Fluidized Bed Jet Milling for Economical Powder Processing

Fluidized bed jet mills offer reduced manufacturing costs, product purity and quality to processors of rare earths and ceramic powders

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Abrasive ceramic powders used in manufacturing components for metal cutting, metal forming, mining, drilling and the production of wear parts have replaced metal in many areas due to their thermal stability, corrosion resistance, hardness and durability. In electronic applications, their low electrical conductivity is an advantage.

Similarly, the demand for rare earth compounds, such as samarium-cobalt and neodymium iron, is increasing for the manufacture of permanent magnets. These compounds permit the production of magnets with higher magnetic energy potential than conventional ferrite magnets. In both cases these powders must be subjected to size reduction and classification to achieve a steep particle size distribution (PSD). The powder produced must be easily sinterable, free of contamination and provide strongly reactive surfaces.

Size reduction processes

Conventional size reduction usually involves the precrushing of raw materials by mechanical means and subsequent wet grinding in a ball or pebble mill. This is typically a batch process that achieves the production of relatively fine powders. This method is uneconomical as well as having other disadvantages. Process water removal is energy intensive, and the disposal of that water is becoming increasingly expensive because of the iron contamination from the milling process. The ground product also may be contaminated with iron, which results in a lower quality product.

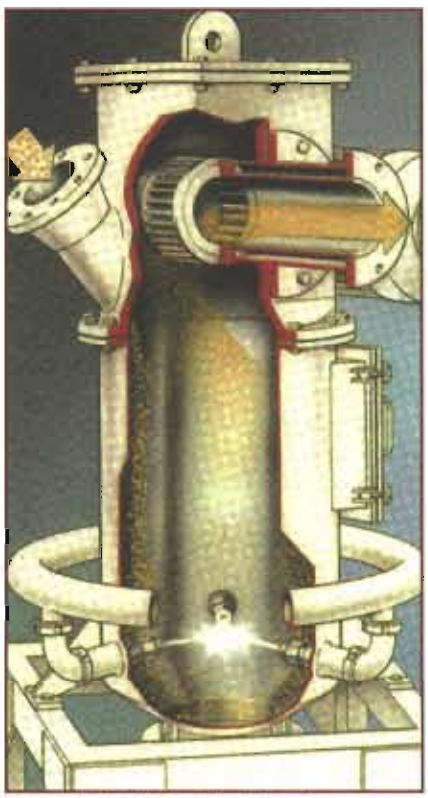


Fig. 1. AFG fluidized bed jet mill.

As an alternative, a continuous dry process utilizing through-pass ball mills in circuit with an air classifier or a conventional jet mill can be used. These methods are effective, but also have several disadvantages. Wear and product contamination are increased, the PSD is wider, and specific energy consumption is much higher. Furthermore, a secondary classification step may be necessary to separate the required fine fraction from oversized particles. When processing pyrophoric rare earths with their highly reactive surfaces, inert processing under nitrogen is a requirement.

To reduce or eliminate these disadvantages, alternative powder processing technologies for carbides, nitrides, borides and rare earths have been developed. One such technology involves the development of a fluidized bed jet mill design. This design is characterized by its continuous dry process size reduction of material without contamination by interparticle collision and a high-efficiency air classifier for precise particle size control incorporated into a single unit. The fluidized bed

jet mill can be operated in closed circuit with nitrogen blanketing, making possible the safe and efficient processing of pyrophoric materials.

Advantages of fluidized bed jet milling

Jet mills are based on the principle of impact size reduction. In mechanical grinding mills, particles are accelerated mechanically by hammers, beater bars, plates, rotors or pins. Size reduction occurs as a result of impact against a solid surface or by interparticle collision. In jet mills, the particles are accelerated in a fast gas stream and reduced by interparticle collision or impact against a solid surface. The disadvantages common to conventional jet mills are high energy consumption and high wear at the point of impact when processing abrasive materials.

