Dry grinding: Reducing costs and increasing product quality with an agitated media mill

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Agitated media mills have long been used for wet-grinding bulk materials to very fine sizes. Today, dry-grinding applications for agitated media mills are growing. After explaining how the mill operates, this article details the mill's dry-grinding applications, benefits, and limitations; typical process layouts; and tips for selecting equipment for your application.

Until recently, dry grinding in an agitated media mill (also called an *agitated* or *stirred ball mill*) has been far less common than wet grinding. In fact, not every agitated media mill can be used for dry grinding. Yet many bulk materials are needed in dry form, and removing liquid from wet-ground materials by drying them is costly. An agitated media mill also can dry-grind materials in less time and use less energy than a drum mill or ball mill, the conventional choices for dry-grinding bulk materials to medium fineness.

These reasons make it worthwhile to take a closer look at dry-grinding applications for the agitated media mill. Let's start by examining how the mill works. [***Editor's note:*** For more information on wet grinding, see the later section "For further reading."]

How an agitated media mill works

An agitated media mill, as shown in Figure 1, has a narrow cylindrical grinding chamber with a length-to-diameter ratio greater than 3. The chamber can be horizontal or vertical and, depending on the manufacturer, typically is available in lab-size units of a few gallons in capacity and production-size units up to several hundred gallons.[1] Up to 90 percent of the chamber's capacity is consumed by grinding balls, also called *grinding media.* An agitator inside the chamber rotates at up to 20 m/s, moving the grinding media in the chamber. The agitator can be fitted with elements of various shapes to suit the grinding application; common agitator elements are grinding disks (Figure 1) and pins mounted in various positions on the agitator. The chamber wall (also called the *grinding pan*) is typically stationary and can be lined with steel, ceramic, or polyurethane to resist wear and prevent material contamination. Components in the mill vary by manufacturer; some variations include a rotating grinding pan and flow deflector at the raw material inlet (Figure 1).

In operation, bulk material to be ground is loaded into the raw material inlet at the mill's front. For dry grinding, the dry raw material is metered into the mill by a dry feeding device, such as a screw feeder. (For wet grinding, the material is suspended in liquid and fed into the mill by a pump.) As the agitator rotates, the agitated media grind the material and cause it to pass through the entire chamber and out the opposite side via a vacuum extraction port. A separating screen or similar device at or downstream from the outlet prevents the media from discharging along with the ground material. The unit can operate in batch or continuous mode.

More about the grinding media. The mill's operating principle allows the use of very small media, typically ranging from ⅛ to ½ inch in diameter. The small media produce large numbers of high-energy impacts on the particle surfaces, efficiently reducing the particle size. The grinding media can be steel or ceramic. The media material and size are selected to suit the application.

Adjusting the grinding energy density. Adjusting the agitator's rotation speed varies the *energy density* inside the grinding chamber, enabling you to adapt the mill to extremely different jobs. The energy density is the drive power (in kilowatt hours) per unit volume (in gallons or liters) of the grinding chamber. By varying the agitator speed, you can ensure that the amount of energy input to the grinding chamber is no more than that required for grinding, which reduces energy costs and wear on the mill components.

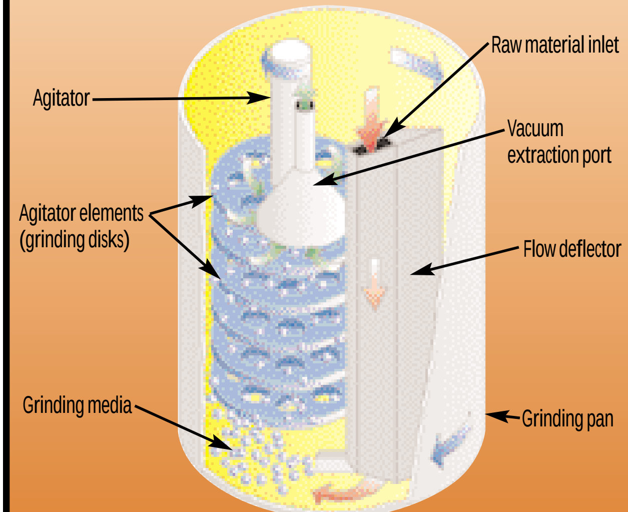
Dry-grinding applications, benefits, and limitations

In dry-grinding applications, the agitated media mill can reduce relatively coarse particles (up to about 200 microns) to a fineness ranging from about 5 to about 60 microns. Typical materials handled include limestone, ores, frits, pigments, plaster, and hard minerals such as heavy spar, feldspar, and quartz. The mill isn't suitable for sanitary applications.

