High Viscosity Mixer Designs and Applications

ROSS

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Abstract

Efficient mixing of viscous applications takes into consideration, among many other factors, viscosity and level of shear. It is common for batch materials to exhibit fluctuating rheology during different stages of mixing and demand varying shear intensity depending on ingredient additions or temperature limits. The appropriate mixing equipment must therefore have the ability to control flow pattern and fine tune shear input at any point of the mix cycle. Achieving this basic requirement is more straightforward in some applications than others, but even the complex ones can now be processed at better efficiencies due to new developments in high viscosity mixer designs.

The mixing equipment and applications discussed in this paper are based on the collective experience of Ross mixing experts. For over 150 years, Ross has partnered with thousands of companies making high viscosity products for almost all uses and applications. The aim of this paper is to provide a brief compilation of technical and practical information on high viscosity mixing and how specific process needs can be successfully met through the efficient use of specialty mixing equipment.

Introduction

Anyone who has worked with materials over 100,000 cP knows that viscosity by and in itself presents a distinct mixing challenge. These products require sufficient torque and thorough agitation to achieve a homogenous state. In reality, this requirement is often compounded by other constraints such as the presence of shear- or heat-sensitive raw materials, hard-to-disperse fibers, powders that form tough agglomerates, fragile or abrasive components, highly volatile solvents, or batch material that is very sticky, dense, dilatant, etc. The suitable mixing system must typically tackle one or more of these issues in addition to the underlying rheology factor.

The complete spectrum of high viscosity mixers available to today's manufacturers vary widely in terms of mixing mechanism, agitator style, energy consumption, cost, etc. Some of these technologies are comparatively new and offer several advantages over older mixer designs which may be deemed as "standard equipment" for certain specific applications. At the same time, a number of these classic mixers remain to be the best at what they are known to do but have evolved and incorporated new features for improved efficiency, cleanability, maintenance, etc.
From a business perspective, knowing which advances in mixing technology apply to your own process is a great opportunity for upgrading production lines, solving recurring problems, or increasing production with a quick return on investment and improved mechanical reliability.

Multi-Shaft Mixers

Multi-shaft mixers consist of two or more independently driven agitators working in tandem. A low-speed anchor complements one or two high-shear devices, such as a saw-tooth disperser blade or a rotor/stator mixer. Let's examine each agitator design in detail.

On its own, an open-style saw-tooth disc blade will produce acceptable flow patterns for products up to around 50,000 centipoise (cP). Running at tip speeds around 5,000 ft/min, the saw-tooth disperser creates vigorous flow within the mix vessel and imparts greater shear compared to other open-blade mixing devices such as propellers or turbines. It generates a vortex into which solids can be added for quick incorporation into the batch.

On the other hand, a rotor/stator mixer typically features a four-blade rotor running at tip speeds in the range of 3,000-4,000 ft/min within a close tolerance fixed stator. This type of device creates mechanical and hydraulic shear by continuously drawing product components into the rotor and expelling them radially through the openings in the stator. Due to the differential speed and close tolerance between the rotor and stator, this mixer offers higher shear but less pumping capacity than the open-disc saw-tooth disperser blade. By itself, a batch rotor/stator mixer can handle viscosities from water-like to around 10,000-20,000 cP.

Thus, for the processing of high viscosity mixtures, there is an obvious need for a supplementary agitator to improve bulk flow and deliver viscous product to the high-shear device(s). The addition of an anchor agitator allows a multi-shaft mixer to process formulations that are several hundred thousand centipoise.

The most common low-speed anchor designs have two or three wings. For added efficiency –especially in terms of axial flow – the anchor can be modified to feature helical flights in between adjacent wings, or the vertical wings can be entirely replaced with helical ribbons supported from the top and bottom. The anchor provides a means for agitating product near the vessel surface. Its horizontal and vertical wings are designed to run at close proximity to the vessel walls. This, in itself, helps to constantly remove product from the sidewalls and bottom so that fresh material can fill those areas. However, the use of scrapers, which actually contact the vessel surfaces, significantly increases heat transfer efficiency, especially in cooling operations. Only in certain cases are scrapers not used in a multi-shaft mixer, such as when the product being handled is abrasive – hard, sharp particles can imbed in the scrapers and may cause aggressive wear on the vessel surfaces.