Alpine eliminated these inherent problems with the AFG fluidized bed jet mill. Fig. 1 provides an illustration of the unit. In this mill material is accelerated by high-velocity gas streams focused centrally in a fluidized bed. Size reduction occurs in the fluidized bed, and the resulting fines are transported upward in the expanded air to the centrifugal air classifier installed above the grinding chamber. The classifier then rejects the oversize material back into the grinding chamber for further size reduction while the fines are conveyed out of the mill.

This design has several advantages over conventional ones, including reduced wear in the grinding chamber. All size reduction is the result of interparticle collision, not impact against the walls of the mill. The fluidized bed itself provides wear protection, which is referred to as active wear protection.

Further protection in the material contact area is provided by soft or very hard material lining, referred to as passive wear protection. Passive measures may include a urethane lining in the grinding chamber and a new patented monobloc classifier wheel fabricated from silicon carbide. Nozzle wear is also practically nonexistent since only compressed air passes through the nozzles.

Another major advantage is decreased energy consumption. All energy is used to accelerate particle against particle, causing size reduction. Unnecessary grinding of fine material is prevented because fines are transported out of the grinding zone.

TABLE I: Adjustment of Particle Size

Nozzle Diameter	Grinding Pressure	Total Air Volume	Classifier RPM	Particle Size
Constant	Constant	Constant	Higher	Finer
Constant	Constant	Constant	Lower	Coarser
Constant	Higher	Higher	Constant	Coarser
Constant	Lower	Lower	Constant	Finer
Smaller	Constant	Lower	Constant	Finer
Larger	Constant	Higher	Constant	Larger

Rare earth compounds, such as samarium-cobalt and neodymium iron must be subjected to size reduction and classification to achieve a steep particle size distribution (PSD). The powder produced must be easily sinterable free of contamination and provide strongly reactive surfaces.

Steeper PSDs are also achieved due to the highly efficient classifier, the efficient fluidization of fines and their transport away from the grinding zone. In addition, very low noise emission is maintained with a fluidized bed serving as an absorption silencer. In all sizes, the noise emission does not exceed 85 db(a).

Operating principle

Material is introduced into the grinding chamber by a volumetric feeder (either a screw feeder, vibratory feeder or rotary valve), then conveyed through double butterfly valves which provide a positive air seal in the chamber. The feed material entering the mill is gravity fed (not introduced through an injector), therefore there is no limitation to the feed size. However, for practical reasons, it is usually desirable to precrush the feed material to 2 mm or smaller, which can significantly reduce total specific energy consumption.

Size reduction occurs as a result of interparticle collision in the fluidized bed where particles are accelerated by a high-velocity gas stream. The nozzle design accelerates the grinding gas above Mach 1, resulting in extremely high impact velocity. The fluidized material in the grinding chamber provides active wear protection by preventing high-velocity particles from impacting against the mill walls.

All of the velocity and energy is absorbed in particle-to-particle collisions. A urethane lining provides additional protection to the mill surfaces, and materials such as aluminum oxide or silicon carbide protect the classifier wheel. The ground material is then conveyed upward by the expanded gas and presented to the classifier wheel.

The upper particle size limitation is controlled by the speed of the classifier wheel and air flow through the mill. As with other types of classifiers, an increase in classifier wheel speed or a reduction in air flow results in a lower cut point. In the case of a jet mill, a finer PSD is the result. Once the correct product quality specification is obtained by adjusting mill parameters, the proper bed level is maintained by a feedback loop from the classifier ammeter or alternative methods.

The rotating classifier wheel is separated from the stationary fines outlet by a gap of approximately 0.3-0.4 mm. This gap is rinsed by air to prevent oversize material from bypassing the classifier wheel and contaminating the ground product. This is a major advantage of the classifier design over other types used in jet mills and mechanical mills, and it makes possible the characteristic sharp top size limitation.

One other air supply is required

in the mill to purge the classifier bearings and shaft, which prevents premature wear of the rotating parts and reduces maintenance costs.

Supporting equipment for these types of jet mills is similar to most other mill types. Collection of ground product is primarily in a cyclone with ultrafines collected in a bag or cartridge collector. Typically, a safety filter protects the exhaust fan.

