperature and humidity of the process air (or other gas), the rotor's peripheral speed, and the influence of the material's residence time in the machine. During this process, work closely with the equipment supplier, who can provide detailed information about each of these factors.

For most applications, more than one size reduction machine is capable of doing the job, but each machine has its own advantages and disadvantages when compared with the other suitable units. For this reason, you should have the supplier run tests of your material in the machines you're considering, using different settings (such as the grinding tool size and shape and the grinding gap). The tests will not only help you determine which machines can achieve your desired final particle size distribution and material characteristics, but which unit can provide the most economical size reduction for your material. For more details on selecting the right machine for the long term, see the related sidebar, "What every size reduction

Figure 1

Schematics for common size reduction machines that provide coarse to fine grinding



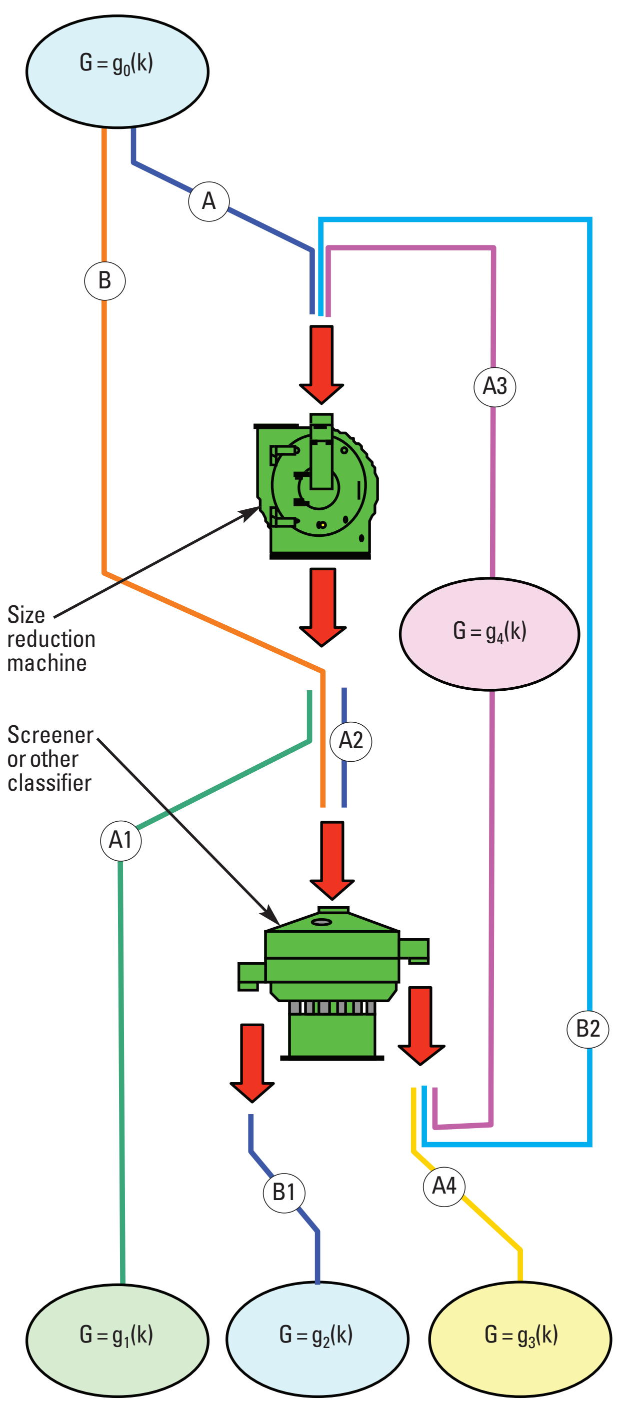
machine should have: Basic requirements for reliable, economical performance."

Designing a size reduction system

Once you select a size reduction machine, you must design an effective grinding system to integrate the machine into your process. The typical system includes a grinding step and, often, a classifying step. Figure 2 shows how material flow through the grinding system can vary for different size reduction applications.

Figure 2

Material flow through grinding systems for various applications



One-pass grinding, grinding with classifying. For many grinding applications, the feed material, which is usually not homogeneous but has a particle size distribution $G = g_0(k)$ (where G is the particle size distribution, g is particle size as a function of k, and k is relative units of measure), is metered directly into the size reduction machine (A).

One-pass grinding: In many applications, the ground material discharged from the size reduction machine is correctly sized for further processing (A1). Such a one-pass system yields a ground material with a wider particle size distribution, $G = g_1(k)$, than grinding systems that incorporate a classifying step.

Grinding with classifying: In other applications, the ground material discharged from the size reduction machine includes some coarse particles that don't meet the grinding requirement. In this case, the ground material is passed to a classifying step (A2), which may be a classifier mill inside the size reduction machine, or another machine, such as a screener, downstream from the grinder. The on-size material discharging from this equipment has a narrower size distribution, $G = g_2(k)$, than the discharge from a one-pass system. The coarse material, with a size distribution of $G = g_4(k)$, can be reintroduced to the size reduction machine for additional size reduction (A3). Or sometimes the coarse material, with a size distribution of $G = g_3(k)$, is passed to the next process step (A4).

Classifying with grinding. In applications where the feed material already contains a large amount of on-size particles, the feed material is metered first to a screener (B). The screener discharges the on-size particles to the next process step (B1) and passes the coarse particles to the size reduction machine for grinding (B2). This type of grinding system allows the use of a smaller grinder. **PBE**

For further reading

Find more information on selecting size reduction equipment, as well as on how various machines operate, in articles listed under "Size reduction" in *Powder and Bulk Engineering*'s comprehensive article index at www.powderbulk.com and in the December 2007 issue.

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