Solutions to Batch Mixing Issues

A White Paper Prepared By

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Solutions to Batch Mixing Issues

Abstract

Inefficiencies in batch mixing operations manifest themselves in a number of ways such as long cycle times, frequent reworks, defects or low product quality, difficulties in maintaining temperature, losses in raw material or finished product, and intensive clean-up, to name a few.

This white paper presents some strategies for improving commonly encountered batch mixing problems. Because mixing processes vary from one application to another – with different objectives, design configurations, rheologies, operating limitations, etc. – there are no fix-all solutions that will apply to every situation. A particular type of agitator or level of mixing intensity may be beneficial to one formulation but detrimental to another product. The ideas discussed in this paper are recommendations of Ross mixing experts based on the company's collective experience as a mixing equipment provider to the process industries for over 169 years. Mixer testing and simulation trials are encouraged to confirm the suitability of a specific mixing strategy.

Introduction

Mixing, like any other unit operation, should be viewed as an evolving technology. Many mixing processes in place today were designed decades ago, a time when process efficiency was not considered as important as it is in the current competitive market. Settling on a "norm" that takes time but works can put a business at risk of losing customers to competition that follow an updated and more profitable manufacturing process. The ability or failure to mix efficiently and economically can profoundly influence the growth or decline of a product line.

The good news is that improving the mixing operation does not necessarily have to involve huge costs or a complete process overhaul. Simple upgrades and practical techniques can bring better mixing performance within reach. The following discussion explores ways to improve a number of batch mixing practices. Some of these procedures involve small changes to the mixing method or minor equipment upgrades, while others entail a shift to an altogether new mixer design.

Simplify, simplify

It is quite common for batch production set-ups to consist of a large tank equipped with a slow-moving impeller serving as the main mixing vessel to which raw materials and intermediate components are added. Intermediates are batched in side tanks which may be equipped with high shear, high speed devices such as rotor/stators or saw-tooth disperser blades.

If cycle times and batch-to-batch variability are an issue, see if the overall mixing process can be simplified. In certain applications, the appropriate mixer system makes it possible to combine several operations and eliminate transfer steps of intermediates.

For relatively flowable products (approximately ≤ 20,000 cP), install an inline high shear rotor/stator mixer that will take product from the bottom of the main tank and recirculate it back into the vessel. By providing supplemental shear and agitation to a gently-stirred batch tank, an inline rotor/stator can significantly reduce cycle time. Depending on the formulation, the enhanced turbulent mixing may also allow some raw materials to be added directly into the main vessel instead of being prepared in separate intermediate batching tanks. Testing is recommended to confirm that the process can be modified without affecting end product quality.

The inline rotor/stator mixer is often a practical solution to apply in large-scale batch processes since it is easily installed without the need to disturb pre-existing equipment. It is also versatile – with appropriate piping, a single inline mixer can serve multiple batch tanks of various sizes. Simple valves can be utilized to conveniently divert the finished mixture downstream or instantly switch from our source vessel to another.

Accelerate and improve powder dispersion

When large amount of powders are involved, especially those that are difficult to wet out completely, a mixer with sub-surface powder induction capabilities is extremely worth considering.

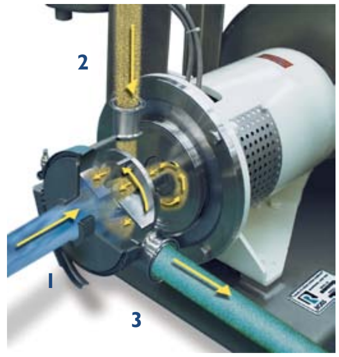
In earlier powder induction systems, a pump would propel the liquid stream into an eductor, creating a vacuum. Powders fed through an overhead tube would be drawn by this vacuum into the eductor where it joined the liquid flow. The resulting ‘pre-mix’ moved on to a rotor/stator mixer which then applied shear and mixing action, breaking down agglomerates and transporting the mixture downstream.

In its day, this system offered a useful tool for powder induction. The inline system eliminated the floating solids problem of batch systems, and it offered a more precise control over the mixing process. But this set-up also presented some serious limitations. With three separate devices in series, maintenance — in terms of labor, required expertise and spare parts — was intensive. Balancing the performance of the pump, eductor and mixer was often difficult, and in many applications, downtime was quite high.

