Five Ways to More Energy-Efficient Mixing

ROSS

A White Paper Prepared By Charles Ross & Son Company

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Abstract

This white paper explores five ways to increase energy efficiency in new and existing mixing processes.

The ideas discussed in this paper are recommendations based on Ross' collective experience as a provider of specialty mixing equipment to the process industries for over 170 years. Mixer testing and simulation trials are recommended to confirm the suitability of a specific mixing strategy.

Introduction

A well-specified mixing system is essential to fulfilling overall energy efficiency in a production facility. Ideally, mixing equipment and procedures are evaluated periodically or at least as often as production needs change and when new products or raw materials are introduced. Yet, perhaps because it is perceived as a simple operation constituting only a minor percentage of total manufacturing costs, mixing is seldom upgraded until it becomes a source of drastic losses due to low yield, recurring contamination or inconsistent product quality. The five points outlined in this white paper can help manufacturers resolve or avoid these inefficiencies while decreasing energy consumption.

This paper also offers some ideas to optimize existing processes that may not necessarily be problematic but stand to gain tremendous improvement. By challenging current practices and exploring new approaches to different mixing objectives, companies can increase their competitive advantage and uncover a huge potential to boost energy efficiency along the way.

1. Select the right mixer.

In some ways, mixer selection has become more complicated over the years with the development of mixing technologies that have overlapping functions and uses. Today, most applications can actually be successfully produced in more than one distinct type of mixer. In plants that already have an elaborate mixing system in place, new products are often processed in such a way that suits the available equipment. The desired end product results are achieved but, in more than a few cases, at the cost of energy efficiency.

Take the case of hot-melt adhesives, thermal compounds, reinforced plastics, industrial sealants and other viscous compounds typically prepared in either Multi-Shaft Mixers, Double Planetary Mixers or Horizontal Kneaders, in order of increasing working viscosity. All three machines offer a unique set of advantages yet have intersecting capabilities. To illustrate, let us look at each mixer design in closer detail.

Multi-Shaft Mixers consist of two or more independently-driven agitators working in tandem. Viscous products are batched in heavy-duty Multi-Shaft Mixers which, for instance, may include two high-speed disperser blades and a low-speed anchor sweep. Such a configuration requires three motors, one for each agitator shaft. Multi-agitator systems are operationally versatile and can handle a wide range of viscosities up to several hundred thousand centipoise. Their versatility mainly results from independently-controlled drives: the agitators can be engaged in any combination and at any speed for any interval during the mixing cycle.

But when the product goes through viscosity peaks over a million centipoise, there is a strong tendency for the motors to overload. Some manufacturers solve this issue by over-engineering the drives and using larger horsepower motors, effectively diminishing the mixer's energy efficiency. As the batch becomes too sticky or too heavy to flow freely, agitation close to the axes of rotation becomes limited, even more so around the edges of the batch. The anchor may start carving a path through the highly viscous material instead of turning it over. Operators will then usually resort to stopping the agitators several times during the batch cycle to open up the mixer and manually move pieces of material that have stagnated in certain areas of the vessel and blades. Another coping strategy being done is the gradual addition of raw materials, particularly solids, in smaller amounts and over more increments to allow the mixer to "catch-up", further exacerbating the overly long mix time.

Triple-Shaft Mixer

In the manufacture of barely flowable compounds, a better alternative is to use a mixing system with agitators that move through all the points in the batch, instead of rotating from a fixed axis or in a sense *waiting* for new material to come around.


Double Planetary Mixers with High Viscosity Blades (left) and classic Rectangular Blades (right).

The Double Planetary Mixer consists of two identical blades that rotate on their own axes while orbiting on a common axis. The agitators continually advance into the batch and contact fresh product all the time. Raw materials are thoroughly mixed regardless of large differences in density or viscosity. This type of mixer is a relatively low speed device; it relies on a product's high viscosity to impart shear as the blades move through the batch, pushing materials against the vessel surfaces and between the blades. In addition to its rugged processing capabilities, the Double Planetary Mixer requires only one motor to drive both blades. Hence, it is not uncommon for manufacturers switching from an over-designed Multi-Shaft Mixer to the proper Double Planetary Mixer to reap significant savings in energy consumption while also reducing their cycle time and labor costs.

