Mixers: Four Innovations Worth a Closer Look

Many factors can impact the success of mixing in chemical process operations. The design breakthroughs profiled here address some of the most commonly encountered issues

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IN BRIEF

FOUR RECENT ADVANCES IN MIXER DESIGN

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CLOSING THOUGHTS

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FIGURE 1. This planetary disperser is equipped with two helical, planetary stirrers, four saw-tooth blades (two on each high-speed shaft), a removable sidewall scraper arm, and a bottom scraper (attached to one of the stirrers)

The last few decades have not lacked for innovations in mixing technology. As the chemical process industries (CPI) have made great strides in developing novel raw materials, enhanced value-added formulations and improved processes — in response to ever-changing consumer preferences and legislation — the science and art of mixing has continued to evolve, too, to meet the demands of modern production.

Mixer manufacturers have needed to quickly adapt and respond to real issues that are encountered, from research and development (R&D) all the way through scaleup and commercial production. While many of the solutions commonly take the form of strategic modifications applied to prevailing technologies, there are others that ultimately give rise to more drastic innovations and thus become a new mixer category all their own.

As with most novel devices and ideas, mixing innovations do take time to spread and gain widespread usage, some more than others. In this article, we review four specialty equipment designs that provide a range of processing and operational advantages over traditional mixers. While they may not yet be considered standard workhorses (and are often are known only within specific industry sectors), they are worth a closer look by most CPI operators, because of the universal benefits they offer.

Four recent advances in mixer designs

1. Planetary dispersers. The classic high-speed disperser, also sometimes called a dissolver, is a popular mixing tool used in the manufacture of paints, inks, coatings, adhesives, plastics and other applications. It is economical, simple to operate and usually equipped with a saw-tooth blade, which works well for straightforward, powder wet-out and dispersion applications. However, its efficacy is significantly diminished once the product viscosity exceeds 50,000 centipoise (cP).

And, a high-speed disperser can easily raise product temperature due to frictional heat. In a viscous batch, when not enough material is able to flow toward the blade, localized heating sets in. Eventually, colder materials near the vessel periphery can become stagnant. This further contributes to poor mixing, and increases the risk of product degradation due to overheating in the vicinity of the high-speed blade.

The addition of an anchor agitator, designed to sweep the vessel walls and promote bulk flow, can improve the disperser's rheological limitation, but only to a certain extent. As viscosity climbs to around 500,000 cP and higher, such a multi-shaft mixer configuration — one that combines a disperser and an anchor — will ultimately begin to suffer, as a result of inadequate product turnover and uneven heating.

Manufacturers familiar with the above scenarios could learn from the battery industry, where many producers have standardized their operations using planetary dispersers for producing viscous, electrode pastes and similar materials with high solids content. These are hybrid mixers that deliver simultaneous planetary agitation and high-shear dispersion.

Planetary dispersers are highly efficient at incorporating large amounts of dry ingredients into a liquid, even if the fluid is thick or tacky to begin with. The most robust configuration of this style of mixer consists of two low-speed planetary stirrers, and two high-speed shafts, each equipped with multiple, saw-tooth disperser blades (Figure 1). All four agitators rotate on their own axes, while

FIGURE 2. The agitators in this 300-gal planetary disperser are lifted out of the vessel via a dual-post hydraulic lift, allowing complete access for cleaning and maintenance

revolving around the vessel. A more basic version, with just one planetary stirrer and one disperser, can be considered, as well.

Both sets of agitators are independently controlled, so flow patterns and shear rates can be fine-tuned as the product undergoes changes in rheology and other physical characteristics throughout the mixing cycle. In a planetary disperser, the concern of localized overheating is reduced to a large extent, because the sawtooth blades do not turn from a fixed location. Just as importantly, two other agitators are essentially "feeding" the dispersers with product from all other areas of the vessel. Polytetrafluoroethylene (PTFE) scrapers can be added for the sidewalls and tank bottom, as well, for even tighter temperature control.

