How to Specify the Right Multi-Agitator Mixer for Your Application

Multi-agitator mixers do more with less.

As competition in virtually all industries intensifies and becomes more global, all manufacturers must do more with less in order to remain competitive. On the process line, that means producing more product in faster mix cycles, with higher quality.

The drive to remain competitive also requires an ongoing effort to eliminate redundant pieces of equipment and combine separate process steps wherever possible. The new breed of multi-agitator mixers are ideal contenders to take on this challenge, because they offer an extraordinary level of efficiency. In fact, multi-shaft mixers often enable manufacturers to retire specialized pieces of equipment by combining multiple mixing steps into an integrated, multi-step cycle within one mix vessel.

Multi-agitator mixers truly offer remarkable versatility on the process line. With several independent agitators and a flexible control system, these mixers can readily switch gears to accommodate a fast-changing variety of products. While this presents an obvious advantage for contract manufacturers whose business is based on short campaigns and fast changeover, it can also be extremely advantageous for manufacturers who are simply looking for greater flexibility on the plant floor. Flexible process lines – capable of handling a diverse range of products – can make any plant more responsive to changes in market demand and other business pressures.

A “multi-agitator” mixer (sometimes called a “multi-shaft” mixer) is typically defined as a mixer with two or three agitators mounted on shafts that are stationary within the vessel. Unlike planetary mixers, the shafts in a “Multi-Agitator Mixer” turn on their own individual axes but do not orbit the vessel. This lack of orbital movement restricts the mixer to materials with a peak viscosity of approximately 500,000 centipoise (cps), but it also makes the mixer extremely cost-effective.

They also do more...with more!

Today's multi-shaft mixers are far more sophisticated than their predecessors of only a few years ago. Advances in agitator design, powder/liquid induction, heat transfer, and control design have made them even more capable and efficient. They are ideally suited to handle the current trend that we have observed toward more demanding product formulations. In our test center, working with hundreds of customers each year, we have seen a steady increase in formulations that involve higher peak viscosities, more precise solid/liquid additions, faster and more complex cycles, and tighter control over critical parameters such as shear and batch temperature.

Multi-agitator mixers enable you to operate two or three different agitators in an endless variety of functional combinations during the process of charging ingredients, mixing and discharging finished product. Typically, the agitators are independently controlled and each is powered by an electronic variable speed drive.

For applications that are simple, and for manufacturers who do not place a high priority on versatility, dual-shaft mixers are the least expensive choice for basic mixing. They usually combine a slow speed, low shear anchor agitator and a high-speed disperser that applies moderate shear.

The addition of a third agitator dramatically broadens the mixer's span of functionality. This advantage is especially pronounced when the third agitator is a rotor/stator high shear mixer, because its capabilities complement those of the high-speed disperser so well. Providing the ultimate in control over all the critical mixing functions – along with the ability to adapt to fast-changing process needs – the triple-shaft mixer generally proves to be a more cost-effective choice than the dual-shaft mixer over the long haul. In the remainder of this article, we will focus solely on triple-shaft mixers.

Three separately driven, individually controlled agitators

The best way to survey the process of specifying a multi-shaft mixer is to start by examining each agitator individually.

1. Three-Wing Anchor Agitator

Design & Operation – The anchor is a low-shear agitator that promotes gentle mixing and stimulates radial and axial flow. Running at peripheral speeds from 40 to 400 feet per minute[1]

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[1] Agitator speeds are best expressed in terms of their peripheral speeds (or "tip speeds"), as feet per minute rather than shaft rpm. Peripheral speed relates much more directly to the energy and shear we are actually applying to the batch. It also allows us to compensate easily for changes in the diameter of agitators.

(fpm), its functions are mainly to support efficient heat transfer and batch homogeneity, and to "feed" material to the high-shear agitators.

The anchor helps to disperse heat within the vessel by stimulating mass flow and constantly removing stagnant material from the tank walls and bottom, and pushing it toward the interior. Teflon® scrapers mounted on the agitator prevent an insulating layer from accumulating on the interior surface of the vessel.

The polished triangular section of the anchor shown in Photo 1 helps to direct flow toward the batch interior. Squared sections are much less efficient, and they often worsen cleaning problems between batches.

The basic anchor agitator generally features three horizontal arms and vertical flights, which may be fabricated with a triangular section to accentuate flow. But for applications that require enhanced top-to-bottom flow, a helical ribbon can be added. This is an excellent design strategy to promote axial flow and prevent stratification. Because the helical anchor stimulates downward flow with slow, gentle action, it also helps to accelerate the wetting out of powders without excessive aeration.

