



The Art of High Shear Mixing

The high-shear rotor/stator mixer (HSM), once relegated to a relatively narrow niche of mixing applications, has become a mainstay in many applications in the chemical process industries (CPI). The ability to apply intense shear and shorten mixing cycles gives these mixers broad appeal for applications that require immiscible fluids to be formulated into emulsions, or agglomerated powders to be dispersed into a liquid medium. Especially during the last decade, the emergence of new variations on the original rotor/stator mixer concept has extended the HSM's usefulness to more diverse applications. For instance, conventional HSMs in both top-entering batch configurations and inline versions, are widely used today for high-intensity mixing, dispersion, disintegration, emulsification and homogenization.

Applications range from dispersions involving gums, pigments, fumed silica, calcium carbonate and active drugs, to emulsions such as cosmetic creams, lotions, and flavors. However, despite the growing popularity of HSMs in many industries, they are still widely misunderstood. Industry-based and university researchers have focused mainly on working out the dynamics of conventional low-shear mixing technologies, such as axial- and radial-flow turbines. With only a few notable exceptions, high-shear mixing has been largely overlooked in terms of fundamental research to unlock its mysteries and help users to better predict mixing outcomes, particularly during scale-up.

Since the body of literature available for predictive engineering related to rotor/stator mixing is extremely thin, the application of HSMs is often approached empirically — with heavy emphasis on application-specific testing and development by individual manufacturers in the process industries. A few users have invested heavily and achieved impressive success with HSMs in narrowly defined applications such as ones involving emulsion polymers and pigment dispersions. Others have been less successful on their

own. Most prospective users of HSMs rely on the recommendation of mixer manufacturers, who often keep their proprietary application guidelines a closely guarded secret. The result of this lack of available knowledge about high-shear mixing is that misconceptions regarding the proper application and use of HSMs have proliferated. There are numerous commonly held misconceptions and commonly made application errors. Readers who are able to avoid these errors will save time and money in their search for the best rotor/stator mixer, and reduce their risk of choosing a mixing system configuration that looks fine in the laboratory but fails to perform adequately on the plant floor.

Scaling up

In virtually any application, scale up is a critical process that impacts your business in a multitude of ways, from proper planning of plant floor design and equipment configuration, to operating procedures, to the net operating and capital-cost impact on the bottom line. In laboratory-scale trials, misjudging the time required to achieve mixing equilibrium by just a few seconds can ultimately cost your company millions of dollars, not to mention wasted time and effort and increased wear-and-tear on the equipment, during commercial-scale production.

The laboratory tabletop HSM usually represents the first step in exploring the particular benefits of rotor/stator technology for a given application. This familiar laboratory tool is generally equipped with a variety of interchangeable attachments that allow it to operate in a variety of mixing modes — as a conventional HSM, as a propeller mixer, and as a high speed “saw tooth” disperser. Such versatility is vital in bench-scale development, because it allows the research-and-development person to quickly test many diverse processing strategies.

However, as valuable as the lab scale mixer may be, it is also the source of one of the most common and costly mistakes in the scale up from laboratory- scale HSM to pilot-scale and production machines. Unless laboratory testing is conducted systematically and with great care and accuracy,

subtle errors in over-processing on the benchtop can produce enormous errors in scale up projections. Such errors are particularly common, because many engineers underestimate the lab-scale mixer's extraordinarily high throughput- to-product-volume ratio.

Before we move further, let's explore one more concept: equilibrium mixing results. For practical purposes, this is the point at which the mixed product has acquired a target characteristic — such as a specific droplet or particle-size distribution — that will not change significantly, no matter how long you continue to process the product. When we work with dispersions, this is the point at which we reach the equilibrium particle size. For emulsions, it's the equilibrium droplet size. Whether we are working with emulsions or dispersions, this much is certain: we will reach equilibrium much faster with a lab-scale mixer than with a scaled-up pilot or production unit. Depending upon the application and the rotor/stator design we use, we may reach this mark in one tank turnover or in several hundred-tank turnovers.

Now, consider this typical real-world scenario involving a test with a lab scale mixer. Take a two-liter beaker and add the following ingredients to prepare an emulsion:

- Water phase
- Oil phase
- Water- or oil-miscible surfactant

Now, lower the batch-type lab HSM into the liquid. But before you push the start button and head down the hall for another cup of coffee, consider this: That little 1-3/8-in. rotor/stator generator on your mixer may operate with a throughput of 100 liters per minute or more. With a 2-liter batch in the beaker, that translates to one complete batch turnover every 1.2 seconds. Presuming that in this application 10 tank-turnovers produce the desired emulsion (a plausible number for many simple emulsions), this means that you may reach mixing equilibrium in just 12.0 seconds!