Compared to double planetary mixers and sigma-blade mixers — which apply a lower-speed kneading action and thus rely on elevated viscosity in order to effectively disperse agglomerates — planetary dispersers deliver very high levels of shear over a wider viscosity range and are better

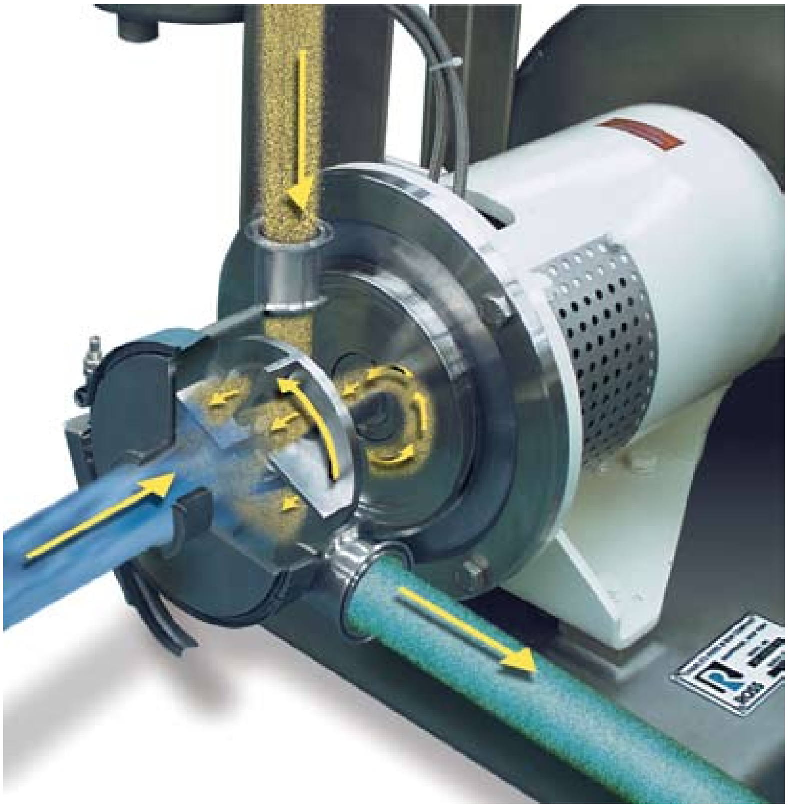

FIGURE 3. This illustration shows how a powder-induction mixer works. The liquid stream (blue) enters the mixer and immediately encounters the powder addition. Drawn by a powerful vacuum, free-flowing powders (yellow) are injected into the liquid and instantaneously mixed under high shear. The resulting dispersion (green) is expelled centrifugally through the stator openings at high velocity

able to accommodate extreme fluctuations in consistency.

Adding to their functionality and efficiency, the "change can" design of planetary dispersers allow the use of multiple vessels for semi-continuous production. Upon completion of a mix cycle, the agitators are lifted completely out of the finished product so the vessel can be wheeled away to a discharge station (Figure 2). Another vessel is then rolled into position under the mixer to immediately begin the next batch.

Case history snapshot 1. A manufacturer of structural adhesives was previously batching one of its formulations in open vessels equipped with high-speed dispersers. After mixing, the product required further processing in a three-roll mill, to achieve a 6 Hegman grind.[1]

Testing revealed that vacuum mixing in a planetary disperser produces a superior finished product, which no longer requires additional milling. The much-improved material turnover throughout the mixing cycle, coupled with vacuum conditions, consistently results in a final product with a 7–8 Hegman grind.

The company has since installed 40- and 100-gallon planetary dispersers with interchangeable vessels and accompanying discharge systems. The new production method is essentially a "one-pot" process, which is more streamlined and capable of significantly greater output in less time, compared to the former approach.

2. Powder-induction mixers. As many process engineers and operators can attest, poor-quality dispersions occur even when the application has a relatively low viscosity and is relatively easy to agitate. Stubborn agglomerates, "fish eyes" (that is, partially hydrated clumps of powder characterized by a tough outer layer that prevents the complete wetting of particles within the interior portion), and floating powders are a frustrating sight that can take several hours of mixing to remedy. Unfortunately, it does not take a large amount of solids to create this type of bottleneck.

Consider the case of fumed silica, carbomers, cellulose gum (CMC), starch, alginates, pectin, xanthan gum, carbon black and other hydrophobic or low-surface-energy solids. Dispersing powders like these into water, solvent, resin or other liquids is typically time- and energy-consuming. To aid wetting, chemical surfactants and dispersants are typically utilized, allowing manufacturers to continue relying on existing and legacy mixing equipment with reasonable success. However, the option to upgrade to a better method of powder dispersion should not be overlooked as an opportunity to sharpen competitive advantage.

Thanks to innovations in rotor-stator technology, sub-surface induction has become arguably the best technique for handling hard-to-disperse powders — provided the dispersion has a maximum viscosity no greater than 10,000 cP (Figure 4). Today's powder-induction mixers are capable of pumping liquid while simultaneously drawing powders and dispersing them into the fluid stream (Figure 3). After inducting all of the dry ingredients, the mixer continues to recirculate the product until the desired level of dispersion or dissolution has been achieved, usually in just a few tank turnovers.

