MILLING METHODS COMPARISON GUIDE

An Introduction to the Finer Points of Particle Size Reduction

Milling and grinding: the terms are virtually interchangeable and refer to the application of physical forces to reduce particle size. Not that complicated, right?

In fact, milling methods — hammer milling, jet milling, wet milling, and more — are unique in their actions, and raw materials' characteristics vary so greatly that it takes scientific know-how, technical mastery, and significant hands-on experience to determine and apply the best processing technology for any given application.

Desired particle size can range from nanometers to millimeters, but that's not the only criterion for selecting the right milling method. Other factors can include:

- Desired final product form (dry or fluid slurry)
- Quantity
- Material characteristics (e.g., hardness, friability, elasticity, stickiness, melt point, combustibility)
- Packaging
- And many more

A trusted toll processor can guide you through determining the best process to achieve your desired particle size.

THE FUNDAMENTALS: MECHANICAL MILLING, MEDIA MILLING, AND JET MILLING

Mechanical milling uses moving parts to apply various forces to materials, fracturing the structure of particles into smaller sizes. Mechanical mills often are limited in how far they can reduce particle size, and the friction generated in mechanical processes causes heat. This can influence whether a material is a good fit for mechanical milling.

Media milling employs a medium rather than internal moving machine parts to use impact, abrasion, and attrition to reduce particle size. Media milling can be wet or dry.

Jet milling uses high-speed particle collisions in a grinding chamber, rather than moving parts, to achieve a desired particle size.

MILLING OR GRINDING? WHAT'S THE DIFFERENCE?

There really isn't one.

Grinding can describe some non-milling activities like cutting brick or tile, as in construction, and often is used to describe the application of shear force. Milling refers to using a milling machine — and the action of the machine is milling or grinding, more or less interchangeably.

MECHANICAL MILLING

Crushing/Pulverizing (and Pre-crushing)

Coarse crushing may be required as a pre-milling initial step to reduce a material to a quarter-inch, the largest acceptable mill feed size for most processes. Materials are reduced by fracturing under stress, using compression, shear, or impact forces.

Coarse crushing processes can include jaw crushing, roll crushing, and impact crushing. Crushing exerts less control over particle size range.

Jaw crushers, often used for coarse material like rocks or ceramics, have two metal plates, one stationary and one reciprocating, for fracturing large pieces using compression force.

Roll crushers combine impact, shear, and compression forces to fracture mill feed by rolling over it, or by moving it between pairs of rotating rollers.

Impact crushers either strike material with a blow bar or project material against an anvil. Either process causes the material to break on impact.

Hammer Milling

Hammer mills, technically a subset of impact crushers, employ tiny hammers (also called beaters, which may be blunt or sharp) mounted on a rotating shaft inside a drum to repeatedly impact material — using impact, shear, and centrifugal forces — to reduce material, usually to intermediate particle sizes. Hammer mills are best for brittle, friable, nonabrasive materials.

Universal Milling

Universal mills are, as their name implies, versatile. Depending on the application and the product, these mills can be equipped with up to four rotating and stationary milling elements to dry grind mill feed to particle sizes ranging from 50 microns to 2 millimeters.

MEDIA MILLING

Media milling refers to a process in which grinding media — such as balls or beads made of steel, glass, ceramic, or plastic — and the material to be milled are rotated together in a drum. The rotation creates a cascading motion, which applies shearing forces (tearing), impact (crushing), and attrition (particles tear and crush each other), breaking the material into very fine particles. Media milling can be wet or dry, and is best for mixing, fine grinding, and achieving homogenization and dispersion.

Wet Media Milling

In **wet media milling**, the mill feed material is first dispersed in a carrier fluid to create a liquid slurry before going into the drum with the grinding media, where it is recirculated until the desired particle size is achieved. Wet milling enables fine particle size results, uniform size distribution, and certain desirable morphological (shape) characteristics in the outcome — which can affect material performance in end products. Wet media milling can create particle distributions in the nanometer or sub-micron ranges, and the liquid slurry can either be used in that form, or the milled solid can be dried and separated for use.

CRYO-MILLING

Cryogenic mills use liquid nitrogen to lower the temperature of the mill feed. Because the energy involved in milling often generates heat, cryogenic milling is useful for polymers, waxes, and materials that are sticky, elastic, or have low melt points. Cryo-milling also prevents overheating of the mill itself, which can be a risk with very hard materials. Cryo-milling can apply to mechanical milling, media milling, and jet milling.

JET MILLING

Jet milling is an indispensable method for particle reduction in toll processing. Jet mills use no moving parts to apply force, generate no heat, and process material in a single pass.

Jet mills use high-pressure (approximately 50-120 psig), turbulent condensed air (or other gases) to force high-velocity collisions between mill feed particles in a one-step milling process, inside a chamber. The mill's power can be adjusted to achieve the desired particle size, but jet milling is most often used to achieve particle sizes ranging from one to 10 microns. Factors that affect the product's fineness include:

- Initial particle size
- Feed and air flow rates
- Nozzle pressure and angle
- Chamber diameter and width
- Product outlet diameter

In some applications, superheated steam (100-220 psig and 392-980°F) is used; in others, the compressed gas may be nitrogen, argon, helium, or others as required for safe and optimal processing. Gases are selected for their added effects on the process: nitrogen and argon prevent oxidation in the milling process, and helium can enable higher impacts than compressed air.

Fluid Bed Jet Mills

Fluid bed jet mills (FBJMs) have built-in air classifiers that can be tightly adjusted to the desired particle morphology and size. Impact velocities in a fluid bed jet mill can range from 300-500 meters per second, compared to 50-150 meters per second in a mechanical impact mill. A fluid bed jet mill's high-energy micronization lower chamber can be combined with an integral forced vortex air classifier, allowing for greater control of the maximum particle size.

Jet mills without fluid beds have classification action built into the grinding chamber of the mill.

Spiral Jet Mills

Spiral jet mills consist of a flat cylindrical grinding chamber with nozzles arranged around the peripheral walls. A pneumatic feed injector accelerates feed into the grinding chamber where the material is subjected to two forces: centrifugal force created by the nozzles and drag force by the spiraling airflow.

Several factors affect the product's fineness: feed particle size, feed and air flow rates, nozzle pressure and angle, chamber diameter and width, and product outlet diameter.

MICRONIZING

Micronization refers to the reduction of particle size into micrometer or nanometer ranges — anything under 10 microns. These very small particles are often required for catalysts, pigments, biopolymers, and other materials that serve as active chemical ingredients, foodstuff ingredients, and pharmaceuticals.

Particle size differences can alter properties like particle shape, surface area, and porosity. That can affect the end product in many ways — product performance, efficacy, processability, stability, and appearance — so particle size is critical. Micronization can ensure uniform content/flow and mixing capabilities.

Supercritical fluids are sometimes incorporated into the milling process for micronization. These are substances (often carbon dioxide) heated above their critical temperatures to achieve a state between liquid and gas. Supercritical fluids enable more efficient processing and better control of particle shape and range of size.

NANO-MILLING

"Nanometer level" refers to particles smaller than 1 micron (1 micron = 1,000 nanometers). The average nano size is 200-500 nanometers. These particle size ranges are often achieved using media milling or jet milling.

The combinations of available process technologies offer virtually unlimited possibilities for achieving almost any particle size and characteristic. Our capabilities, processes, scientific problem-solving, and technical mastery deliver market-changing solutions to our customers.

As "Architects of What's Possible," we welcome your most challenging particle reduction and processing projects.

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