A major advantage of dry grinding in an agitated media mill is that the material remains dry as it's ground in the mill, requiring no moisture removal after grinding and thus eliminating a need for costly drying equipment and its high energy requirements. Another advantage is the mill's ability to efficiently separate the coarse and fine particles during operation so that only the coarse particles are ground, which conserves grinding energy and increases the throughput rate. While some separation is possible in wet grinding, the mill must wet-grind the total charge for as long as it takes to reduce the last coarse particle.

Figure 1

Agitated media mill



On the other hand, dry grinding in the agitated media mill can't produce particle sizes as fine as those achieved by wet grinding. Achieving a particle size distribution finer than 98 percent smaller than 5 microns is very difficult in dry grinding because such fine particles are very likely to reagglomerate. Grinding agents known as *surface-active substances* can be added to the raw material to limit reagglomeration of particles larger than 5 microns during grinding. The type and quantity of such agents needed for dry grinding depend on the material (or mixture of materials) to be ground. Typically, for particles smaller than about 60 microns, such agents can help reduce reagglomeration; for particles smaller than 20 microns, the agents are indispensable.

Another limitation for dry grinding in the agitated media mill is the difficulty of cooling the mill during operation. This limits the energy density in the mill and the mill's throughput rate. Although a thermal jacket that circulates water or another cooling medium can be installed on the mill's grinding chamber to help cool the mill during dry grinding, no water is present inside the grinding chamber itself, as in wet grinding.

Dry grinding in the agitated media mill also requires more peripheral equipment, and thus greater investment and floor space, than wet grinding in the mill. While wet grinding requires only a feed pump and the mill itself (although downstream processing must include drying), dry grinding requires a feeder, the mill, an air classifier (or, less often, a mechanical screener) to separate the desired-size particles, and an air-material separator to separate the final product from the process airstream and discharge it to a container. Using the mill to achieve finer final products by recycling intermediate material back to it for further grinding can require additional equipment for intermediate storage.

For dry grinding, the mill also requires discharge equipment for changing out or cleaning the grinding media. This equipment, which can simply and quickly separate the ground material and retain the media in the mill or return it to the mill, falls into two basic types, depending on the mill manufacturer: In one, the ground particles are discharged through an outlet with a very large cross section (for fast discharge) while the grinding media's weight keeps the media in the mill, and in the other type, the grinding media are continuously discharged along with the ground particles, separated from the particles by an external screen, and returned to the mill along with fresh raw material.

Comparing the agitated media mill with two other mills commonly used for medium-fineness dry grinding — the drum mill and ball mill — reveals additional advantages.

The agitated media mill typically has a much smaller footprint than the other mills, conserving plant floor space. The agitated media mill can also grind materials to medium fineness in less time than a drum mill or ball mill, greatly reducing the required grinding energy and increasing the throughput rate.

Typical dry-grinding layouts

Several process layouts are possible for dry grinding with an agitated media mill. Typical options are closed-circuit (or *circulation*) grinding, without or with preclassifying, and open-circuit (or *continuous*) grinding, without or with postclassifying.

Closed-circuit grinding without preclassifying. An agitated media mill in a closed-circuit process can circulate the ground material to an air classifier (or, for a larger final product, to a mechanical screener) without preclassifying the raw material, as shown in Figure 2. In addition to the mill and air classifier, the equipment includes a supply hopper, feeder, and air-material separator (or *filter receiver*), all connected by pipes or chutes. The vacuum created by the air-material separator's blower draws material through the process. The feeder (typically a screw feeder) continuously meters raw material from the supply hopper to the mill. After the grinding cycle ends, the material is discharged from the mill outlet and drawn through a pipe directly connecting the mill outlet to the air classifier's inlet. The classifier separates the desired-size particles from the coarse particles and recycles the coarse to the mill. The interconnecting air atmospheres of the mill and classifier allow the classifier air to be used both to cool the mill and to convey material from the mill's outlet to the classifier. The material exiting the classifier is drawn to the air-material separator, which separates the desired-size particles from the airstream and discharges the particles to a container such as a bulk bag or drum.