The exhaust fan is sized to convey the ground product in the air generated in the grinding operation, including rinsing air, and maintains near atmospheric conditions in the mill chamber. Air flow controls and monitoring instrumentation are mounted on a prepiped gas manifold, and a control panel for fully automatic operation including in-line particle size analysis with feedback control can be provided.

Controlling particle size

The PSD is primarily controlled in two ways (Table 1). The first is by classifier wheel speed. This is simply an increase in the classifier speed results in a smaller top size. In most cases, a change in classifier speed will not change the shape of the particle size curve, but only move it up or down in the particle size range. A finer particle size will generally result in lower capacities.

The second method of controlling PSD is by varying air flow through the mill and, therefore, across the classifier wheel. Once again, the effects of classification must be considered. A reduction in air flow will result in a lower cut point and a smaller top size. Thus, by grinding with a lower air pressure, a smaller particle size is obtained.

By reducing air pressure in this way, the shape of the PSD can be adjusted. In some cases, a lower pressure and the resultant lower velocity will create less fines in the product. Grinding air pressures as low as 25-30 psig have been used, but in denser products fluidization will not occur.

Changing nozzle diameter will also affect the air volume used. A larger diameter nozzle at the same air pressure at a given classifier speed, will result in a larger particle size and a higher capacity. Within the range of the classifier, it is possible to match the fineness of the smaller nozzles with an increased capacity proportional to the increased air volume. The use of smaller diameter nozzles with grinding air pressure up to 150 psig may result in a wider PSD.

It is certain that a conventional spiral jet mill can equal the average particle size (d50) for each of the products listed in Table 2. However, the incorporation of a forced vortex classifier integral to the jet mill in the AFG design results in a much steeper PSD, with less oversized spatter grains and less fines. Furthermore, the patented multiple wheel classifier can result in finer PSDs at higher capacities than other jet mill designs (see Fig. 2).

TABLE II: Representative Powder Fineness and Unit Capacity*

Material	Required Fineness	Unit Capacity
Aluminum oxide	95% less than 20 µm	91 kg/hr
Titanium carbide	100% less than 6 µm	46 kg/hr
Silicon carbide	50% less than 8 µm	50 kg/hr
Zirconium oxide	95% less than 20 µm	91 kg/hr
Zirconium oxide	50% less than 6 µm	60 kg/hr
Zirconium oxide	50% less than 3.6 µm	30 kg/hr
Boron carbide	50% less than 5 µm	15 kg/hr
Magnesium oxide	50% less than 4.8 µm	100 kg/hr
Neodymium boron compounds	3.0-3.5 FSSS	100 kg/hr
Samarium cobalt compounds	3.5-4.0 FSSS	100 kg/hr

**ALPINE 400 AFG, FSSS=Fisher Sub-Sieve Sizer* Thickness .160 in. (4.06 mm)*

New developments in mill design

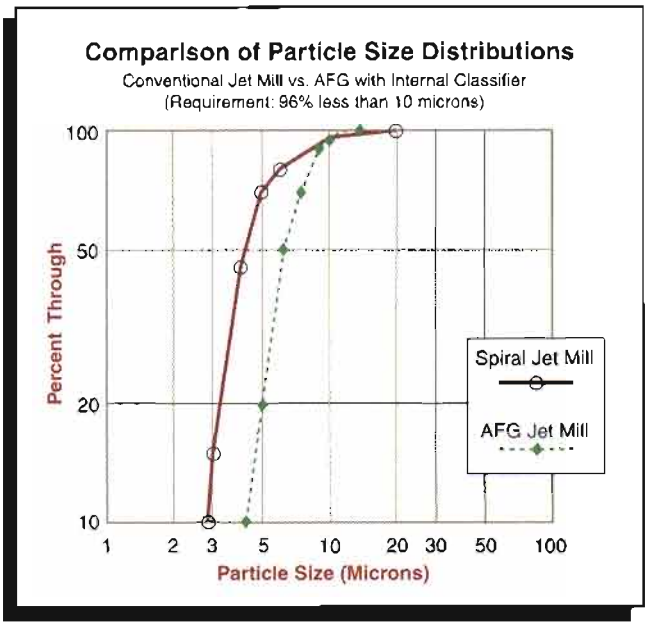
Significant developments have occurred in the past several years in the fluidized bed jet mill line. New mill configurations incorporating single and multiple wheel designs have been added. Three configurations will provide high capacities for products not requiring ultrahigh fineness. These are the 710/1, 800/1 and 1000/1, all utilizing large single wheel classifiers.