Aside from the improved capability of multi-shaft mixers over single-shaft devices from a viscosity and heat transfer standpoint, another design advantage is that they are closed systems and can offer benefits in vacuum mixing. When processed under vacuum, certain applications such as adhesives and sealants develop higher densities and achieve better tensile properties as a result of improved shearing and contact of the different components. With other formulations, like food and pharmaceuticals, vacuum mixing keeps entrapped oxygen to a minimum, which ensures longer shelf life and improved stability. Mixing under vacuum also eliminates unwanted air voids that can be produced through agitation under atmospheric conditions. Pulling vacuum during mixing eliminates costly downstream de-aeration steps and shaves overall processing time.

One of the primary decisions in the selection of a multi-shaft mixer is the agitator combination that will best serve a specific process. Below are some common configurations and sample applications.

Dual-Shaft Mixer Equipped with Two-Wing Anchor and Disperser

Dual-shaft mixers are used for straightforward dispersion requirements. It is the most economical multi-shaft mixer configuration. The saw-tooth disperser blade enables fast powder wet-out and dispersion, while the two-wing anchor supplies a steady exchange of materials from different parts of the vessel, essentially "feeding" the high-speed blade.

Applications range from cosmetic dispersions to hot-melt adhesives, peanut butter, RTV silicon compounds and carbon black slurries, to semiconductor encapsulants, paints and coatings.

Dual-Shaft Mixer Equipped with Three-Wing Anchor and Disperser

This configuration is typically more customizable than the previous mixer style. For instance, provisions can be made for the future addition of a third agitator. The three-wing anchor is also better able to accommodate helical flights than a two-wing anchor.

Shown on the right photo is a 100-gallon Dual-Shaft Mixer. A thermocouple is mounted through the cover for accurate measurement of product temperature at the center of the batch; an additional thermowell can be installed on the vessel sidewall too. The hydraulic air/oil lift of this change-can design mixer allows complete operator access to the agitators and batch material. Safety limit switches and proximity sensors prevent the operation of the drives when the stirrers are in the raised position or when the vessel is removed from the mixing position. Larger capacities (>750 gallons) are typically built as fixed-tank designs.

Application Snapshot

This Ross Dual-Shaft Mixer is used to prepare acrylic coatings and polyurethane sealants for roofing systems. The anchor features helical flights in between the wings which produce better top-to-bottom mixing. Vacuum is pulled during mixing to fully deaerate the mixture. After the mix cycle, the vessel is rolled out of the mixer and moved under a heavy-duty discharge system. The platen-style hydraulic discharge system improves speed, efficiency and cleanliness of the discharge operation. As the platen is lowered hydraulically into the vessel, a specially-fitted O-ring rides against the wall, literally wiping it clean. Product is forced out through a valve in the bottom of the vessel, or through the top of the platen. The discharge system eliminates wasted hours of scraping heavy or sticky materials off the mix vessel.

Dual- or Triple-Shaft Mixer Equipped with Three-Wing Anchor and Multiple Disperser Blades

In this configuration, the disperser shaft is equipped with two blades: the bottom blade is fixed at the lowest point of the shaft, and the other blade (of equal or smaller diameter) is usually adjustable along the length of the shaft. This supplementary upper blade helps create a more powerful vortex to quickly draw large amounts of solid ingredients into the liquid phase. It is typically positioned one blade diameter below the liquid surface.

For a more demanding process, a second disperser shaft may be added; thus, the mixer can use a total of four disperser blades. Proven applications include greases and lubricants, food sauces, plastisols, candy syrup, ceramic slurries, epoxy-based adhesives and cement pastes.

