Mechanical fluidized-bed plow mixers: Fast, intense processing without high shear

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Intense mixing generally applies high shear, which can degrade particles and generate heat from energy buildup. By mechanically fluidizing particles, a fluidized-bed plow mixer intensely but gently mixes the particles, reducing shear and minimizing heat buildup without the problems associated with gas fluidization. This article first discusses how the mixer works, how to use the mixer for other processes, and mixer variations. Then it explains how to select the mixer for your application.

A mechanical fluidized-bed plow mixer can quickly mix a batch, typically in less than 10 minutes, and can handle a mixture with over 600,000-centipoise viscosity and a mix ratio up to 1-to-20,000. This efficiency is possible because the mixer fluidizes and rapidly agitates the mixture in three dimensions. The gentle but intense mixing action is well-suited both for mixing solids with solids and solids with liquids and minimizes mechanical heat buildup. The mixer's enclosed environment also makes it suitable for applications other than mixing.

How the mixer works

The mechanical fluidized-bed plow mixer, as shown in Figure 1, typically has a horizontal, drum-shaped vessel that can range from 4 to 25,000 liters in capacity. In the vessel, several mixing elements called *plows* are mounted on a rotating agitator shaft. A standard plow has a triangular blade (another plow style for other applications is discussed later). A charging port is located in the vessel top, and a discharge is at the vessel bottom. Access doors along the vessel walls permit cleaning between batches.

In operation, ingredients for the batch are loaded through the charging port. The agitator shaft rotates, spinning the plows, which lift and separate the particles. The agitator shaft drive has high horsepower (typically 75 to 150) and provides high rotational speed (up to 100 rpm or above). The type, spacing, and number of plows and the shaft speed contribute to the particle fluidization. When properly designed, the mixer can rotate the particles in a *torus,* in which they move in three directions while intermingling in suspension, as shown in Figure 2. The resulting fluidization lifts the particles gently, applying only moderate shear to them. When mixing is complete, the mixture exits through the discharge.

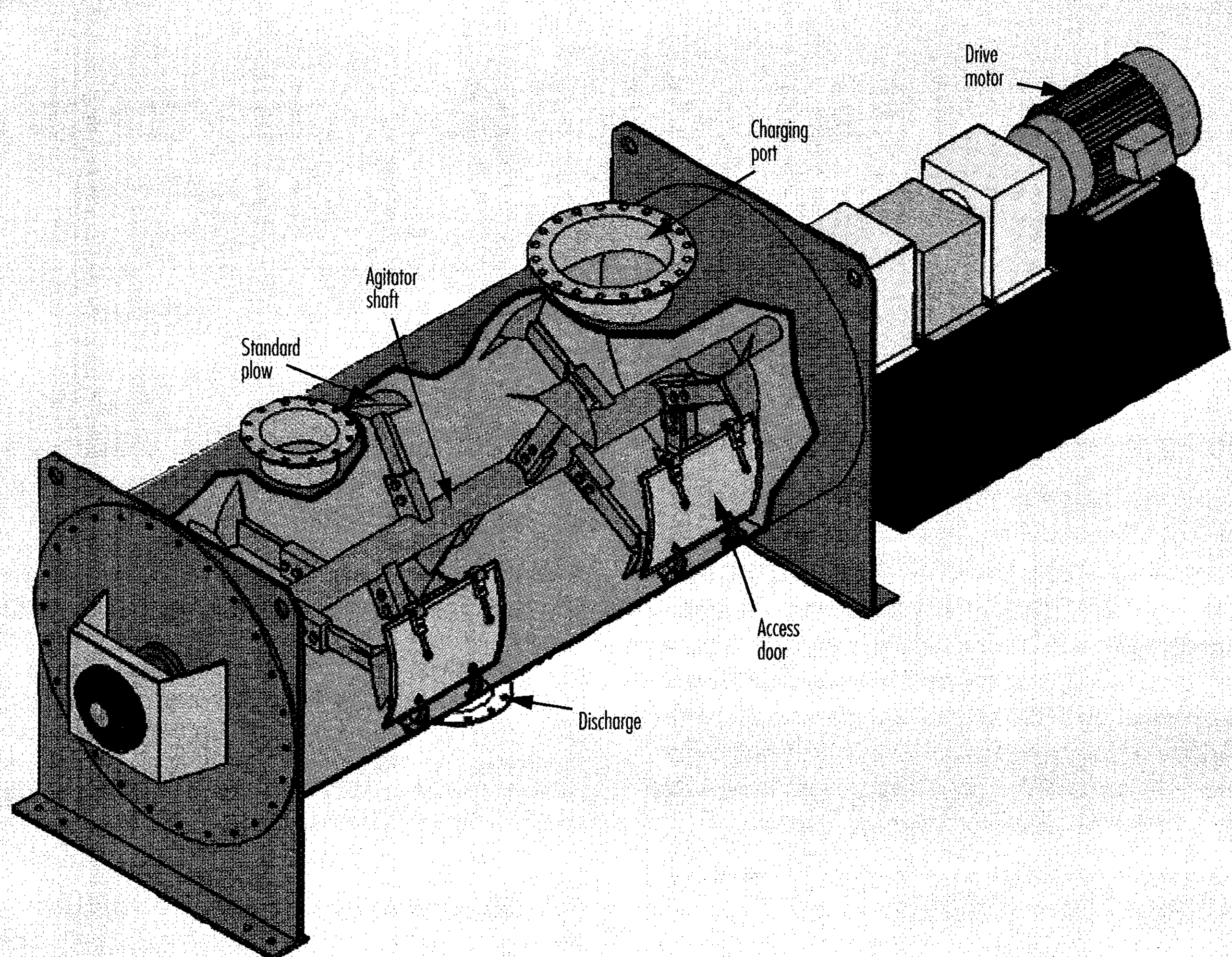
Comparison with other fluidized-bed mixers. The mixer's mechanical fluidization is directly controlled by the plows' rotational speed, which is a simple mechanical variable to control. This provides advantages over a gas fluidized-bed mixer, because the gas is the mixer's controlling factor and causes complex fluid dynamics to affect the particle movements. And using gas to suspend particles is inefficient both for propelling the particles and conditioning the gas.

