How to select and start up a fluidized-bed jet mill system

Gary Liu  DuPont

The fluidized-bed jet mill provides fine to superfine material grinding and allows for precise control over the final product’s maximum particle size. To achieve that level of precision, however, requires that the mill system components be carefully selected for the application and optimized during startup. This article explains how to select a fluidized-bed jet mill for your application and optimize your system during startup.

The fluidized-bed jet mill (FBJM) is widely used across various industries to dry-mill bulk solid materials down to 1 to 10 microns in average particle size. The mill features an air classifier that tightly controls the final material’s maximum particle size. This gives the FBJM a unique advantage over other jet-mill types (such as the spiral jet mill and the opposed jet mill), which don’t use an air classifier.

To ensure that you select the best FBJM for your operation, you should thoroughly understand your application requirements and material characteristics and have your supplier conduct pilot-scale milling tests with your material. This article explains why these recommendations are important and discusses how to optimize your FBJM’s operation during startup. Before you can select a mill for your application, however, you need to know some FBJM system basics.

FBJM system basics

An FBJM system, as shown in Figure 1, can be divided into three sections: the feeding section, the milling section, and the air-handling section. When milling combustible materials, dust explosion protection equipment (not shown) is also necessary. The system’s feeding section includes a material charge hopper, a feeder, such as a screw feeder, and an air-isolation valve, such as a rotary or double-flap gate valve. The milling section includes a material inlet, a grinding chamber, air nozzles, an air classifier, and an air-and-material outlet, as shown in Figure 2. The air-handling section includes an air compressor, a conveying line, a dust collector, a fan, and other ancillary equipment. The air-handling section also includes compressed air lines to the classifier bearings and the gap between the classifier wheel and the housing. This purge air prevents material buildup on the bearings and prevents oversized particles from escaping the mill through the classifier gap. [Note: Some highly explosive FBJM applications require the use of an inert gas such as nitrogen rather than air to prevent dust explosions, but for the purposes of this article, we’ll use the term “air” to refer to the system’s grinding, conveying, and purge gas.]

In operation, the system’s feeder continuously feeds material from the charge hopper through the FBJM’s material inlet into the grinding chamber. At the same time, the air compressor forces opposing high-pressure jets of air through the nozzles at the grinding chamber’s base. The material is fluidized by the opposing air jets, which force the particles to impact each other at high speed and break apart. The fluidized particles continue cycling in and out of the air jets until they become small enough to be carried with the airstream through the air classifier and discharged from the mill. The fan then draws the air-material mixture through the conveying line and into the dust collector, which filters out the material and exhausts the airstream.

The FBJM is typically mounted on load cells, which monitor the weight of the material in the grinding chamber and communicate with the control system to regulate the material feed rate.
Know your application requirements

The first step to selecting an FBJM is to understand your application’s required final particle size distribution (PSD) and mill capacity (or output). Final PSD and mill capacity are closely related — the finer the PSD, the lower the mill capacity. In the range of particle sizes typically produced by a jet mill, achieving a slightly finer particle size can require a great deal more energy, so you should avoid specifying a finer particle size than necessary.

For example, an FBJM milling test for an herbicide yielded a 950 kg/h capacity at a particle size of $d_{50} = 2$ microns (50 percent of particles having a diameter less than 2 microns). Reducing the particle size to $d_{50} = 1.5$ microns, however, dropped the mill’s capacity to 600 kg/h. This means you would have to operate the mill more than 50 percent longer to achieve the same output at the smaller particle size, which would result in a corresponding increase in energy costs.

Understand your material

The second step to selecting an FBJM is to understand your feed material’s properties, including particle size, bulk density, moisture content, flowability, toxicity, and explosivity.

Particle size. Every FBJM has a maximum feed particle size for efficient operation. Feed particles that are too large won’t fluidize well, making the material very difficult to mill. You can solve this problem by pregrinding the material feed down to a manageable particle size (typically 100 to 500 microns) using a hammermill.
**Bulk density.** Your feed material’s bulk density provides information for properly sizing the mill’s feeder and estimating the weight of the material bed in the grinding chamber during operation.

**Flowability.** A material’s flowability is affected by the material’s moisture content and surface chemistry. In dry milling applications, a high-moisture feed material can flow poorly and build up on the grinding chamber wall, classifier wheel, and conveying line. This can reduce mill capacity and air-classifier performance. If your feed material’s moisture content is too high, you may need to add a predrying step to reduce the moisture to a manageable level. Particle surface chemistry can affect many material properties that affect flow, including stickiness, affinity for water, and tendency to accumulate electrostatic charge. Your material’s flowability also dictates which type of charge hopper and feeder you should select to effectively feed material into your mill.