In the real world, this is where human nature takes over. As you go for coffee, you keep the tabletop batch going for five minutes, and when you check the results you find that

the droplet size distribution of your emulsion is right where you want it to be. A success! But what really happened? You processed the batch for five minutes, turned the batch over 250 times, and reached the right endpoint. But your product did not change once it had reached its mixing equilibrium in just 12 seconds — so the remaining four minutes and 48 seconds produced no appreciable change in the mixed product. That's the margin by which you actually overshot your mixing equilibrium. In a lab-scale example, over processing by four minutes and 48 seconds may not seem like a big deal — but consider the implications in terms of productivity, energy costs, labor, and wear and tear when such an error is propagated during scale up to a larger pilot- or production-scale unit.

Now, fast-forward to your scale up requirements using the above example. Consider that you will need to produce this product in 500-gallon batches. If you assume that you will need 250 tank turnovers to accomplish your process goals (instead of 10, which is really all you need), then you will select a top-entering, batch HSM that will process 125,000 gallons through its rotor/stator generator in an acceptable period of time. Drawing from experience, we assume that a 30-hp unit with a 7-in.-dia. rotor will pump roughly 500 gal/ min. Therefore, our 250 tank turnovers (125,000 gallons) will require 250 minutes (4 hours, 10 minutes). This projects to a capacity of roughly two batches per 8-hour shift, or 10 per single-shift week. If, at the lab scale, we had better understood that the process goal was reached in just 12 seconds (10 turnovers), we could have projected that the same production unit would complete the task in about 10 minutes. This projects to roughly 240 batches per week — an increase of 230 batches per week.

Batch versus inline mixing

The emergence of an inline HSM represented a profound step in the evolution of high-shear rotor/stator mixing technology. The innovation was a breakthrough, but the essential concept was simple: First, take the same rotor/stator generator that works in the top entering batch HSM and install it in a housing with inlet and outlet connections. Next, drive the rotor through a shaft seal and you have a rotor/stator mixer that behaves like a centrifugal pumping device. The inline HSM offers many benefits.

Because the inline mixer is positioned in a flowing stream, the mixing process is more closely controlled than in a batch configuration, so the number of passes through the high-shear zone can be monitored with greater confidence. Solid and liquid additions can also be injected into the flow and dispersed with well-understood results. Inline HSMs also provide practical solutions for real-world problems on the plant floor. For tanks that are already equipped with low-shear, gentle-mixing agitators, for example, the use of an inline HSM lets operators add a high-shear mixer without disturbing pre-existing equipment. The inline mixer can simply be positioned on the floor alongside the tank. Batch materials can be tapped from the tank for processing through the high-shear rotor/stator generator, and then returned to the vessel.

This configuration eliminates all the difficulties of trying to squeeze a top-entering mixer into the vessel along with pre-existing mixers, baffles and other obstacles. It allows the plant engineer to forget about headroom issues that sometimes arise when long shafted batch HSMs are retrofitted to existing tanks. It also simplifies maintenance, since the inline HSM doesn't need to be removed from the tank for periodic maintenance. The appeal of the inline alternative is strong, but how do we translate a batch mixing process to an inline equivalent? Starting with our earlier example involving the 30-hp batch HSM with a 7-in.-dia. rotor, your first impulse might be to swap it for a 30-hp inline HSM with a 7-in.-dia. rotor. This is a presumption that many process engineers make every day, but it overlooks an essential difference between batch and inline HSMs.

Unlike the batch HSM, whose discharge is restricted only by the fluid surrounding the rotor/stator, the discharge of an inline HSM is severely restricted by the mixing chamber, the pressure drop from the outlet connection, and all other downstream sources of pressure drop. To understand the magnitude of the flow reduction in the inline HSM, consider a 30-hp batch HSM with a 7-in.-dia. rotor that produces a throughput of roughly 500 gal/min in a low-viscosity liquid. An inline HSM driven with equal horsepower will pump less than 250 gal/min. Adding long piping lengths, elbows, valves and other restrictions will lower the throughput even further. So, how does the limited flow of the inline HSM affect scale up? Consider the 30-hp batch HSM mounted in a 1,000-gal. tank.

In our hypothetical application, the process requires 10 tank turnovers, so it will require 20 minutes to reach our process goal. On the other hand, the 30-hp inline HSM, servicing the same 1,000-gal. vessel will take 40 minutes — twice the processing time. Over a year — or even just a week of single-shift processing — the accumulated impact of this disparity will become enormous and can easily make the difference between profitable and unprofitable production.

If an inline mixing solution is necessary (that is, if a batch solution is simply impractical with your current equipment, available space or throughput requirements), you will need to consider a substantially larger inline unit to duplicate the processing capacity of the batch unit. In this case, to match the batch mixer's 500-gal. Flow rate, you would have to step up from the 30-hp inline mixer to a 50- hp inline unit equipped with a 11-in. rotor/stator generator.

The essential principle to remember here is that an inline rotor/stator mixer is not a drop-in replacement for a batch mixer of equivalent horsepower. You will have to compromise on throughput or invest in a more substantial inline mixer. The correct choice will depend on your business and processing priorities in each application. You should also consider whether a switch to an inline configuration will provide additional advantages of value in your application — such as the ability to inject hard to- disperse powders into your batch using the same inline mixer.

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