In this layout, the air classifier is just as important as the mill in achieving the desired final particle size, because the classification quality determines the size of the *circulating load* (that is, the material quantity returned to the mill for further grinding) and, hence, the grinding cycle's effectiveness. Any parameter change in the mill, such as an increase in agitator rotation speed or cycle time, can have a great impact on the classifier's operation, and vice versa. For this reason, operating the mill and classifier always involves some compromise, because it's possible to optimize only one or the other's operation. But this drawback is counterbalanced by the process layout's advantages: Not only is the layout relatively cost effective, but the ground material exiting the mill is already evenly dispersed in the air flowing to the air classifier, allowing the classifier to more easily separate the particles by size.

Closed-circuit grinding without preclassifying can be used in several applications, particularly those where a relatively wide particle size distribution is acceptable. This process is less well-suited to applications with difficult-to-handle materials when the mill or classifier's operation changes greatly with even slight parameter changes.

Closed-circuit grinding with preclassifying. The closed-circuit grinding with preclassifying process layout differs from the previous layout only in how the raw material is fed to the agitated media mill. In this process, as shown in Figure 3, the material is first fed to the air classifier. The classifier separates the raw material, sending only coarse particles to the mill. As in the previous layout, the mill and classifier are directly coupled. This process is especially suitable for a raw material containing a high proportion of fines.

In another variation of this process layout, you can use preclassifying to dry a slightly moist raw material. Moist material can cake inside the agitated media mill, increasing mill

Figure 2

Closed-circuit grinding without preclassifying

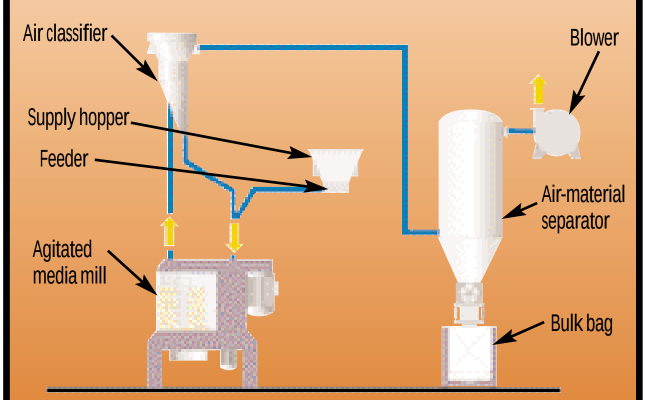
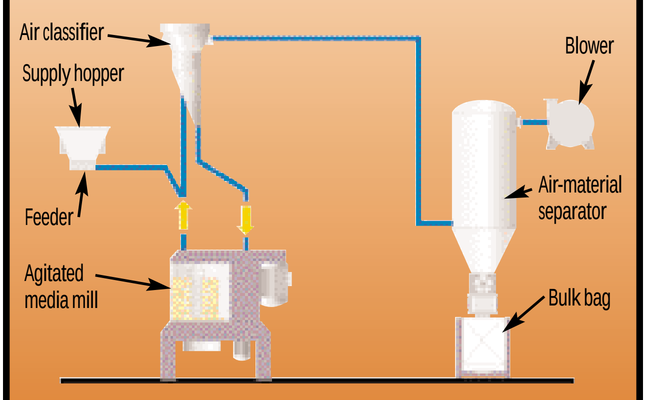


Figure 3

Closed-circuit grinding with preclassifying



wear and drastically reducing grinding performance. To prevent this, you can feed the damp raw material to the air classifier and briefly keep it in the classifier while air from the mill, heated by the grinding process, circulates through the classifier and removes residual moisture from the material. Simultaneously, the damp raw material mixes with dry ground material drawn out of the mill, which has been exposed to a far higher temperature. When this material mixture enters the mill, it contains far less moisture than the raw material alone. (Be aware, however, that an agitated media mill can't be used as a grinder-dryer.)