**Toxicity.** Understanding your material’s toxicity is critical to protecting both workers and the environment. If the material is highly toxic, for example, and mustn’t be released into the environment, you may need to use a chemical suppression system to contain a dust explosion inside the dust collection system rather than a less expensive explosion panel that vents pressure and flames outside the building.

**Explosibility.** An FBJM system generates superfine particles and then suspends them in an enclosed stream of air, creating the ideal conditions for a dust explosion. Unless your material is one of the few commonly known to present no dust explosion risk (a stable oxide, for example, such as titanium dioxide or sand), you should always test the material’s explosibility characteristics. Your material’s dust deflagration index ($K_\text{st}$) and maximum explosion pressure ($P_{\text{max}}$) values are important for determining your system’s design characteristics and any necessary dust explosion protection equipment. For example, if your FBJM and connected equipment aren’t designed to withstand your dust’s $P_{\text{max}}$, your system will require explosion vents or active suppression and isolation equipment in accordance with NFPA 68. Knowing your feed material’s explosibility characteristics, such as minimum ignition energy (MIE), can also provide guidance for selecting a safe unloading method for material received in bags, bulk bags, or drums.

**Perform milling tests**

Once you fully understand your application requirements and your material properties, you should have your supplier conduct milling tests with your material. Milling tests are important even if the supplier has data from a similar application, since every material has unique properties. These tests will not only validate the mill’s feasibility, they’ll help you determine what size mill you need. The first test is typically a feasibility test in a bench-top mill with a small amount (5 to 10 pounds) of material to prove that the FBJM can achieve the required final particle size. Sometimes this test isn’t necessary if the FBJM’s feasibility has previously been determined.

Next, the supplier will perform pilot tests using hundreds of pounds of material. To ensure a successful pilot test, the material sample must be representative of the material in your process. This is sometimes neglected since maintaining the sample’s temperature and moisture level as it sits in the supplier’s warehouse can be difficult. Coordinate with the supplier to minimize the storage time, and package the sample in a way that reduces the risk of moisture loss.

These pilot tests, along with your application requirements and material characteristics, will help the supplier recommend the right mill capacity, nozzle size, and air-classifier type for your FBJM. In general, FBJMs scale up proportional to gas flow. For example, if the tests reveal that 2 pounds of compressed air grinds 1 pound of material to the desired particle size, you can use that 2-to-1 air-to-material ratio to determine the FBJM size for your required production rate.

The supplier will also be able to specify your system’s air-handling components and other ancillary equipment. This is critical because a poorly designed air-handling system can significantly reduce mill throughput, resulting in overmilled material and an inefficient process.

**Optimize your FBJM system at startup**

How you commission and start up your FBJM system is as important as the system’s design to optimizing production and efficiency. The three key parameters that you can typically adjust to get the desired particle size and mill capacity are air-classifier speed, air-jet velocity, and fan airflow.

**Air-classifier speed.** Air-classifier speed is typically the first adjustment to make when optimizing your FBJM system. The air classifier uses the balance between the centrifugal force generated by the spinning classifier wheel and the drag force generated by the system’s exhaust fan to separate oversized particles from right-sized particles, as shown in Figure 3. When material enters the spinning classifier wheel, the exhaust airstream carries the smaller, lighter particles to the mill’s discharge, while the wheel’s centrifugal force rejects the larger, heavier particles back into the grinding chamber. The balance between these two forces can be illustrated by Equation 1:

$$\frac{1}{2} C_D \rho_a V_r^2 \pi x^2 = \frac{\pi}{6} x^3 \rho_s a_c$$

where, $C_D$ is drag coefficient; $\rho_a$ is air density; $V_r$ is air radial velocity; $x$ is classification particle-size cut; $\rho_s$ is particle density; and $a_c$ is centrifugal acceleration.
After some simplification of Equation 1, the particle-size cut, \( x \), can be described by Equation 2:

\[
x = \frac{\mu_g}{\rho_g} \left( \frac{0.25Q_g}{Q_g^{0.875}N^{0.25}} \right)^{0.375}
\]

where, \( \mu_g \) is the air’s dynamic viscosity; \( Q_g \) is airflow rate; and \( N \) is the classifier’s rotation speed in rpm.

Increasing the classifier speed generates a finer maximum particle size; decreasing the classifier speed generates a coarser maximum particle size. Note that, in addition to generating finer particles, increasing the classifier speed also reduces the mill’s capacity, since fewer particles are discharged.

**Air-jet velocity.** The purpose of the nozzles in an FBJM is to increase the air jets’ kinetic energy (velocity). In an FBJM, a higher air-jet velocity reduces the material’s particle size faster, increasing the mill’s capacity. To achieve high air-jet velocity, an FBJM uses convergent-divergent nozzles (also called de Laval nozzles), as shown in Figure 4.