More important for industries which require finer PSDs at high capacity are the new multiple wheel designs, the 400/4 and 1000/3. The 400/4 uses four 100 mm classifier wheels for increased fineness at the same throughput of the 400/1 AFG, which has one 200 mm classifier wheel.

The other noteworthy addition to the AFG line is the 1000/3. It can be described as an enlarged version of the 800 AFG with a larger grinding chamber for higher capacity. This is an excellent choice for materials well within the top size limitations of the 315/3 classifier (normally used on the 800 AFG), but, due to their difficult grinding characteristic, results in very low rates.

Significant developments have occurred in the past several years in the fluidized bed jet mill line. New mill configurations incorporating single and multiple wheel designs have been added.

One type of fluidized bed jet mill incorporates a bottom nozzle and 3D grinding zone and is available in all mill sizes. This design was originally developed for rounding thermoplastic materials. By using low grinding pressures and warm air, particles become rounded in a batch type operation.



Another, and possibly more widely used approach with this type, is to use lower air pressures with larger nozzles to produce material with a narrower PSD with less fines. Because of the bottom nozzle, material of very high density can be fluidized.

It is also possible to completely empty the mill at the end of the grinding process. This feature is useful when processing pyrophoric materials under an inert atmosphere, when residual material in the mill can be extremely hazardous. Standard mill design is a single chamber, direct feed version. For the processing of low bulk density materials, models incorporating a feed bin and feed screw are available. The feeding screw, mounted low in the grinding chamber, densifies the feed material as it enters the mill.

Saving energy, maintenance costs

In response to the demand for more energy efficient grinding systems, an improved jet nozzle design has been developed. Studies have shown that greater than 50% of the actual size reduction occurs on the surface or along the free jet. Low-velocity particles drawn into the free jet collide with particles at higher velocity already in the free jet. The balance of size reduction continues at the focal point of the nozzles.

This is a disadvantage of the standard style nozzles since they are limited in the amount of material that can actually be drawn into the free jet, thus their energy conversion is limited also. To improve grinding efficiency, several methods were investigated which would allow more material to be entrained into the free jet and increase its surface area.

A multiple free jet design has been developed that produces a vacuum at the nozzle outlet to enhance entrainment of particles into the core of the jet. The grinding air is divided into several jets placed close together. The jets produce a single core which is highly loaded with particles.

A larger free jet surface area is also generated. There is a corresponding increase in the size reduction process, both on the surface of the jet and in the core of the jet. This results in a more complete use of the energy input and a higher energy conversion.

In response to customer requests for easier maintenance and cleaning, especially in larger mill designs, removable classifier bearing housings equipped with slide rails are now being employed. This enables the user to gain access to the classifier section for cleaning, wheel changes and bearing maintenance by simply unbolting the bearing housing and retracting it on the sliding rail fixture.

Other features for easier cleaning and maintenance include: a single chamber mill that eliminates feed bin and feed screw; wider fines outlets in classifier to prevent product build-up; removal of all internal ledges; and radiuses on all inside corners.

Applications

Fluidized bed jet mills can be used for any material that can be fluidized by the expanded compressed air in the grinding chamber. Some common applications include:

- Nonoxide ceramics such as silicon carbide, silicon nitride and boron carbide.
- Oxide ceramics such as zirconium oxide, aluminum oxide, magnesium dioxide.
- Rare earth magnet raw material such as samarium cobalt and neodymium iron boron, where processing in inert gas is required. □