The mixer also has advantages over other mechanical fluidized-bed mixers. Some mechanical fluidized-bed mixers are redesigned ribbon or paddle blenders, in which the ribbons or paddles have been replaced with plows but the horsepower and rotational speed haven't been increased. As the plows rotate through the material they merely stir the material back and forth and don't mix as efficiently as the higher power, higher speed mechanical fluidized-bed plow mixer.

Comparison with fluidized-zone mixers. Other mixers — usually equipped with two rows of ribbons or paddles on a rotating shaft — throw the material upward to suspend material in the vessel's upper center. This mixing action is called *fluidized-zone mixing,* which means that

Figure 1

Typical mechanical fluidized-bed plow mixer



only some of the material is fluidized at one time. In contrast, the mechanical fluidized-bed plow mixer's higher horsepower and rotational speed completely fluidize the material bed, increasing efficiency. To handle the higher power and increased torque, the mixer also has heavier construction — thicker vessel walls and stronger bearing supports — than most other mixers.

How to use the mixer for other processes

By equipping the mixer with components such as a vacuum filter stack and solvent recovery system, you can apply the unit to processes other than mixing. Applications include coating and granulation, vacuum drying, and chemical reactions.

Coating and granulation. For coating and granulation, liquid injectors (also called *spray lances*) are mounted inside the vessel's upper half to spray downward. One (or more) high-speed dispersion mill (also called a *chopper*), which consists of several small blades on a small rotating shaft, can be mounted on the vessel's lower wall, as shown in Figure 3. The mill helps to disperse the injected liquid evenly throughout the fluidized bed. As the mixer agitates the material, the particles are suspended, exposing maximum particle surface area.