At the end of the spectrum of high viscosity mixing equipment are Sigma Blade Mixers composed of two z-shaped blades mounted on a horizontal trough and designed to rotate toward each other at different speeds. The blades pass the trough walls and each other at close clearances, providing a shearing and tearing action on the product as it is moved in opposite directions. The Sigma Blade Mixer has been an industry standard for many years and though its design has not changed much in the last few decades, it remains to be the most powerful high viscosity mixing equipment available in the market. However, with the introduction of heavy-duty Double Planetary Mixers with more efficient agitators, such as the helical High Viscosity Blades (US Patent No. 6,652,137) which can handle peaks as high as 6 million centipoise, manufacturers are encouraged to reevaluate their mixing methodologies. For several reasons, it is worth investigating if a process that used to rely on horizontal sigma blade mixing can be transferred to a vertical Double Planetary Mixer with platen-style discharge system. Not all applications can be moved across to the newer technology, but those that can are usually improved on many levels. Typical benefits include significantly lower capital cost, reduced energy consumption, faster cleaning and easier maintenance.

PowerMix Planetary Disperser   Planetary Dual Disperser

High speed dispersion in a planetary mixer

In addition to the mixer choices enumerated in the previous discussion, there are new "hybrid" mixers that combine the thorough kneading action of a planetary mixer with the high speed mixing power of a saw-tooth disperser. The Ross PowerMix Planetary Disperser is one such mixer design. It utilizes two motors to drive a planetary stirrer and a disperser shaft at different speeds, which makes it a more complex machine compared to a traditional Double Planetary Mixer.

Unlike a Multi-Shaft Mixer wherein the disperser rotates from a fixed axis, the high speed blade(s) in a PowerMix moves around the vessel and contacts fresh product all the time. As a result, it has the ability to impart high levels shear over a wider viscosity range: from water-like to around 2 million centipoise. Each agitator is controlled independently allowing the operator to fine-tune flow patterns and shear rates at any point during the mixing cycle. Most PowerMix applications are highly-filled compounds requiring ultra-fine dispersion quality. For very demanding formulations, a Ross Planetary Dual Disperser with two stirrer blades and two disperser shafts delivers even greater processing power. This machine operates within the same viscosity range as a PowerMix but the combined mixing intensity of all four agitators enables more rapid incorporation of large amounts of solids into an already viscous starting liquid. It is driven by two motors, one for each speed range.

2. Re-evaluate your batch size as production expands.

Rising product demand eventually necessitates an adjustment in batch size. However, many process engineers answer the call for greater capacity by simply adding more mixers identical to the ones they already have. This strategy increases production but may fail to capture economies of scale. With every square foot of floor space occupied by numerous small mixers, the associated labor and maintenance costs also go up when they really don't need to if only a larger mixer is used instead.

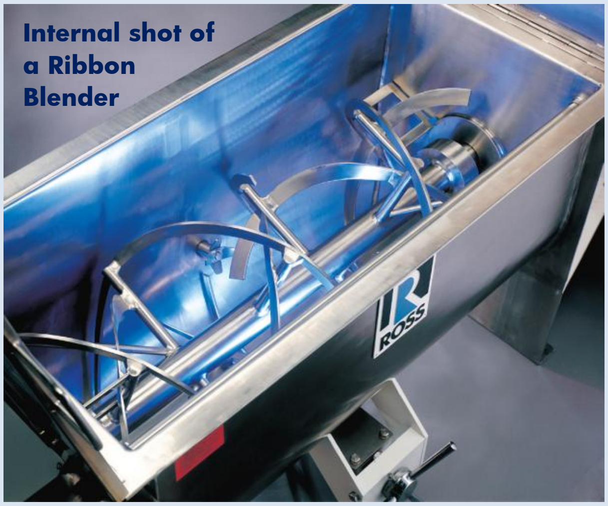
At the same time, it is important to note that too large a batch size can be just as disadvantageous as having multiple under-sized mixers. Ultimately, it is a management decision to define the best balance between batch volume and frequency, number of mixers, set-up and changeover costs, inventory levels, and other related factors. In some cases, the solution might be to utilize different size mixers that can offer processing flexibility and allow for more nimble production.