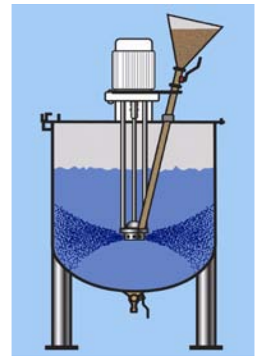
Today's inline rotor/stator mixers with integral powder induction capability are more ideal. These new generation high shear mixers no longer require the use of centrifugal pumps or eductors to create the suction for powder injection. These systems are much more tolerant to flow and viscosity changes, easier to operate and simpler to maintain.

Certain batch rotor/stator designs also offer this functionality, enabling powders to be added subsurface without having to seal the tank and pull vacuum on the batch using a vacuum pump.

Combining liquids and powders right at the region where intense mixing takes place reduces the formation of agglomerates and fish eyes, and also eliminates the occurrence of floating powders.



The liquid stream (1) enters the mixer and immediately encounters the powder addition. Drawn by a powerful vacuum generated by the ported rotor, powders (2) are injected directly into the high shear zone and dispersed instantaneously. The resulting mixture (3) is expelled centrifugally through the stator openings at high velocity.



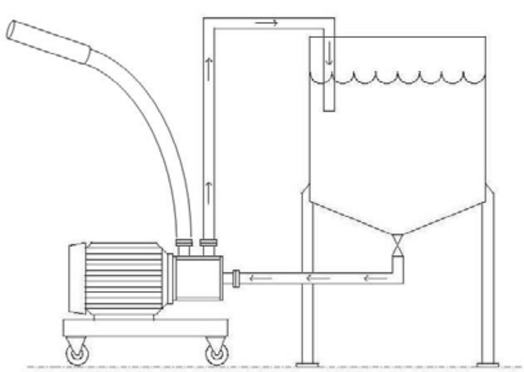
In this batch mixer configuration, powders are loaded into a hopper. As soon as the rotor reaches operating speed, the hopper valve is opened and the solids are quickly drawn into the batch via the vacuum generated by the rotor.

Leave the dust behind

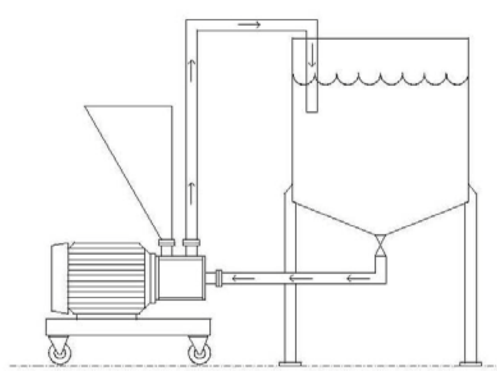
Another batch mixing issue is dusting, which is a nuisance from a housekeeping and operator health standpoint but can be an even more immediate danger if the powders pose an explosion-risk. Dusting can be resolved by a powder induction system.

Powders may be drawn from out of a bag or container using a flexible wand connected to the solids inlet port. This technique is particularly useful when the powders are relatively lightweight and free-flowing. Another method is to transfer powders into a hopper directly above the mix chamber. This configuration facilitates the highest rates of powder induction.

Flexible Hose & Wand Attachment



Hopper Attachment



Control foaming and air entrapment

In many applications, foaming is an unavoidable side-effect of mixing, shearing and powder incorporation. The higher the agitator speed, the better the mixing; however this also produces a greater amount of foam and entrains more air into the product. Excessive foam generation can interfere with the mixing operation by artificially raising batch volume, causing prolonged cycle time, difficult handling, reduced productivity, product loss and extensive clean-up. Entrapped air that remains in the finished mixture can cause structural problems, clouding, discoloration, voids, instability and other undesired qualities depending on the product and end use.

The presence of surfactants causes or exacerbates foaming but they often play a number of essential functions in the formulation and so are typically indispensable. To combat this issue chemically, defoamers are added to the batch. Defoamers or anti-foam agents serve to prevent and destroy foam. Different applications require different levels and types or combinations of defoamers. Unfortunately, these additives are often costly and, in some products, they are considered to be contaminants.

One way to reduce dependence on chemical defoamers is to apply modifications to the mixing operation. When using a top-entering agitator to add powders into a foamy liquid, position the mixer blade off-center to decrease the vortex. Reducing the size of the vortex will minimize foaming and reduce the amount of air incorporated into the batch. If practical, replace or supplement a top-entering agitator with an inline mixer piped for recirculation. The return line must extend below the liquid surface to help prevent foam generation.