For *coating,* small amounts of liquid ingredients flow through the injectors and disperse into the fluidized bed. Here the liquid ingredients contact the particle surfaces and precisely and consistently coat the particles, thus re-

Figure 2

Mixing action

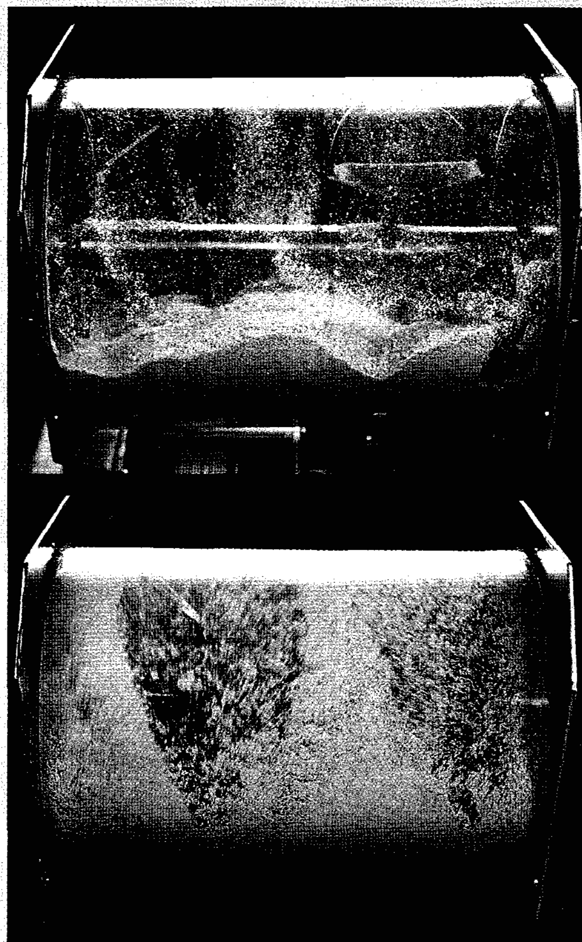


Figure 3

High-speed dispersion mill

A batch coating or agglomeration cycle is typically less than 10 minutes. If required, the coated particles or granules can then be dried under vacuum in the same vessel.

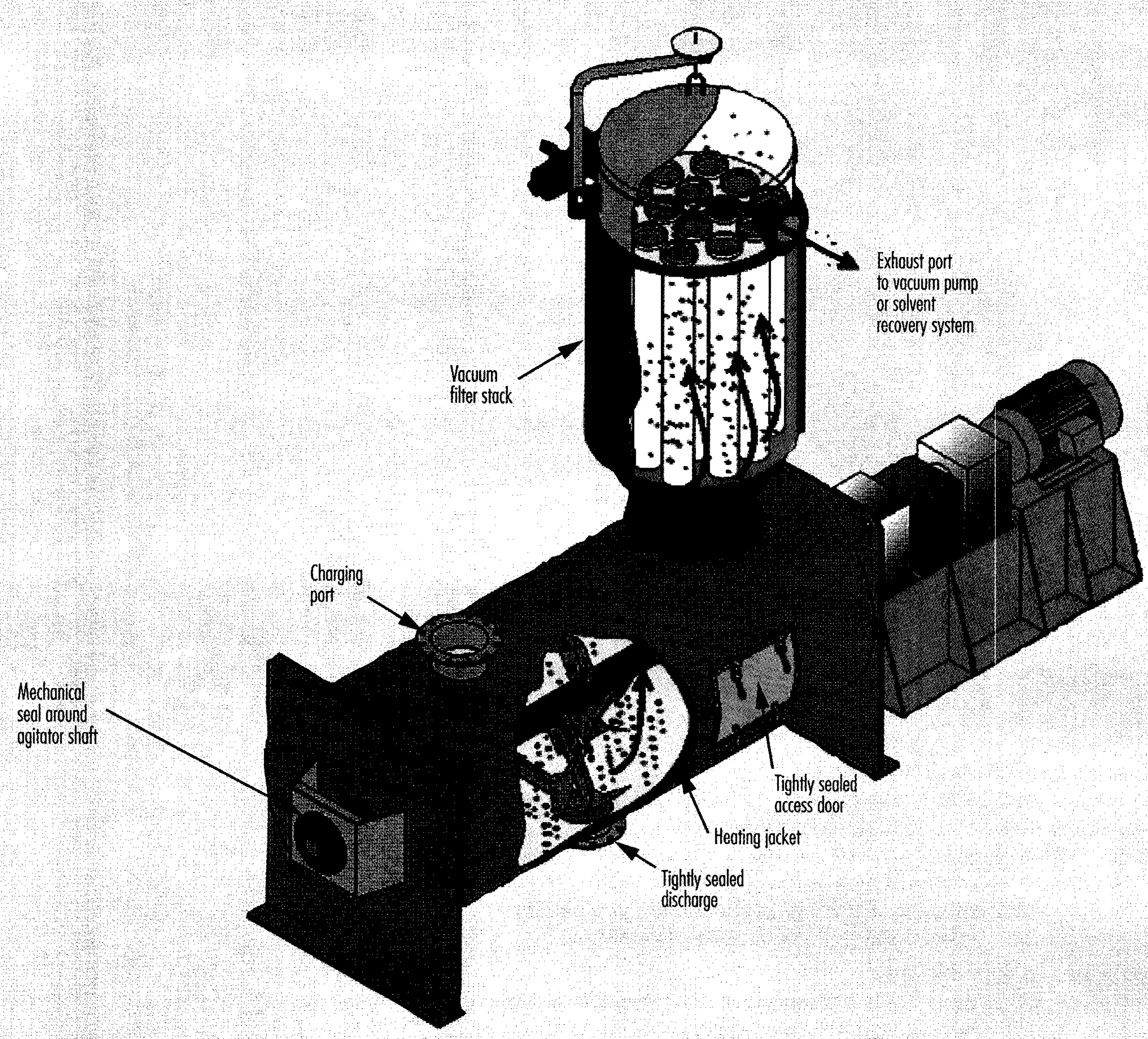
quiring less liquid and speeding drying. Typical applications include coating pharmaceutical particles with lubricants and coating alkaline battery cathode materials with potassium hydroxide.