The preclassifying process layout increases the mill's throughput rate because the mill isn't loaded with as many fines. However, because preclassifying increases the classifier's throughput rate and requires the classifier to handle coarser material, expect to select a larger classifier with wear-resistant components for this application.

Preclassifying can also be useful for a closed-circuit process with more than one mill that produces multiple final products with widely varying degrees of fineness. For example, you can install an air classifier downstream from a drum mill and upstream from an agitated media mill, as shown in Figure 4. The relatively coarse material discharged from the drum mill passes through the classifier, which separates material that meets final product requirements and sends coarse particles to the agitated media mill for further grinding, thus producing final products with a wide fineness range. However, the large amount of floor space required by such a layout can make it impractical for many applications.

Open-circuit grinding without postclassifying. If your application doesn't require close control of the final product's maximum particle size, you may be able to use an agitated media mill without a downstream air classifier. In this case, the only way to control the final particle size is by setting the mill's grinding parameters.

Open-circuit grinding with postclassifying. An agitated media mill that provides open-circuit, continuous grinding with postclassifying is used when the mill and classifier must be operated separately, without interconnecting their air atmospheres, to optimize each unit's performance and produce final products that meet strict quality-control requirements. This layout is also the most expensive, because separating the milling and classifying operations requires a far greater equipment outlay than the other process layouts. Despite its high cost, this process layout is best for high-quality products that require a tight final size distribution.

In this process layout, as shown in Figure 5, a feeder meters raw material from a supply hopper to a continuously operating agitated media mill, which delivers an intermediate product (with a sufficiently high fines fraction to meet the intermediate product's size requirements) to an air-material separator. The separator removes the material from the airstream and discharges the intermediate particles to a second (intermediate) hopper. A feeder at this hopper's outlet meters the intermediate particles to an air classifier. The classifier separates the material, discharging the intermediate particles to intermediate storage and delivering the coarse particles to another air-material separator. In this layout, the agitated media mill and air classifier function as two distinct machines with completely separate air atmospheres, allowing you to fully optimize each machine's operating parameters.

In some cases, it can make sense to operate the air classifier in this layout in two stages so it recycles the coarse to the mill; this allows you to obtain as large a desired-size fraction as possible and avoid overloading the mill with

Figure 4

Closed-circuit grinding with preclassifying and more than one mill

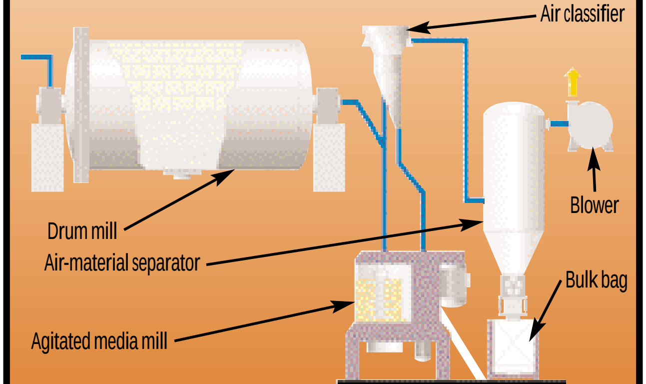
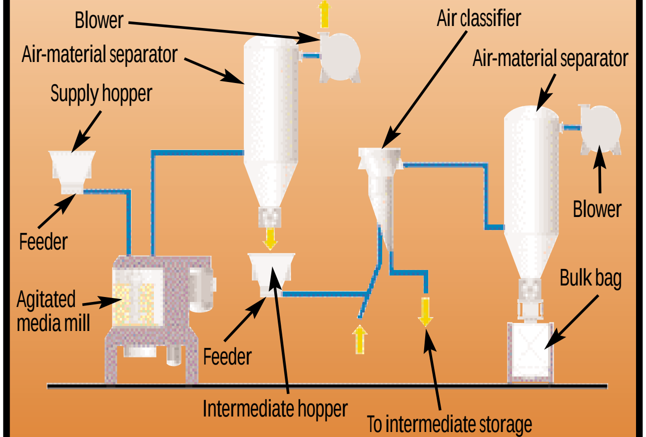


Figure 5

Open-circuit grinding with postclassifying



fines. When operating the classifier in two stages, adding the coarse particles discharged from the classifier at a steady rate to the raw material entering the mill will help ensure that the material feed is consistent.