When trying to reduce air entrapment, the first impulse of many operators is to reduce agitator speed. But often this technique is counter-productive because it also reduces the rate of batch turnover and the level of shear provided by the agitator, which may be necessary to complete a good quality batch within a reasonable amount of time. Processing under vacuum is a better solution. Vacuum mixing allows full-speed agitator operation without entraining air.

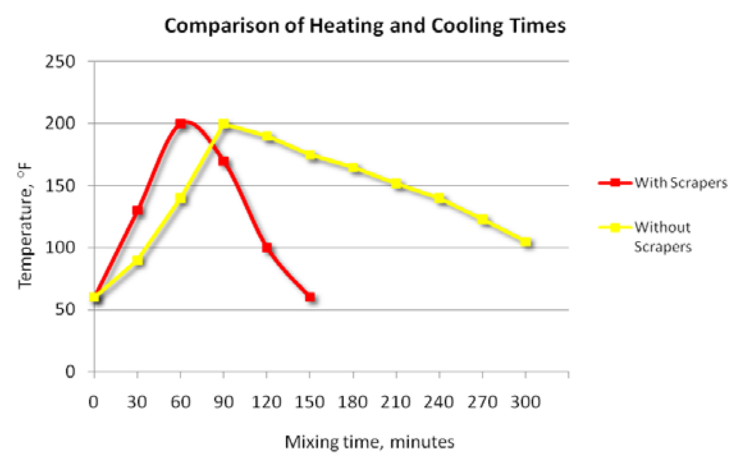
Aside from removing air in the mixture, vacuum enables certain applications, such as adhesives and sealants, to develop higher densities or possess better tensile properties as a result of improved shearing and contact of the different components. In food applications, keeping entrapped air to the minimum ensures longer life and more lasting flavors. Pulling vacuum during mixing also eliminates costly downstream de-aeration steps and reduces processing time.

Bench-top saw-tooth disperser suitable for vacuum operation and equipped with interchangeable mix vessels.

Can you handle the heat?

If a batch takes too long to heat up or cool down, a number of variables may be at play: insufficient bulk flow within the vessel, low jacket surface area to product volume ratio, inadequate flow of heating/cooling fluid or poor jacket design.

To combat insufficient bulk flow, a wide-sweeping anchor agitator may be employed to gently stir the batch. The addition of wall and bottom scrapers mounted on the anchor to remove batch materials off the vessel surfaces is important as well. Scrapers make a world of difference in mixing applications that require precise and responsive temperature control, especially during cooling cycles.



In the above graph, the plotted data show a 33% reduction in heating time for a gel material when scrapers were installed on the anchor agitator. Meanwhile, a greater improvement was seen in the cooling cycle which was reduced by approximately 60%. The disparity between heating and cooling rates can be explained by the normal tendency of most materials to decrease in viscosity when heated and to increase in viscosity when cooled. During the heating cycle, the jacket is hot, which drops the viscosity of the layer of product adhering to the vessel wall. At low viscosity, materials on the wall and those from the center of the batch readily exchange. During the cooling cycle, the jacket is cool which increases the viscosity of materials near the vessel surfaces. An insulating layer is created and this impedes heat exchange between the jacket and the bulk of the product.

Mix cans should be jacketed along the sidewall and the bottom. Large vessels especially stand to benefit from multi-zone baffled jackets which improve heat transfer rate by creating a higher temperature gradient. Vessels with dished or hemispherical bottoms are chosen for critical processes because they have a higher surface area to volume ratio and transfer heat better compared to flat-bottomed tanks.

Invest in an efficient temperature control system with both heating and cooling capabilities. To properly size an oil or water circulation system, your vendor will need a complete picture of your process (initial/final temperatures, target cycle times, specific heat of materials being mixed, batch size, mix vessel dimensions, etc.).

Multi-shaft mixer with heating unit installed on a mobile bench.

Manual scrape-downs

Between material additions or whenever practical, perform a scrape-down. Open the mixer and manually scrape any un-wetted powders clinging to the shaft(s) and areas of the vessel above the product level. This practice seems to be counter-intuitive – stopping to scrape down lengthens the mixing cycle after all. True. However, waiting for those powders to be incorporated into the batch without intervention could take much longer. In some applications, a portion of the solid component(s) would tend to remain above the product level despite prolonged mixing and this can affect composition and properties of the end product. Incorporating even just one or two manual scrape-downs into your mixing procedure could improve product quality and consistency.