Another strategy is to consider semi-continuous mixing. For example, many mixing systems up to 500-gallon capacities can be supplied in a "change-can" design. Using interchangeable multiple vessels with a single mixer, one mix can could be at the loading stage, another under the mixer, another at the discharge step and yet another at the clean-up stage. This arrangement maximizes both machine and labor utilization.


100-gallon Dual-Shaft Mixer and Discharge System with two interchangeable mix vessels.

Mixing Tip:

Take into account that as mixers increase in size, power per unit volume can often decrease. When scaling up from a laboratory or pilot process to a larger geometrically similar mixer, make allowances for a longer mixing time to compensate for the lower energy density. A good starting point is to take a ratio of the power per unit volume of the two mixers and use that to estimate a new mixing time. Establishing an optimal cycle time for a scaled-up process can normally be fine-tuned through trial-and-error testing.



Application Snapshot

A fast-growing food manufacturing company specializing in flavor systems is reaping the rewards of strategic equipment selection as their offerings and customer base continue to expand. At each stage in the company's growth, it acquired different size Ross Ribbon Blenders to serve distinct production goals as well as higher-level business goals. This has allowed the production team to achieve steady improvements in efficiency and quality control while increasing capacity.

Below is an excerpt of an interview with the company's VP of Operations:

We use ribbon blenders to mix many of our flavor concentrates. As the company grew, the production team recognized that with order sizes ranging from 500 lbs to more than 20,000 lbs we could improve process efficiency with a combination of equipment scaled to accommodate specific batch sizes, material densities, and production runs. Meanwhile, the management team set priorities geared to bring more and more process functions in-house. As the company became more vertically integrated, we gained great control over quality and consistency, while we lowered costs and sharpened our competitive edge.

We got down to the specifics of design and sizing to optimize for our most important batch sizes. In all cases, we were looking for blenders made with Type 316 stainless steel throughout, engineered and polished for easy maintenance, fast discharge and quick cleaning between batches. Our first step was to optimize production for mid-sized batches of 500 lbs or so. That required a 25-cu.ft. blender. Next, we optimized for smaller batches in short, fast runs – which we handled with a 10-cu.ft. blender and an 18-cu.ft. blender. In each case, by matching our blenders to key batch sizes and densities, we improved our equipment utilization and accelerated the changeover process. That enabled us to deliver even faster.

Finally, with the company growing quickly to keep up with customer demand, we optimized for large batches of 5,000 lbs with a 120-cu.ft. blender and that's where we really saw a huge gain. Compared with contracting large batches to an outside processor, we saved thousands of dollars in freight alone with every batch. Even more important, we gained complete control over batch-to-batch quality and consistency.

Source: *Processing Magazine*, 2008. "Maximizing Comax's Sweetness"

3. Take control of your mixer controls.

The control system of your mixer plays an important role in optimizing energy consumption. More than just an interface between operator and machine, a well-specified control system also contributes to more consistent product quality, shorter changeover periods and lesser room for operator errors.