Application – In large batch sizes, and especially as viscosity rises, mass flow in a multi-shaft mixer almost always requires the action of an anchor agitator. Except at very low levels of viscosity, the high-speed agitators alone cannot stimulate enough flow to properly motivate the whole batch to achieve homogeneity. For this reason, the anchor in a multi-agitator mixer is virtually always running (though speeds may vary substantially).

Running alone, the anchor is particularly effective during cooling cycles. Providing slow agitation, it adds minimal energy into the batch. At the other end of the temperature scale, it is also used alone during the early stages of many processes – whenever solids need to be melted and brought up to an elevated temperature before other mixing functions can begin. Finally, capitalizing on the gentle action of this agitator, it is often used alone to safely disperse delicate ingredients, such a glass microspheres.

2. High Speed Disperser

Design & Operation – The High Speed Disperser applies moderate shear while it generates substantial flow and a vortex both above and below the blade. It can be configured with many different blade styles, which makes it flexible in application, simple to use, and easy to clean.

Working alone, a high-speed disperser easily handles viscosities up to about 50,000 cps. When used in combination with the anchor, its operating range extends to at least 500,000 cps.

Application – The High Speed Disperser is a simple and effective tool for mixing many materials. During the last few years, we have seen increasing demand across many industries for smaller particle sizes and more uniform particle size distributions, because an improved dispersion leads to a significant improvement in end-product quality. There will always be a place for the high-speed disperser, but in many industries this trend has contributed to a decline in its popularity as a stand-alone mixer.

In the multi-agitator mixer, however, the high-speed disperser plays a vital new role. Because its capabilities complement those of the high shear mixer, it often functions as a flow-generator, *pre*-mixer, and simple powder induction device.

One of the disperser's advantages is that it can disperse and reduce the size of solid materials that are too large for the rotor/stator mixer. Once these large chunks are broken apart by the high-speed disperser, they can be disintegrated by the high shear mixer.

Perhaps the high-speed disperser's most important advantage is that it creates a vortex above and below the blade, so it pulls material from both the top and bottom of the batch into the high shear zone. In some instances this provides a simple method to draw powders into the batch. However, this method can also create serious problems because the surface vortex also draws a great deal of air into the batch – which often necessitates a vacuum phase later in the cycle. New powder injection technology provides a far better method for introducing powders without undue aeration. Another alternative is to introduce powders with the surface vortex, but only after pulling vacuum in the vessel.

3. Rotor/Stator High Shear Mixer

Design & Operation **–** The high shear mixer uses a high-speed rotor/stator generator to apply intense mechanical and hydraulic shear. The four blades of the rotor run at peripheral speeds of 3,000 to 4,000 fpm within a fixed stator. As the blades rotate past each opening in the stator, they shear particles and droplets, expelling material at high velocity into the surrounding mass. As fast as material is expelled, more is drawn from beneath into the high shear zone of the rotor/stator, promoting continuous flow and fast droplet/particle size reduction.

Application: This mixer's intense shear works well to reduce droplet/particle size for homogenization, dissolution, solubilization, emulsification, grinding, and dispersion. Operating alone, the high shear mixer is most suitable for mixing materials with a maximum viscosity of 10,000 cps. Used in tandem with the anchor, it can handle viscosities up to approximately 200,000 cps.

In applications that require the rapid induction of powders, the rotor/stator mixer includes a solid/liquid injection manifold. With a specially modified rotor/stator design that generates a strong vacuum, the system draws solids through a feed tube and injects them directly into the high shear zone. Even hard-to-disperse solids such as fumed silica are dispersed instantly.

Interchangeable stators enable precise high shear agitator specification.

The specification of a batch rotor/stator generator is always a matter of balancing shear and flow. This is true whether it is a stand-alone mixer or a component of a multi-agitator mixer. Given a fixed energy input, larger holes in the stator permit greater flow, but apply less shear than smaller holes.

The **Large Square Hole Disintegrating Head** (A) is the preferred choice for applications that require extremely energetic flow. The **Disintegrating Head** (B) with large round holes works best for general purpose mixing. It generates vigorous flow, and rapidly reduces the size of large particles. The **Slotted Head** (C) provides the most popular combination of high shear and efficient flow rate. It is ideal for emulsions and medium-viscosity materials. The **Fine Screen Head** (D) provides the highest shear possible – at the expense of a slower flow rate. It is most suitable for low-viscosity emulsions and fine dispersions.

Key Variables in Multi-Agitator Mixing

Now, having reviewed the capabilities of the three individual agitators, we consider a wider perspective on multi-agitator mixing. A number of critical variables must be considered when specifying a mixer, including:

- the motivating force needed to generate adequate flow within the vessel;
- the peak viscosity anticipated during *each phase* of the mixing cycle;
- the level of shear required to accomplish essential mixing functions during the course of the mix cycle;
- the material's tolerance to heat and shear.