When used in conjunction with, or in lieu of, top-entering agitators like propellers, turbines, paddles or anchors, a powder-induction mixer virtually eliminates the occurrence of floating powders, excessive dusting and

1. A Hegman grind gage is one method for determining the presence of coarse particles or agglomerates in a dispersion. The gage resembles a flat block of steel with grooves machined into it, decreasing in depth from one end of the block to the other. The Hegman scale ranges from 0 to 8, with numbers increasing as the particle size decreases. A value of 0 Hegman correlates to approximately 100 microns, while a value of 8 Hegman is equivalent to 0 microns.

FIGURE 4 (above). Combining this powder-induction mixer with a work bench eases material handling. This mobile system pumps liquid from a tank, while simultaneously drawing powders from a built-in hopper. The resulting mixture is pumped by the mixer back into the tank and recirculated until dispersion is complete

persistent fish eyes. Other processing advantages include greatly reduced mixing times, less rework and waste, and increased operator safety.

The design breakthrough of today's newer powder-induction mixers is particularly valuable because it has removed the need for eductors and auxiliary pumps. In earlier designs, solids were combined with the moving liquid stream in an eductor by means of the Venturi effect, and then mixed further down the line. These systems worked to some extent but were often temperamental and prone to clogging. They also required constant attention by an experienced operator in order to maintain a careful balance between the pump, eductor and mixer.

The latest iteration of the powder-induction mixer utilizes a modified rotor-stator that creates a powerful vacuum, which draws powders directly into the high-shear zone, where they are instantaneously dispersed into the liquid stream. In essence, the rotor-stator generator assumes all three functions of the pump, eductor and mixer in a compact machine that is simpler to use and far more reliable than the prior approach.

Case history snapshot 2. At a chemical plant, fumed silica dispersions were being made in a 4,000-gal tank equipped with a propeller agitator vessel and a rotor-stator mixer in the recirculation line. An oily liquid with surfactant was charged into the tank and heated to 110°F, followed by fumed silica powders, which were added slowly and deliberately, one bag at a time. The batch took several hours to complete, even with the recirculation mixer providing some level of shear.

By simply swapping its regular, inline rotor-stator mixer with a newer model capable of powder induction, the company was able to cut down the cycle time to under two hours, and reduce operator exposure to airborne particles. The powder-addition step is especially more convenient — operators no longer have to climb the mezzanine carrying bags of fumed silica.

3. Ultra-high shear rotor/stator mixers. Ultra-high-shear mixers are super-close-tolerance rotor-stator devices (Figure 5) designed for very high tip speeds (upwards of 11,000 ft/min, which is three to four times that of conventional rotor/stators). What makes them an essential innovation is their ability to produce very fine dispersions and emulsions, which previously could only be made in colloid mills, media mills and high-pressure homogenizers. Such machines are popular in certain industries, but are known for their notoriously low throughput, high energy consumption, costly maintenance and long downtimes.

Many of the companies currently using ultra-high-shear mixers have switched to this technology because of applications that require intense mixing, but

FIGURE 5 (below). Shown here are some examples of the rotor-stators used in modern ultra-high shear mixers. The combination of high tip speed and extremely close tolerances between the interlocking channels subjects the product to intense shear in a single pass. The gap between adjacent surfaces of the rotor and stator is adjustable, allowing operators to fine-tune shear levels and flowrates

actually tend to degrade when exposed to excessive shear. In other words, ultra-high-shear mixers offer a "sweet spot" of intensity necessary for particle- or droplet-size reduction beyond what regular single- and multi-stage rotor-stator mixers can deliver.

At the same time, they are not exact drop-in replacements for high-pressure homogenizers, but offer an alternative strategy for certain applications, including pharmaceutical, cosmetic and food emulsions, fine pigment dispersions, electronic inks and specialty coatings, to name a few. Manufacturers reap the advantages of lower equipment cost, significantly higher production capacity, faster changeover and easier maintenance. Sanitary models, which can be cleaned and sanitized in place, also make ultra-high shear mixers a very practical option for sensitive applications.

Case history snapshot 3. A pharmaceutical company uses several ultra-high-shear mixers to produce a topical emulsion made up of a slightly thickened aqueous phase and a smaller-quantity oil phase. The aqueous phase is charged into a recirculation vessel and the mixer is started up. Once the mixer has ramped up to the operating speed, the oil phase is added to the tank at a controlled rate, as the emulsion recirculates with the aid of a pump. Within minutes, a tight distribution with submicron median droplet size is achieved.