Tips for selecting equipment to meet your product requirements

For best results, consult the mill manufacturer's test center for help choosing an agitated media mill and related equipment for dry grinding. The test center can test your raw material in pilot-size mills to determine which mill size, motor horsepower, agitator and agitator-element type, agitator rotation speed, grinding media material and size, and related components and peripheral equipment can help you achieve your desired particle size distribution. The tests will also help you determine how much energy your application requires and the throughput rate you can expect to achieve.

The following information provides general advice for choosing the agitated media mill and air classifier, the method for interfacing the classifier with your mill, and other equipment and equipment features depending on your final product's required particle size distribution and other factors.

Achieving medium-fine particles. In general, to achieve medium-fine particles of 60 microns or smaller — the larger end of the agitated media mill's range — the relatively larger the mill grinding chamber and grinding media you'll require. For particles in this size range, you can directly couple the agitated media mill to a simple mechanical screener rather than an air classifier, reducing your investment and operating costs. Such a screener can effectively separate most medium-fine materials, and the milling and classifying processes aren't so sensitive in this size range that they have to be separate operations. Reducing processing costs in this way will also help control your final product's price.

Achieving fine particles. You'll need to select a relatively smaller mill with smaller grinding media to grind particles to 10 microns or smaller. For particles in this size range, you can separate the agitated media mill and air classifier to allow each unit's operation to be independently controlled for best particle size control. Optimizing each unit's operation in this way can improve your grinding efficiency by a few percent that can add up to considerable cost savings, justifying the greater equipment investment you'll need to make in intermediate storage and feeding equipment. Because operating the mill and air classifier separately requires removing the intermediate product from the airflow and storing it for a time, the particles can reagglomerate, thereby eliminating any advantage in using a separate air classifier. To help prevent reagglomeration, it's best to select an intermediate storage vessel that can accommodate only a small amount of material to guarantee fast throughput and short storage time.

You may also need to separate the mill and air classifier when no classifier that can produce fine particles is large enough to accommodate all material discharged from your mill. In this case, you'll need to install several air classifiers in a parallel arrangement so that each receives only a portion of the mill discharge. Since directly coupling multiple classifiers to your mill isn't practical, you'll need to separate the mill and classifiers, increasing your equipment investment.

Making frequent material changes and producing various particle size distributions. If your application requires frequent material changes and achieving final products with various particle size ranges, your mill and air classifier must be flexible and easy to clean. For this kind of application, check that the mill you select provides for simple grinding-media changeouts and that both the mill and classifier have easy-to-clean interiors. A typical application requiring such equipment is a contract grinding plant, where the agitated media mill is typically operated with a small material load and each load must meet widely different purity and size requirements. In this case, directly coupling the mill and air classifier is best, because fully optimizing the mill and classifier's separate operation wouldn't be cost-effective in the contract plant, and customers' demand for high-purity final products requires using as few equipment components as possible to prevent contamination by equipment wear particles. However, the air classifier and air-material separator's blower have to be designed for the finest material the mill will handle, which makes this arrangement very expensive for coarser materials. For this reason, you need to think carefully about the range of materials your mill and air classifier will handle before selecting the units and determining how to interface them. **PBE**

Reference

1. Some manufacturers list agitated media mill capacity in liters; to convert from liters to gallons, multiply the number of liters by 0.26.

For further reading

Find more information on agitated media mills and other equipment for dry and wet grinding, as well as air classifiers and mechanical screeners, in articles listed under "Size reduction" and "Screening and classifying" in *Powder and Bulk Engineering*'s comprehensive "Index to articles" (in the December 2002 issue and at www.powderbulk.com). More information on wet grinding in an agitated media mill is available from the author.

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