Triple-Shaft Mixer Equipped with Three-Wing Anchor, Disperser and Rotor/Stator

This configuration is popular in the processing of formulations wherein droplet size or particle size distribution is critical. Using a high speed saw-tooth blade to incorporate powders into liquid results in acceptable levels of dispersion, but applying a more shear-intensive device such as a rotor/stator mixer typically achieves a finer and more uniform particle size distribution. The same holds true for formulations involving two or more immiscible liquids; a high-shear rotor/stator achieves a more stable emulsion due to the formation of smaller droplets.

Sample applications include printing ink and other pigment dispersions, battery slurries, cosmetic creams, ointments, pureed foods, gum dispersions and rubber solutions. The rotor/stator mixer assembly is very effective at disintegrating solid pieces of polymer and accelerating dissolution processes.

Dual-Shaft Mixer Equipped with Three-Wing Anchor and Rotor/Stator

Emulsion adhesives, thickened solutions and other intermediates with low solids content are commonly batched in this dual-shaft mixer configuration. A candidate formulation may be one that could be processed using a stand-alone rotor/stator but would benefit from improved temperature control or processing under vacuum. The impact could be as dramatic as cutting processing time in half, especially if a cooling cycle is involved.

When processing solids that tend to form tough agglomerates or "fish eyes" upon contact with liquid, consider a rotor/stator mixer equipped for sub-surface powder induction. This simplifies material handling and eliminates issues of floating powders and dusting in the plant atmosphere. The Solids/Liquid Injection Manifold (SLIM) available on Ross high shear rotor/stator mixers offers this functionality. The SLIM technology utilizes a ported rotor and stator specially designed to generate a powerful vacuum that draws powders right into the high shear zone within the stator.

Application Snapshot

A manufacturer of specialty chemicals was looking for a better way of preparing their fumed silica dispersions. They were using a Triple-Shaft Mixer equipped with a sweep agitator, a sawtooth disperser and an auger blade. The process took several hours to finish, dispersion quality was inconsistent and dusting was a major issue.

A visit to the Ross Test & Development Center confirmed that this was a fitting application for the Ross Triple-Shaft Mixer with SLIM Technology. In a matter of minutes, the modified rotor/stator inducted fumed silica into the starting low viscosity liquid. Independent control of the saw-tooth disperser and three-wing anchor allowed the operator to fine-tune flow patterns and shear levels as viscosity climbed with each material addition. Total process time was cut by more than 50% and virtually no dusting was generated.

A SLIM system has two modes of powder addition: by hopper attachment (bottom left photo) or by a hose & wand attachment (bottom right photo). In the first method, powders are loaded into the hopper and as soon as the rotor reaches operating speed, the hopper valve is opened to allow the flow of solids into the shear-intense region within the rotor/stator assembly. Powders are quickly drawn into the batch via the powerful vacuum generated by the ported rotor. Alternatively, attaching a hose & wand device to the powder inlet of the SLIM allows the operator to simply draw powders straight from within the bulk container. This second method is recommended for free-flowing, lightweight powders. Talc, calcium carbonate, titanium dioxide, carbon black, carboxymethyl cellulose (CMC), clay, flour, starches, gums, pectin and resins are materials commonly inducted through the SLIM system.

Mixers operating with multiple agitators are exceptionally versatile, but they still have limitations in their range of viscosity. 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. Although this sounds complex, multi-shaft mixers are actually engineered to be comparatively simple, effective and economical.

When the batch material becomes too viscous to flow freely to the agitators, shifting to a different style of mixer is recommended. For example, as agitation close to the axis of rotation becomes limited, the anchor in a multi-shaft mixer may start carving a path through the highly viscous material instead of turning over. In these situations, the logical design alternative is a system consisting of agitators that move through all the points in the batch. This is the forte of planetary-style mixers and kneaders.

Planetary Mixers

As viscosities reach 500,000 cP or higher, planetary-style mixers perform better than agitators with a fixed axis of rotation. In a planetary mixer, two or more blades 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. The classic double planetary mixer (DPM) is a relatively low speed device; it relies on a product's viscosity to impart shear as two identical blades move through the batch and push materials against the vessel surfaces and between the blades. Depending on the blade configuration, a DPM can handle viscosities up to 8 million cP.