For *granulation,* small amounts of a liquid binder are injected into the vessel, contacting the fluidized particles and causing them to agglomerate and form granules. Compared with other agglomeration methods, this method generates more shear and particle-to-particle contact and thus uses less binder, producing stronger agglomerates. The unit's high horsepower also permits it to handle sticky materials, such as analgesic pastes. Typical applications are binding pharmaceutical intermediaries with water to achieve consistently sized granules before tableting, binding food beverage particles with water to form granules for instantized drink mixes, and binding abrasive particles with wax for sintered materials.

Vacuum drying. By equipping the mechanical fluidized-bed plow mixer with various components, you can use it for vacuum drying, as shown in Figure 4. Components can include either standard or paddle-shaped plows, as shown in Figure 5; a vacuum filter stack (typically a baghouse) located on top of the vessel; a high-speed dispersion mill; access doors and a discharge with tight seals; other tight (typically mechanical) seals around the agitator shaft and high-speed dispersion mill shaft; and a heating jacket. The tightly sealed vessel allows you to maintain a high vacuum (low vapor pressure) in the vessel during drying. A vacuum pump (if the moisture removed during drying is water) or a solvent-recovery system including a vacuum pump, a chiller, and a liquid condenser (if the moisture is a solvent, such as a hydrocarbon) is typically located near the vessel. Typical applications are vacuum-drying chemicals, pharmaceutical intermediates, pigments, stearates, filter cakes, and food products.

Figure 4

Mixer equipped for vacuum drying



In operation, the material is loaded into the charging port (or is already in the vessel after mixing, coating, or granulation) and is mechanically fluidized under high vacuum. Steam (for materials that aren't heat-sensitive) or hot water (for heat-sensitive materials) circulates in the heating jacket, transferring heat to the vessel walls and from there to the particles as they contact the walls. If standard plows are used, they fluidize the particles as in mixing; if paddle-shaped plows (also called *heat transfer plows*) are used, they fluidize the particles as well as scrape them against the walls to enhance the heat transfer. Moisture is pulled off the particles under vacuum through the vacuum filter stack, where particles are trapped in bag filters and returned to the vessel. Moisture exits the vessel through the vacuum pump and, if required, the chiller and liquid condenser. Typical batch cycle drying time is from 1 to 4 hours, depending on factors such as the vessel size, material moisture content, and final product requirements.

Comparison with other drying methods and equipment. Vapor pressure, surface area, and heat transfer all affect drying — that is, removing moisture from solids. Vacuum drying is the most efficient drying method because it reduces the vapor pressure, which permits moisture to vaporize at a lower temperature and uses less heat energy than boiling at atmospheric pressure.