Upward migration of viscous materials

The batching of moderate to high viscosity compounds requires a robust multi-shaft mixer or a planetary mixer design. In either mixer configuration, certain materials have a propensity to climb out of the mixing zone by riding up the shafts or blades. This characteristic migration of batch material reduces mixing efficiency, necessitates intensive clean-up and can even increase contamination risks.

The high speed disperser shaft on this dual-shaft mixer is equipped with a slinger. Helical flights added to the three-wing anchor agitator help improve top-to-bottom mixing.

The tendency of some viscoelastic fluids to flow in a direction perpendicular to the direction of shear is called the Weissenberg Effect. To address this issue in a multi-shaft mixer, a slinger is mounted on each high speed shaft to prevent materials from climbing any higher than the batch level.

Meanwhile, in traditional double planetary mixers, rectangular-shaped paddles move and mix viscous batch material by rotating on their own axes while they orbit on a common axis. Product migration is seen on certain products that tend to climb up the rectangular stirrers and enter the gearbox area.

Newer design helical blades prevent the climbing issue experienced with traditional rectangular stirrers. High Viscosity “HV” blades (US Patent No. 6,652,137) offered on Ross Double Planetary Mixers feature a precisely angled helical contour which generates a unique vertical mixing action: the sweeping curve firmly pushes the batch material forward and *downward,* keeping it within the vessel at all times.

Aside from rectangular blades, a scraper arm can also encourage product migration in a planetary mixer. Many applications which are too viscous to process in a mixer with fixed agitators but are capably handled in a planetary mixer behave in such a manner that any material sticking to the wall usually tends to fold over and return to the batch solely by the planetary stirring action.

Quite commonly, when a scraper arm is affixed to the planetary gearbox, it collects materials from the vessel wall and causes them to build up above the product level where the planetary blades cannot reincorporate them back into the batch. There are non-sticky applications however which do benefit from scrapers to promote thorough mixing and uniform batch temperature. Aside from these cases, not using scrapers is typically advantageous in a planetary mixer.

A good rule of thumb is to utilize scrapers for low to medium viscosity applications, especially when heating and/or cooling accompany the mixing cycle. Viscous products made on planetary mixers must be tested to determine if mixing can be completed successfully without scrapers.

Double planetary mixer with patented helical High Viscosity "HV" blades.

Consider ultra-high shear mixing

For dispersion, deagglomeration and emulsification processes requiring extremely fine particle or droplet sizes, conventional high shear rotor/stator mixers that run at tip speeds around 3,000-4,000 fpm can still fall short in delivering the desired distribution. The next viable alternatives worth investigating are ultra-high shear mixers which run up to 11,000 fpm or higher.

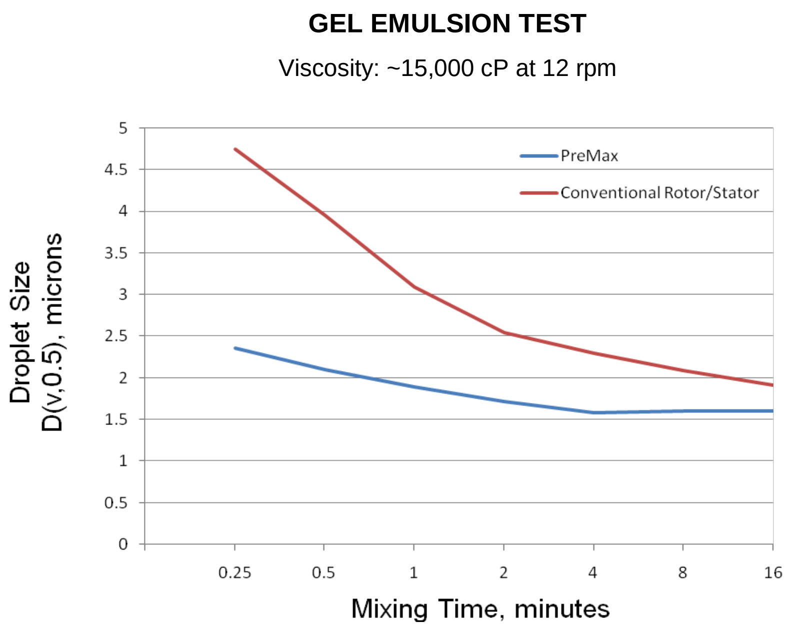
Aside from higher tip speeds, another major difference is the rotor/stator design. The same concept applies – a high speed rotor runs within a close tolerance stator – but in ultra-high shear mixers, the clearances are even tighter and the flow patterns generated are more complex and turbulent. The combination of these factors results in finer particle sizes, more stable emulsions and highly uniform distributions.