The pros and cons of getting simple or sophisticated process controls will be unique to each process. At the minimum, most users benefit from having a Variable Frequency Drive (VFD) for soft-start capability and overload protection. A VFD helps to lessen electrical demand by allowing the motor to gradually ramp up to speed thus reducing current peaks during start-up. Mechanical stress is also reduced in a system where the agitator gently rotates when started. While an electronic soft-starter offers the same advantage, it limits mixer operation at a fixed speed. In applications where varying mixer speed is necessary – in order to fine-tune flow pattern, shear level, throughput or temperature rise – electronic speed control via a simple VFD is an economical solution. In a sanitary or hazardous environment, the VFD(s) for a mixer's agitator(s) may be installed within an appropriate control panel for increased protection. Control panels improve operator friendliness and safety by centralizing all electrical components and enabling single-point power hook-up as well as emergency stopping.

With more elaborate operations, consider your options for PLC control to integrate data acquisition, mix time, agitator speeds, temperature, batch weight, vacuum/pressure level and other parameters into any recipe. When possible, source controls from the same mixing equipment supplier to ensure seamless execution of the project, from design all the way to production, installation and start-up. Adding controls to your mixer order ensures your equipment will be production-ready immediately upon set-up.

4. Simplify raw material additions.

Batch mixing time is influenced by a number of factors which may include solubility, ease of dispersion, extent of particle size reduction or emulsification, heating/cooling rates, etc. In large scale operations, the method of raw material addition becomes another critical variable. For example, when a good portion of the raw materials are solids that need to be dispersed or dissolved into liquid, charging them from the top of the batch can be complicated if they tend to dust or float on the liquid surface. Some powders, such as gums and thickeners, form tough agglomerates when added too quickly, even when the batch is being agitated vigorously. This forces operators to deal with very slow powder additions. In extreme cases, efficiency is further compromised when solid raw materials are added deliberately fast and in overdose amounts so that undispersed agglomerates are simply filtered out after the mixing cycle. In addition to increased energy consumption due to the additional filtration step, unnecessary waste is produced and the process becomes more prone to batch-to-batch inconsistencies.

A relatively large batch mixing operation that involves solids dispersion or dissolution into a flowable liquid will typically benefit from an inline powder injection system. Technologies such as the Ross Solids/Liquid Injection Manifold (SLIM) resemble an external mixer piped to a tank similar to a pump installed in a recirculation loop. Solids are injected into the recirculating liquid stream right within the high shear zone of the rotor/stator mix chamber. Based on user experiences, this method of powder addition routinely cuts cycle times by 80% or more.

At the heart of the SLIM process is a unique rotor/stator designed to generate a powerful vacuum that draws powders into the mix chamber and simultaneously disperse them into liquid. The resulting mixture is expelled through the slots of the stator at high velocity. When used with a large tank or reactor stirred by a slow speed agitator, the inline SLIM delivers sufficient shear for reducing particle size and, in the case of gums and thickeners, prevents lumps or “fish eyes” from forming in the first place. The rapid product turnover via recirculation through the high speed rotor/stator mixer also helps to keep solids suspended in the batch so they can dissolve faster or simply maintain a uniform dispersion.

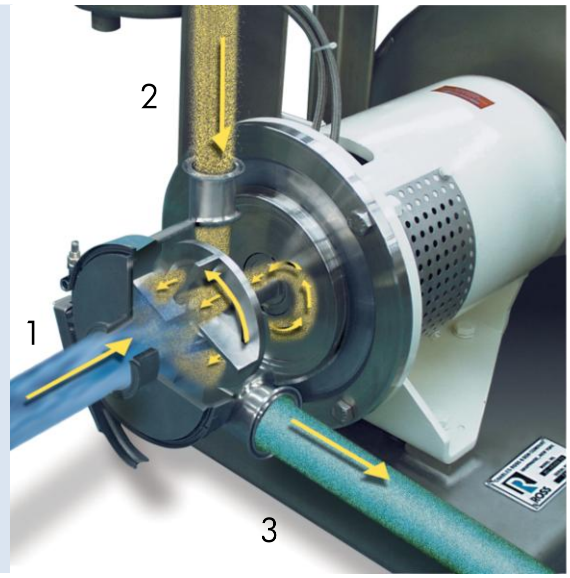
Handling lightweight powders through the SLIM is advantageous as it eliminates dust-generating transfer steps. A hose & wand device may be attached to the powder inlet of the SLIM to allow the operator to simply draw powders straight from the original sack or container. Powders that are easier to handle may be fed through a hopper. This can be done manually or through automatic feeding equipment.

