MODERN

Wet Milling and Material Processing

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The world of material processing and size reduction demands faster and more efficient methods to yield increasingly smaller sizes and narrower particle size distributions. Processes in a variety of industries now routinely demand particle sizes with an absolute maximum of well below 1 micron.

Manufacturers are challenged to integrate a repeatable method of production that is capable of this level of size reduction while controlling labor and energy costs. The system must also be robust enough to handle the most abrasive of raw materials.

Traditional Milling

The ceramic industry is no different from others in its search for modern manufacturing techniques. The traditional ball mill has been the primary method used to mill ceramic materials for hundreds of years, and is still considered to be one of the best mixers ever invented.

Ball mills are generally batch units, which means that all ingredients are charged into the chamber and the mill is run unattended for a specified amount of time (or number of revolutions). The design of a typical ball mill only allows for about a 65% (of total capacity) fill of product, which allows room for the grinding media to rise and fall for impact.

Especially with smaller units, the labor and time required to batch and discharge the machine can become problematic and inefficient. Because of this inefficiency, a typical ball mill will only be available for grinding around 75% of the time, which does not take into consideration both scheduled maintenance and emergency breakdowns.

Continuous ball mills are in use around the world, but they tend to be very large units suitable only for high-volume slurries and non-critical milling applications. Mills like this are commonly used in large ceramic tile factories to prepare slip for spray drying. Advancements in vertical ball mills have been made in recent years but also lack efficiency when compared to other methods.

Another challenge involves finer and finer particle size demands. Traditional ball mills are generally limited to a finished particle size of approximately 5 microns, which can be achieved only with great attention to media size.

Grinding media for ball mills ranges in size from 10-90 mm for most traditional applications. Typical ball mills use high-alumina or porcelain balls for their density, but wear is relatively high. Modern mono-size yttria-stabilized zirconium media is not a practical alternative due to the high cost per charge, as well as the frequent re-charge rate. Simply put, it is difficult for the traditional ball mill to put enough energy into the media charge to reduce particles to the sizes and distributions now required.

In all milling processes, the ultimate performance of the mill is highly dependent on the media size and distribution.

Above: The horizontal media mill has a closed chamber that receives the pumped pre-mixed slurry in one end and discharges the milled product from the opposite end.

Table 1. Effect of different media sizes on the number of cycles required.

Theoretical Passes	Recirculation Time (Min)	1.7-2.1 mm d50 (µ)	1.0 mm d50 (µ)	0.6 mm d50 (µ)	0.3 mm d50 (µ)
0.0	0	2.606	2.606	2.606	2.606
1.2	15	2.310	1.959	0.978	0.427
2.4	30	1.985	1.413	0.550	0.336
3.6	45	1.637	1.059	0.552	0.316
4.7	60	1.411	0.820	0.454	0.297
5.9	75	1.271	0.655	0.440	0.273
7.1	90	1.094	0.477	0.367	0.260
8.3	105	0.950	0.423	0.291	0.251
9.5	120	0.862	0.381	0.284	0.244
10.7	135	0.778	0.376	0.277	0.232
11.8	150	0.673	0.346	0.268	0.221
13.0	165	0.602	0.329	0.260	0.218
14.2	180	0.573	0.307	0.258	0.214

Table 1 shows the effect of different media sizes on the number of cycles required.

Horizontal Media Mills

The horizontal media mill has been used in the inks and coatings industries for over 30 years. Best described as a "high-energy continuous ball mill," the machine's design has undergone continuous changes since its introduction to keep up with the demands for finer particle sizes and narrower particle distributions.

The horizontal media mill has a closed chamber that receives the pumped premixed slurry in one end and discharges the milled product from the opposite end. The mill uses a mechanically sealed shaft that is cantilevered from a heavy bearing housing. This shaft can be fitted with a variety of agitators, including discs, pegs or disc/pin combinations, depending on the particular process. The chamber is typically charged with grinding media to 60-90% of the net shell volume. The high energy imparted by the agitators on the grinding beads creates frictional heat, which is removed by chilled water circulating in the cooling jacket of the chamber.

As the milling shaft rotates, the media is fluidized by the agitators positioned on the shaft. The peripheral agitator speed for this type of mill is typically 8-17 m/sec. The ceramic slurry passes through the length of the chamber under pump pressure while being milled through media-particle impact and shear, as well as particle-particle impact and shear. At the exit end of the chamber, media is retained in the mill by a screen (also called a separator or filter) that is of such size that slurry particles can pass through. It is important to note that the screen plays no role in particle size distribution.

Benefits

Determined by product type and particle size and distribution, these milling systems are unique to each application so design and setup are crucial for success. Equipment manufacturers must be able to supply the latest in wear-resistant materials as part of a successful installation. Selection of the proper construction materials is based on factors such as vehicle system, product end use and the abrasive nature of the raw materials. Materials of construction for milling wearing parts might include various types of ceramics, urethane and urethane coated, high polymer plastics, and composites.

These milling systems are versatile and can be configured for one- or multi-pass operation through outfitting with the proper tanks and pumps. In addition, duplex systems with dual milling heads on a common frame combine the best of both by passing through a second chamber on the same machine that can be charged with media of a different size than the first chamber. Duplex milling (sometimes referred to as "cascading") offers the advantage of operating two grinding chambers with one control system in a reduced footprint compared to two mills. When nano-sized particles are specified, such as those required in ceramic inks used in inkjet applications, the mills are typically setup in high-flow recirculation.

With the onset of digital technology in inkjet ceramic decoration, specially processed inks are critical to success. The higher resolutions created by today's non-contact digital printing technology offers unlimited image variation for ceramic tile production. The digital inkjet printer is quickly becoming the standard on the modern glaze line, using specially formulated and milled pigmented ceramic inks in submicron particle sizes.

System Integration

In today's competitive environment, it's not just about selecting the right wet grinding mill—integration to the overall system is important as well. Whereas a ball mill installation is fairly straightforward and uncomplicated, the successful installation of a high-energy attrition mill requires careful consideration of a number of factors:

- Premix equipment selection for slurry preparation
- Properly sized chiller system to remove BTU energy from the grinding process
- Pump systems sized for optimum flow and resistance to abrasive ceramic materials
- Feed and receiving tanks equipped with mixers for adequate suspension and batch turnover

- Process plumbing designed to minimize waste and optimize product yield
- Controls and instrumentation packages are crucial for process control and automation, as well as data acquisition and product repeatability
- If post milling filtration is required, the selection of a filter system is crucial to upstream mill efficiency
- Moving materials to and away from milling system in the most efficient manner possible

High-energy media (attrition) mills are commonly used in the manufacture of inks, coatings, agricultural, nutraceuticals and pharmaceuticals, electronics, and many other fine-particle products. Ceramic processes using media (attrition) mills include tape casting, specialty ceramic coatings and the milling of digital ceramic inks. As material processing innovations require finer and finer particle sizes, the use of these systems will grow, especially where high strength gains through the use of nano-sized materials are possible.

The special requirements of ceramic materials require the manufacturer to design systems capable of withstanding the abrasion and wear inherent in most processes. If the materials of construction and systems are designed correctly, there is a high probability that high-energy media mills will find new homes in both advanced and traditional ceramics. Industries such as ceramic tile, brick, refractory coatings, oil and gas materials, glass, whitewares, pigments, electronics, polishing compounds, ceramic inks, and crucible manufacturing may use formulas requiring near- and sub-micron particle sizes, opening new avenues to achieving enhanced material properties.

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Integration is important to the overall system.