One such ultra-high shear device is the PreMax, a batch mixer equipped with a high-flow rotor/stator designed to run at tips speeds in the range of 5,000 ft/min. The PreMax is capable of drawing material from above and below the mixing head. This promotes higher turnover rates and enables the mixer to quickly incorporate powders or films from the liquid surface right into the high shear zone.

In the production of paints, inks and coatings, the PreMax can produce results comparable to one or two passes through a media mill. This reduces the number of mill passes required to achieve the final product particle size, and in some applications, eliminates milling entirely.

In side-by-side tests, the PreMax has also been shown to produce low-viscosity and high-viscosity emulsions much faster than a traditional rotor/stator mixer. In some formulations, including cosmetic gels and creams, the average droplet size was smaller in the samples prepared in the PreMax.

PreMax Batch Ultra-High Shear Mixer with "Delta" rotor/stator (US Patent No. 6,000,840) capable of tip speeds up to 5,000 fpm.



Comparison of droplet size reduction performance. The above graph shows droplet size curves for a cosmetic gel emulsion prepared on a conventional high shear rotor/stator mixer and on the PreMax ultra-high shear mixer.

More aggressive ultra-high shear mixers are available in inline (continuous) configurations. These are the Ross Series 700 mixers with interchangeable rotor/stators namely X-Series, QuadSlot and MegaShear (see box on page 10 for detailed descriptions of each design). In many applications, these inline ultra-high shear mixers can effectively replace high pressure homogenizers and colloid mills. Manufacturers that find this to be true for their particular formulations welcome the change because high pressure homogenizers and colloid mills are expensive, high maintenance machines; with every product changeover, the clean-up procedure is very labor-intensive. The Series 700 mixers are easy to clean and disinfect in place. Based on user experiences, the shorter cleaning time equates not only to a faster changeover procedure but also to longer intervals between cleaning cycles (longer production runs). Another important advantage is that the throughput rates of a similarly-powered ultra-high shear mixer are far greater when compared to a high pressure homogenizer or colloid mill.

Proven applications include battery compounds, electronic inks, composites and other formulations dosed with micro- or nano-sized fillers, pigments or additives. In a typical set-up, a batch mixer is used to combine the raw materials and the resulting slurry or paste is then passed through the inline ultra-high shear mixer. More challenging formulations require multiple passes and due to the intense energy imparted to the product, temperature must be closely monitored. Like a regular rotor/stator mixer, an X-Series, QuadSlot or MegaShear mixer behaves like a centrifugal pumping device. It is not self-priming and requires static pressure (gravity-feeding) or positive pressure (pump-feeding) to introduce materials into the mix chamber. With an auxiliary pump, it can process products up to 200,000 cP.

Inline Ultra-High Shear Mixers

X-Series

The X-Series head (US Patent No. 5,632,596) consists of concentric rows of intermeshing teeth. The product enters at the center of the stator and moves outward through radial channels in the rotor/stator teeth. The combination of extremely close tolerances and very high tip speeds (11,300 fpm or higher) subjects the product to intense shear in every pass through the rotor/stator. The gap between adjacent surfaces of the rotor and stator are adjustable from 0.010" to 0.180" for fine-tuning shear levels and flow rates.

QuadSlot

The QuadSlot mixing head is a multi-stage rotor/stator with a fixed clearance. It produces higher pumping rates and requires higher horsepower compared to a similar size X-Series rotor/stator set.

MegaShear

The MegaShear head (US Patent No. 6,241,472) operates at the same tip speed as the X-Series and QuadSlot heads, but is even more aggressive in terms of shear and throughput levels. It consists of parallel semi-cylindrical grooves in the rotor and stator towards which product is forced by high velocity pumping vanes. Different streams are induced within the grooves and collide at high frequency before exiting the mix chamber.

Conclusion

The solutions presented in this paper are aimed at maximizing the efficiency of batch mixing systems while reducing costs. If the opportunity is present, try out your own formulation on several mixer configurations and experiment with different methods and order of ingredient addition, discharge, heating, vacuum, etc. Gathering the necessary technical and financial information with the help of a reliable mixer manufacturer will point you to the right solution.