After the mixing cycle, the inline SLIM can be used to pump the finished mixture downstream to the next equipment or storage vessel.

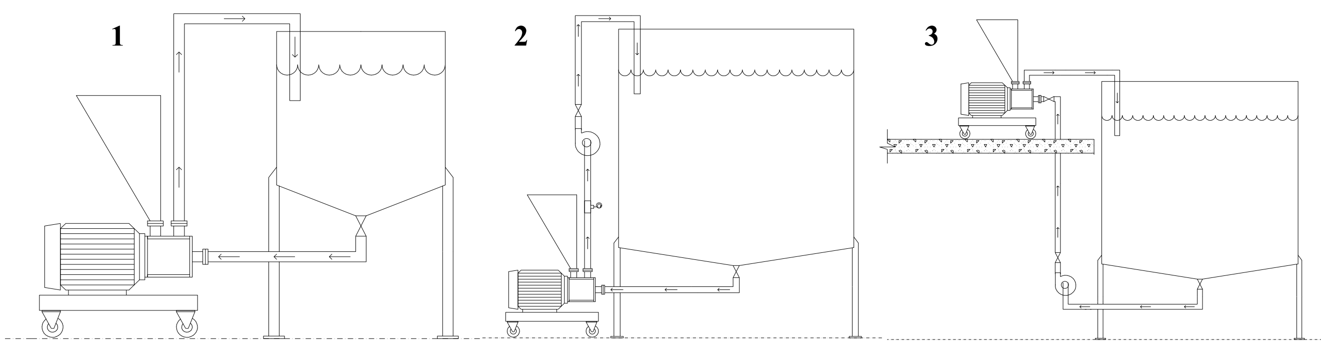
ANATOMY OF A POWDER INDUCTION MIXER

The liquid stream (1) enters the inline SLIM Mixer and immediately encounters the powder injection (2) at the high shear zone of the rotor/stator assembly. The resulting dispersion (3) is expelled centrifugally through the stator openings at high velocity.

After injecting the solid components of a recipe, the SLIM may also be used to deliver liquid additions.



TYPICAL INLINE SLIM INSTALLATIONS



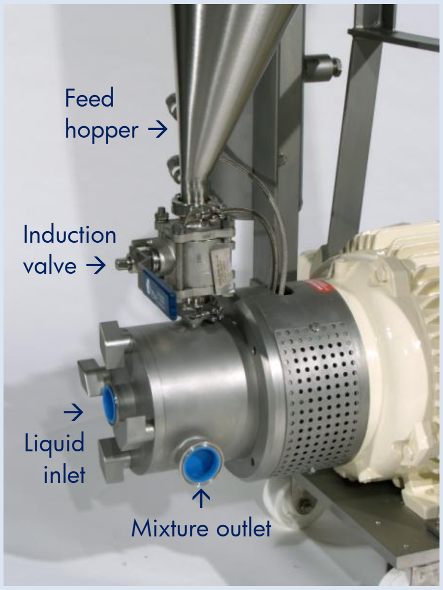
Scenario #1 describes the inline SLIM system being used with a small to medium size (50 – 1000 gallon) recirculation vessel. The mixer is located on ground level and is as close to the outlet of the tank as possible. Discharge tubing is kept to the minimum possible length.

Scenario #2 describes the inline SLIM being used with a large (1000+ gallon) recirculation vessel. Since the discharge tubing is long, a centrifugal pump is used to minimize backpressure on the discharge side.

In Scenario #3, the mixer is located on an elevated mezzanine or upper level floor. The inline SLIM is not self-priming; a centrifugal pump is used to help feed the inlet side.