Although a systematic survey requires that we address these issues one by one, they are actually thoroughly intertwined. Heat is a consequence of applying intense shear. Flow/turnover is the result of energy input, agitator design and speed, viscosity, and the vessel's working capacity. Viscosity, in turn, can be influenced by batch temperature, shear and numerous other factors. It's impossible to consider one without also considering the others. Nevertheless, in everyday practice we do focus on each variable separately – as we assign *priorities* in performance and agitator selection and find the correct balance for each application.

Flow

All batch mixing requires a vigorous flow of material throughout the mixing vessel. Energetic flow helps to achieve complete batch turnover and a high level of top-to-bottom homogeneity as the batch material circulates through the high shear zones.

Flow also helps to disperse the heat created by the high-shear agitators. The build-up of concentrated heat near the high-shear agitators can threaten many materials, and vigorous flow helps to prevent thermal degradation.

At first, the importance of vigorous flow seems straightforward. Seen from a traditional point of view, flow simply carries heat away from the high shear agitators and prevents thermal damage. But, those who want to push the process envelope see the value of flow from a different perspective. Even a small improvement in flow and heat transfer capacity can be immensely important, because it may open an opportunity to apply greater shear. An increase in shear can often provide tremendous leverage – to shorten the mix cycle, increase the output efficiency of the mixer, and lower per-batch processing costs.

Viscosity

Viscosity and product density have always been important factors in multi-agitator design and operation. Today they are even more so. Virtually all industries today are trending toward higher viscosities in their mixing processes. Environmental regulations seeking to minimize discharge of volatile organic compounds (VOCs) have encouraged manufacturers to reduce or eliminate solvents from many products. This results in higher solids content – and increased viscosity. At the same time, many manufacturers are finding that their efforts to meet customer demand for improved product performance are also driving their formulations toward higher viscosities.

The result of this general trend is that multi-agitator mixers today should be optimized for operation near the high end of their viscosity range. Subtleties such as anchor profiles and sidewall/bottom scrapers are more important today than ever before. Drives must be specified with wide speed ranges to accommodate a broad range of working viscosities in the typical mix cycle.

Of course, viscosity greatly impacts flow, and it significantly influences the operation of all three agitators in the mixer. High viscosity and limited flow can restrict the speed and shear of the high shear agitators. For this reason we often modify the viscosity during the batch cycle in order to allow the application of greater shear without risk of heat degradation, then adjust viscosity near the end of the cycle to produce the final product. As we will see in the following sample application, we also watch viscosity carefully and operate the agitators in combinations that are appropriate for the current viscosity of the batch.

Shear

In most mixing operations these days, the rule of thumb is to apply as much shear as possible without overstressing the mix material with excessive shear or heat. This is usually the most direct way to accelerate the mix cycle. With energetic flow constantly driving fresh material into the high shear agitators and carrying away heat, we increase shear by:

- Increasing the speed of the high shear devices;
- Reducing the tolerances between the rotor and stator in the high shear mixer;
- Switching to a stator design that is more restrictive, which increases mechanical and hydraulic shear at the expense of decreasing flow.

In our test center the impact of increased shear is usually observed in any of these three ways, depending on the process goals of each customer: smaller particle/droplet sizes; more uniform particle size distribution; faster cycle.

In some circumstances, we may see only one or two of these improvements, yet they may still be valuable. For example, by adding a second disperser blade to a shaft we will certainly increase the energy that we are applying to the batch, but we will not increase shear meaningfully, and we will not affect particle size significantly in the batch. We *will* stimulate greater circulation in the vessel and perhaps allow a faster cycle time than would be possible with only one disperser blade. Often this benefit alone offers enormous value, because it represents an increase in per-batch production.

Triple-agitator operating combinations in a typical application

Multi-agitator mixers equipped with a high-speed disperser, high shear mixer and an anchor agitator have become extremely popular, because they provide great flexibility. The following test summary provides a step-by-step look at a typical multi-agitator application – and a good indication of the flexibility possible with this type of mixer. The product being mixed is a polymer dispersion.

Mixer Description –

- Triple-shaft mixer with a jacketed change can
- Anchor:
  - 55" diameter with Teflon scrapers
  - 20 HP drive, speed up to 36 rpm
- High speed disperser
  - 14" diameter Type 1 blade
  - 30 HP drive, speed up to 1,090 rpm
- Rotor/stator high shear mixer
  - 7" diameter with slotted stator
  - 30 HP drive, Teflon bushing, speed up to 1,800 rpm
  - Powder/liquid induction system
- Drives and controls:
  - Independently controlled
  - All 10:1 variable speed
  - Explosion-proof motors for hazardous environments
  - Temperature probe in vessel interior
- Auxiliary equipment: oil heat, chiller, vacuum

Phase 1 Mixing –

150 gallons of base liquid (oil) are added to the vessel, and the temperature is raised to 350^{o} F. With a 48 kW heating system, this will require approximately 60 minutes.

