Scale up of High Shear Rotor-Stator Mixers

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 bench top 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 pause to 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

First, 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”. 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.
For our purposes in this article, we are focusing on the target average droplet or particle size. With additional processing, this will not change significantly. However, additional processing (sometimes called over processing) will generally affect the particle or droplet size distribution, which can be an important parameter in many applications “

Tank turnover” refers to the process of subjecting one complete batch of material to a specific mixing action. In a batch process, this is almost always a theoretical approximation based on mixer flow rate and vessel capacity. Actual results conform to a normalized, Gaussian distribution. A true batch tank turnover, in which the entire batch is literally subjected to exactly one high-shear event, occurs only when the batch material is piped from one vessel, through the mixer, into a second vessel.

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.