Application Snapshot

A cosmetic manufacturer was looking to optimize cycle time in their two 500-gallon and two 1000-gallon vessels, each equipped with turbine impellers for turning over a low-viscosity slurry. The source of the bottleneck was a side mixing step carried out in individual 55-gallon drums to disperse calcium stearate powders into glycerin using a sawtooth disperser. Operators had to lift the drums to the top of a mezzanine and manually charge the calcium stearate dispersion into the agitated batch.



Testing done on a 25HP inline SLIM Mixer confirmed that this technology can rapidly disperse the powders right into the main tanks and also improve operator safety. A portable SLIM unit was then installed to serve all four tanks. Calcium stearate powders are now pre-weighed and loaded into the SLIM's feed hopper at floor level; the mixer is turned on to recirculate the process liquid and the operator simply opens the hopper valve to start injecting powders directly into the liquid stream. After a few turnovers, all the solids are completely dispersed. The SLIM mixer is easily disconnected from the recirculation piping and wheeled to another tank to perform the same service.

By eliminating the drum mixing step, the company was able to drastically reduce total mixing and cleaning time from hours to minutes.

5. Consolidate mixing processes.

Examine your production flow and determine if any upstream and downstream mixing operations can be performed in a single piece of equipment. One major benefit to "one-pot processing" is the reduction of energy consumption though many other incentives are equally justifiable including faster throughput, easier clean-up, less transfer steps and lower operating cost.

The below table summarizes just a few examples of distinct mixing processes successfully consolidated in a single mixer.

Process 1	**Process 2**	**Consolidated Process**
Pre-polymer preparation in a conventional gently-stirred reactor.	Dispersion of fillers, plasticizers, thixotropes and other additives into the liquid pre-polymer in a high speed mixer under vacuum.	Pre-polymer preparation and mixing of finish product in a vacuum-rated Multi-Shaft Mixer/Reactor.
Preparation of a highly-filled epoxy formulation in a Double Planetary Mixer, finished with a let-down step to lower viscosity.	Additional mixing using a high speed saw-tooth disperser to provide the extra shear needed for completion.	Batching and dispersion of epoxy product in a PowerMix Planetary Disperser.
Wetting out of pigments in a batch tank equipped with a saw-tooth disperser.	Milling of pigment-resin premix in a media mill for four hours to achieve an "off-the-gauge" dispersion.	Powder wet-out and particle size reduction in a single vessel. The same end point is achieved by a PreMax Ultra-High Shear Mixer in 30 minutes total mix time.
Preparation of a medical gel material in a bench-top chilled glass reactor.	Blending of active ingredient (granular solid) into the sterile gel in a single planetary mixer.	Gel preparation and thorough mixing of active ingredient in a laboratory-size Sanitary Double Planetary Mixer.
Mixing of cocoa powder, milk powder, whey and stabilizer into a cream base in a 750-gallon tank fitted with a custom-made agitator (mixing is deliberately slowed down due to excessive foaming).	Process 1 is performed three times to fill a downstream 2000-gallon tank equipped with a side-entering agitator to finish the mixture.	Charging of powders directly to the 2000-gallon utilizing an inline Solids/Liquid Injection Manifold (SLIM) Mixer and product recirculation until mixing is complete.

Conclusion

In many manufacturing plants across the process industries, mixing is unfortunately commonly overlooked in terms of efficiency. It is not too difficult to find “something that works”. Yet, as we have illustrated in this paper, there may be several ways to achieve an end product but not all are energy efficient or offer a competitive advantage.

The good news is that, in any plant or industry, a careful evaluation of mixing procedures can reveal achievable steps to potentially reduce not only energy consumption but also waste generation, labor cost, cleaning time and maintenance.

It is important to consider that mixing results are almost always *formulation-dependent* in one way or another. Partner with a reliable mixer supplier offering rental and testing resources to help validate a new mixing strategy or technology with empirical data derived from the use of your own raw materials.