As the base liquid begins to warm, we immediately add chunks of solid rubber polymer and start the anchor at 25 rpm and the high-speed disperser (HSD) at 1,090 rpm.

Phase 2 Mixing –

45 minutes after the start of the mix cycle, the rubber polymer has been broken down sufficiently to start fine-grinding with the high shear mixer (HSM) at 1,800 rpm.

15 minutes later, the batch has reached target temperature and all three agitators are running. The HSM is now doing most of the high shear work; the HSD is mainly contributing to batch circulation. The anchor is constantly moving material from the vessel perimeter to the batch interior – where the two high shear devices pull it into their localized flow patterns.

Using the high speed induction system, we charge the vessel with dry solids and liquids:

- 100 lbs. fumed silica in approximately 5 minutes
- 25 lbs. carbon black in 15-30 seconds
- 20 gallons minor liquids in 15-30 seconds

To complete this mixing phase, we pull 29.5" Hg vacuum and deaerate for 10 minutes. In this case, with a batch material whose viscosity is strongly temperature dependent, deaeration is most efficient during this phase – before the product cools in the following phase of the cycle. Viscosity is now approximately 10,000 cps.

Phase 3 Cooling –

The first step in the cooling phase is to shut down the HSM and reduce the speed of the HSD to 110 rpm to minimize energy input. Meanwhile, the anchor runs at 20 rpm. The HSM will not run again in this cycle, for two reasons: we will not need to apply intense shear again; and with the batch temperature lowered by 180^{o} F, viscosity will rise to 100,000 cps – beyond the range of the HSM even with the added flow generated by the anchor and HSD.

Our target temperature is 200^{o} F. With a 20-ton chiller and a ΔT of 150^{o} F this will require 60 minutes in our jacketed change can.

When the batch has cooled, we add 50 lbs. of a fine polymer solid. Since the powder/liquid induction system is unavailable at this viscosity, we charge it directly to the batch surface, pull vacuum again to deaerate the powder, and rely on the vortex created by the HSD to draw the powder into the batch. To accomplish this, we accelerate the HSD to 1,090 rpm for 15 minutes.

Phase 4 Discharge –

Vacuum is released and the finished product is discharged through a flush tank valve, while the anchor turns at 10 rpm. Scrapers clean the vessel sidewall and bottom as the product level falls. When discharge is complete, the walls and bottom have been scraped clean.

Can a multi-agitator mixer make <u>your</u> plant more efficient?

How do you judge whether a multi-agitator can streamline your process line? There are many variables involved, and ultimately the best way to know for certain, is to test in a well-equipped laboratory, using your own ingredients, with analytical resources on hand to *quantify* the results.

But here are a few indicators that might suggest you should seriously consider the multi-agitator alternative:

1) **Transfers –** Are you transferring material from one mix vessel to another for sequential mixing operations? This is usually the first place to look for an opportunity to streamline the operation.

   In cases where materials are transferred from a reactor to a mixer, combining these process steps can be particularly beneficial if the material involved is moisture-sensitive or otherwise vulnerable to contamination during the transfer. The mix vessel can usually serve as a reactor, too.

2) **Pre-mixing and mixing –** More specifically, many manufacturers pre-mix with a high speed disperser, propeller or turbine, then transfer the pre-mixed material to another vessel for more intensive mixing. This time-wasting step can usually be eliminated – along with a lot of unnecessary handling, delay, and equipment costs – by completing the entire process in one multi-agitator mixer.

3) **Plans for future expansion –** If you are using a fixed-tank mixer now and you anticipate expansion, you should consider switching to a "change can" multi-agitator mixer to increase output and boost equipment utilization.

   Change cans are simply interchangeable vessels that are easily moved around the plant floor. By having four available, for example, they can all be in use simultaneously:

   - Can #1 is positioned at a charging station, where initial ingredients are measured and added prior to mixing.

- Can #2 is locked into position at the multi-agitator mixer, where the mix process is under way.
- Can #3 has been wheeled to a nearby location for discharge.
- Can #4 is being cleaned and prepared for the next cycle.

In this scenario, all four vessels – *and the mixer* – are in use almost continuously. This is extremely efficient, and the gain in production can be substantial.

4) **Plans for changes in product formulation –** If you believe that your process may soon change to accommodate updated formulations or new products, you should consider building more versatility into your operation. The exceptional versatility of the multi-agitator mixer can give you the flexibility to meet current process demands as well as the demands that you have not yet foreseen.