The mechanical fluidized-bed plow mixer is better suited for vacuum-drying many materials than some other types of equipment. For instance, in a gas fluidized-bed mixer, suspending the particles requires increasing the vapor pressure, which makes drying in the same vessel difficult. In contrast, particle movement and suspension in the mechanical fluidized-bed plow mixer are independent of vapor pressure. Correctly sealing the vessel prevents excessive air from leaking into it and helps it achieve low vapor pressure (typically less than 0.1 atmospheric or 686 millimeters mercury) — that is, high vacuum — for efficient drying.

In another example, a low-intensity tumble dryer, vacuum dryer, or ribbon blender provides slower drying than the mechanical fluidized-bed plow unit because the particles aren't efficiently exposed to the low vapor pressure or heated vessel walls. Such a unit merely stirs the particles, exposing only some of their surface area to the low vapor pressure at any given time.

A gas fluidized-bed mixer uses gas along with heated vessel walls to transfer heat to the particles. This heat transfer method is highly efficient because it provides good gas-to-particle contact. However, the gas must be heated by a steam coil before it's released into the vessel, which adds another step to the process. In a low-intensity mixer, the particles are stirred and only eventually contact the heated vessel walls. In contrast, a mechanical fluidized-bed plow mixer's intense mixing action quickly and repeatedly pushes the particles to the vessel walls so they rapidly pick up heat.

Breaking up agglomerates. One problem that can occur during vacuum drying in the mechanical fluidized-bed plow mixer is agglomerate formation. The agglomerate's outer shell becomes dry and somewhat impervious during drying, shielding the inner moisture from the low vapor pressure and available heat. Drying levels off at this point, and little moisture is removed. Although the mechanical mixing action inside the vessel eventually breaks up the agglomerates and exposes the inner moisture to the low vapor pressure, this takes extra time and energy. One solution is to install a high-speed dispersion mill at a right angle to the particles' rotational flow in the vessel. The mill can break up agglomerates as they form, keep the inner moisture exposed to the vapor pressure, and reduce the total drying time.

Chemical reactions. The mechanical fluidized-bed plow mixer also provides an excellent environment for chemical reactions if equipped with many of the same components as for vacuum drying. In addition, either type of plow can be used depending on whether the reaction requires heat transfer, and a cooling jacket can be added for cooling dried or heat-sensitive materials. Typical applications include converting starches, treating materials with gases, and creating endothermic (heat-absorbing) and exothermic (heat-releasing) reactions.

Because the unit's mixing action is independent of vapor pressure, you can increase the vapor pressure inside the unit with gas injection or exothermic reactions. This allows you to vary the unit's vapor pressure while maintaining maximum particle-to-particle contact and high available heat, providing efficient chemical reactions.

Particles inside the mixer go through various rheological (viscosity) stages with little effect on the mixing action so that solids, liquids, and gases can be intimately combined inside the vessel under precise temperatures. After the particles react, you can reduce the vapor pressure inside the vessel to allow the particles to dry. This capability allows the vessel to completely manufacture some materials from raw ingredients through finished product without discharging them until processing is done. This is especially desirable for a product with noxious or hazardous ingredients such as certain cancer drugs. Batch cycle time varies widely, depending on the chemical reaction.

Mixer variations

The mechanical fluidized-bed plow mixer's plows, jacket, seals, and discharge are available in various configurations from several manufacturers. Some variations are suited to specific materials and applications; others are lower or higher cost variations that provide different levels of process efficiency.

Plows. Plow design affects mixing efficiency. The standard plow (Figures 1 and 3) separates and propels the particles in two directions inside the vessel, which achieves fast mixing and provides thorough mixing action, especially for mixing a small amount of one ingredient into a large amount of another ingredient. The standard plow is typically used for mixing, coating, and granulation. In contrast, the paddle-shaped plow (Figure 5) propels particles in just one direction but provides scraping action against the heated vessel walls, enhancing heat transfer to the particles. The paddle-shaped plow is typically used for vacuum drying and chemical reactions requiring heat transfer.

Jacket. Jackets containing hot media (steam or hot water) heat the vessel walls during vacuum drying and some chemical reactions. Jackets containing cool media (cold water or glycol) cool the vessel walls during mixing of heat-sensitive ingredients.