The airflow in a de Laval nozzle is an isentropic process, which means that the increase in kinetic energy comes at the expense of the air’s potential energy (pressure) and internal energy (temperature). For an FBJM using air for grinding gas, you can calculate the air-jet velocity by applying Equation 3:

\[
V_2 = \sqrt{\frac{RT_2}{M} \left( \frac{2k}{k-1} \right) \left[ 1 - \left( \frac{P_2}{P_1} \right)^{k-1} \right]^{\frac{k}{k-1}}}
\]

where, \( V_2 \) is the air-jet velocity at the nozzle exit; \( T_2 \) is the absolute temperature at the nozzle inlet; \( R \) is the universal gas constant; \( M \) is the air’s molecular weight; \( k \) is the air’s isentropic expansion factor (for air, \( k = 1.4 \)); \( P_1 \) is the absolute pressure at the nozzle inlet; \( P_2 \) is the absolute pressure at the nozzle exit; and \( P_2/P_1 > 1.893 \) (a constant for air).

In an FBJM system, if the grinding air is 20˚C (68˚F) and 6 bar gauge pressure (87 psig) and the pressure in the milling chamber is ambient, the air-jet velocity is about 500 m/s. The normal range for FBJM air-jet velocity is 400 to 550 m/s.

The air’s temperature at the nozzle exit can be calculated using Equation 4:

\[
T_2 = T_1 \left( \frac{P_2}{P_1} \right)^{\frac{k-1}{k}}
\]

With the same 20˚C, 6 bar gauge compressed air, the air temperature at the nozzle exit would be about -105˚C (-157˚F)! This is very good for milling heat-sensitive materials. Since the cooling effect is greater than the heat generated by friction from interparticle and particle-to-wall collisions in the grinding chamber, the material will never be heated up during milling. However, the cooling effect may also cause moisture brought in by the feed material to condense in the grinding chamber. The condensed water may cause material buildup on the surface of the classifier wheel, which will increase the load on the classifier motor, reduce mill throughput, change the final particle size distribution, or even trip the classifier motor’s circuit breaker. Predrying the material before feeding it into the mill or heating the compressed air can solve this problem. Heating the compressed air will also have another benefit: the air-jet velocity increases about 60 fpm for every degree F of temperature increase.

You can increase your mill’s capacity by raising the compressed-air pressure. This not only increases the air-jet velocity, it also increases the rate at which the grinding air flows through the mill, which can further improve capacity. This adjustment method is limited, however, since there’s a limit to how high you can raise the air pressure in a compressor.

Another way to increase the airflow rate is to use slightly larger nozzles. For example, if the mill was designed to use 8-millimeter nozzles, you can switch to 9- or even 10-millimeter nozzles to achieve the required airflow. When switching to larger nozzles, however, be sure to verify that the compressor has enough capacity to handle the increased airflow.
Fan airflow. The final parameter you should fine tune at startup to optimize FBJM system performance is the fan airflow. The fan’s airflow is predetermined by the system’s operating pressure. The system’s operating pressure is the total airflow through all the nozzles plus the purge airflow. For example, in an FBJM, the total airflow may be 750 scfm, with 665 scfm being the grinding air flowing through the nozzles, 15 scfm being used to purge the bearings, and 70 scfm being used to purge the classifier gap.

You can estimate the necessary system pressure drop by assuming the pressure inside the grinding chamber to be near zero. In fact, keeping the grinding chamber pressure near zero or at just a slight vacuum is very important for proper mill operation. A pressurized grinding chamber may affect nozzle jet behavior, bearing purging, feeder performance, and load-cell readings. If you do keep the grinding chamber at a slight vacuum, pay special attention to the fan’s suction effect on the mill body, which may cause false load-cell readings and significantly reduce mill capacity due to having too much material in the fluidized bed. To prevent this, reset the load cells to zero after the fan is running but before feeding material into the mill. PBE

References
2. For more information on FBJM air-handling systems, see my previous article, “How to get better grinding performance with pneumatic conveying,” in Powder and Bulk Engineering’s March, 2015, issue, available at www.powderbulk.com.

For further reading
Find more information on equipment discussed here in articles listed under “Size reduction” in Powder and Bulk Engineering’s article index in the December 2015 issue or the Article Archive on PBE’s website, www.powderbulk.com. (All articles listed in the archive are available for free download to registered users.)

Gary Liu is a solids processing and handling consultant in DuPont’s Engineering Research and Technology division (302-695-7627, gary.liu@dupont.com). He holds a PhD in mechanical engineering from the New Jersey Institute of Technology, Newark, N.J.

DuPont
Wilmington, DE
302-695-7627
www.dupont.com