4. Vertical blender/dryers. When drying to very low moisture levels, conventional ovens and tray dryers are often left to run continuously for many hours, perhaps even overnight. Vacuum ovens and tray dryers offer better drying rates compared to their atmospheric counterparts, but agitated vacuum dryers can be even more efficient. In fact, combining mixing and drying in a single simultaneous operation may offer substantial improvements to production rate and energy consumption.

Recognizing the potential savings from lower operating costs and faster drying, more and more manufacturers throughout the CPI are upgrading to agitated vacuum dryers. One of the most reliable systems available is the vertical blender/dryer, which features a slow-turning auger screw and a conical vessel (Figure 6). The motion of the auger screw gently lifts materials upward and reintroduces them to the center of the batch. As it orbits around the vessel, the screw also nudges product near the top to cascade slowly back down. The combination of thorough mixing, deep vacuum and low horsepower makes the vertical blender an extremely efficient dryer. With a very low footprint requirement, the vertical blender/dryer is especially practical for large batch volumes up to 500 ft^3 or even larger, as long as the plant has enough ceiling height.

FIGURE 6. The agitator movement and material flow pattern shown here for a vertical blender-dryer provides favorable results for many applications. Product is heated through contact with the jacketed sidewalls. The vacuum-rated cover may also be jacketed to avoid condensation

As opposed to ovens and tray dryers where product is stationary and relies on convection for heat transfer, the materials inside a vertical blender are heated via conduction. The layer of product in direct contact with the heated sidewalls is constantly renewed, and under vacuum conditions, this continuous but gentle turnover of materials accelerates drying without affecting bulk density or generating an excessive amount of fines.

Another great benefit of the vertical blender is that it can accommodate a wide range of feed forms, from free-flowing powders and pellets to wet granules and paste-like materials. The low-impact blending mechanism also makes it well-suited for delicate, abrasive and high-purity applications.

One particular innovation that is an essential feature of the modern vertical blender is the fully top-supported screw agitator. With-

FIGURE 7. Vertical blenders are easily scalable and available in many standard sizes from 1 to 500 ft^3. Shown here is a 350-ft^3 model, with a cone height measuring 14.5 ft

out a bottom support bearing to get in the way, finished product is quickly and completely discharged out of the steeply angled conical vessel. The blender requires very little maintenance as there is no packing gland in the product zone, which also simplifies cleanup.

Among agitated dryers, the vertical blender is one of the most economical because of its low horsepower-to-volume ratio. For instance, it consumes up to 50% less power than a comparable ribbon blender. It is also the most flexible in terms of batch size. Given the geometry of the cone, the vertical blender can operate efficiently with batches as small as 10% of the maximum capacity, whereas a blender with a horizontal trough generally needs to be at least 30–40% full in order to mix properly. Furthermore, the vertical blender is not sensitive to the order of addition and positioning of raw materials (Figure 7).

Case history snapshot 4. A plastic manufacturer used to dry thermoplastic resin powders (reducing moisture from 35% to less than 1%) in a V-cone tumble blender and transfer them to trays for curing in an oven. The powders were then milled to disperse agglomerates that re-formed during curing. This three-step process took 24 hours to complete.

Simulation trials confirmed that the drying and curing stages could be done in a vacuum-rated, vertical blender/dryer. Temperature at each stage is easy to control and maintain accurately, while the constant agitation prevents agglomerates from forming, therefore eliminating the downstream milling step.

The company ultimately installed a vertical blender/dryer designed for 29.5 in. Hg vacuum and operating temperatures up to 500°F. Heating oil is circulated through a 100-psig stainless steel jacket around the vessel and cover.

Closing thoughts

Innovations in mixing and blending will continue to emerge as long as users and equipment manufacturers remain open to new and unconventional solutions. There is certainly room to grow considering the many processing objectives that mixing accomplishes throughout the CPI — from simple dissolution, suspension and particle-size reduction, to homogenization, emulsification, drying and a host of chemical reactions.

Mixing is a very application-specific operation that should be approached empirically, because the raw materials and their interactions under certain operating conditions affect mixing performance. Hence, the most successful mixing strategies are often those that were grounded on practical experience — and not just theoretical calculations. Process engineers, R&D scientists and managers are encouraged to take advantage of testing opportunities, whether through in-house trials using rental equipment, or spending a day or two at a mixing laboratory. By partnering with a reputable mixer manufacturer, companies from any field can leverage decades of industry experience to solve their operating issues and fuel their own innovations. ■

Edited by Suzanne Shelley

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