Figure 5

Paddle-shaped plow

The jackets are available in various styles. Two styles, the *dimpled jacket* (consisting of a hollow, dimpled metal sheet) and *half-pipe jacket* (consisting of hollow pipes cut in half), don't cover the entire vessel. A large percentage of the jacket area is also used to weld the jacket to the wall, reducing the available heat or cold transfer area and greatly reducing the overall transfer efficiency. However, these jacket styles are relatively inexpensive.

Another style, called a *baffled jacket,* has a hollow metal casing with interior baffles to control the media flow through the jacket. It covers the entire vessel and is welded to the vessel wall only at the edges, providing maximum heat or cold transfer area and the most transfer efficiency. However, this jacket style costs more and requires thicker vessel construction to withstand the jacket's greater pressure effect on the walls.

Seals. Seals are available as packing glands or mechanical seals. While packing glands are commonly used for sealing mixers, they can't provide the tight seal the mechanical fluidized-bed plow mixer requires for vacuum drying and some chemical reactions. The packing glands also require frequent maintenance. A mechanical seal provides a tight seal and can require less maintenance.

Discharge. The mechanical fluidized-bed plow mixer can have a paddle-type or ball valve discharge. The former only stops flow from the vessel; it doesn't throttle or control flow. The discharge also requires an elastomer seal that can become damaged by solvents or wear during repeated opening and closing. A ball valve discharge (also called a *hemispherical valve*) provides better discharge because it shears the material to close, an action that naturally throttles flow and eliminates the need for an elastomer seal. However, the ball valve must be carefully designed for mounting as close as possible to the vessel's interior to eliminate dead space between the valve and the wall.

How to select a mechanical fluidized-bed plow mixer

When choosing a mixer, pay attention to the differences among similar units. The following information explains what to ask, as well as discusses pilot-plant testing and costs.

What to ask. The following questions are the basics; make sure you ask other questions specific to your application.

- Does the mixer provide the right shear for my product? (The shear level can be ideal for some materials but too high for others.)

- What are the mixer's construction materials? Are they heavy and strong enough to handle the mixer's horsepower and torque? Are the vessel walls and agitator shaft solid stainless steel or stainless-clad carbon steel? (Keep in mind that the latter, although inexpensive, can cause iron oxide contamination over the mixer's service life.)

- How efficient is the mixer's heating or cooling jacket?

- For vacuum drying, can the unit meet my product temperature limits? For instance, can it remove all the moisture my spec requires without damaging my heat-sensitive pharmaceutical?

- Does the mixer have mechanical seals? Are they readily available, and can you provide quick turnaround if one fails?

- Are the seals adequate for preventing vessel leakage during vacuum drying that can affect my downstream solvent recovery system? (Be aware that the percentage of air leakage into the vessel equals the percentage of noncondensable gases passing through the liquid condenser, so excessive leakage can load the condenser down. This requires a larger vacuum pump and liquid condenser even though the amount of solvent remains the same. Without a large enough pump or condenser, uncondensed solvent can pass into and pollute the atmosphere.)

- What kind of discharge does the mixer use? (If the manufacturer uses a ball valve, make sure the valve is designed and fabricated to minimize dead space in the vessel.)

Pilot plant testing. Once you've chosen a mixer, expect to work closely with the manufacturer to select the features and components that are right for your application. Pilot plant testing is an important part of this process. Typically the manufacturer invites you to witness the testing, in which your material samples are processed in vessels of various sizes and with different components under several operating conditions. The testing helps you determine information such as:

- Whether the mixer can achieve the results you desire.

- How much horsepower the mixer pulls to accomplish your desired results, which is important for accurate scaleup to a production-size unit.

- How long the batch cycle is.

- Whether your material is subject to buildup inside the vessel and how long cleaning takes between batches.

Costs. When comparing costs of various mixers, be sure to look not only at each mixer's capital cost but at the costs of its ongoing maintenance, performance, and energy requirements. What you'll probably discover is that a mixer that's more expensive to purchase can be much less expensive to operate than a unit with a lower capital cost. **PBE**

Suggestions for further reading

For more information on mixers, see articles listed under "Mixing and blending" in *Powder and Bulk Engineering*'s comprehensive "Index to articles" in the December 1996 issue.

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