Newer planetary mixer designs feature one or two stirrer blades (similar to those in a DPM) supplemented by one or two high speed disperser shafts which also revolve on their own axes while orbiting the mix vessel. These "hybrid" planetary mixers are ideal for processing viscous (~2 million cP), highly-filled applications requiring ultra-fine dispersion quality.

The following section covers three planetary mixer configurations and the high viscosity applications for which they are typically used.

Double Planetary Mixer with Rectangular Stirrers

For many years, rectangular paddle-shaped stirrers were the "standard" blade design for double planetary mixers. These blades mix with a powerful kneading action and are capable of processing viscosities as low as 50,000 cP, but work most efficiently at higher levels. As the viscosity of a heavy paste approaches 2 million cP, shear in the batch increases steadily, agglomerates disintegrate and average particle size drops quickly. For this reason, operators often artificially raise the viscosity of a batch to accelerate dispersion and mixing and then let it down to the desired final viscosity. Common applications include battery pastes, caulking compounds, syntactic foams, silicone rubbers, pharmaceutical gels, food products, solder pastes, propellants, etc.

Double Planetary Mixer with Helical Stirrers

The introduction of the Ross High Viscosity "HV" Blade (US Patent No. 6,652,137) has offered tremendous improvements to the operational capabilities of the double planetary mixer.

Due to their geometry, rectangular stirrers rely on centrifugal forces and gravity to keep product within the mixing zone. At elevated viscosities, some products tend to climb the standard rectangular stirrers and out of the mix vessel. This characteristic migration of batch material reduces mixing efficiency, necessitates intensive clean-up and can even increase contamination risks.

Helical-style HV planetary blades prevent the 'climbing' problem commonly experienced with traditional rectangular stirrers. These blades feature a precisely angled helical contour which generates a unique mixing action: the sweeping curve firmly pushes the batch material forward and downward, keeping it within the mixing zone at all times. This enhanced control over batch level ultimately leads to improvements in mixing efficiency, clean-up time and product purity. Superior top-to-bottom mixing is easily accomplished, even in extremely heavy materials.

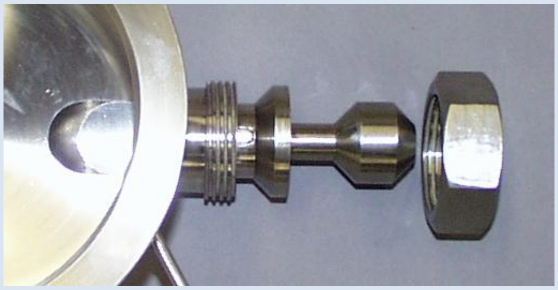
Another important benefit to the helical blade design is that it extends the double planetary mixer's operating viscosity, from 2 million cP to up to 8 million cP. The open paddle design of traditional rectangular blades features a bottom crossbar which makes it difficult to raise or lower the blades through a highly viscous batch. The vertical flights of the rectangular stirrers also tend to generate a power spike in certain high viscosity applications as a lot of blade surface area pass each other at the same time and at very close tolerances. In contrast, the HV blades' helical contour causes the agitators to pass each other in a slicing motion, so that even at the same close tolerances, the spike in power experienced with rectangular blades is eliminated. The absence of horizontal crossbars also allows the helical agitators to be lifted very easily out of a viscous batch. Less product hangs on the blades and wipe down is easier.

The combination of all these design advantages enables a double planetary mixer with HV blades to handle extremely viscous applications that previously required a more expensive double-arm kneader/extruder. These include dental compounds, rubber-based adhesives, elastomers, injection molding feedstock, dilatant materials and advanced composites among others.

Application Snapshot

At a manufacturing facility for medical products and devices, a Ross Double Planetary Mixer is being used to make sterile bone putty. The mixing application is a moldable dough-like material, almost like the consistency of chewing gum.

Calcium stearate and tricalcium phosphate powders are charged into the mix vessel followed by polyethylene glycol, isopropyl palmitate and other liquid ingredients. The helical planetary blades are set at half-speed (to prevent the powders from dusting) and the raw materials combine to form a crumbly, lumpy consistency. After this stage, mixer speed is increased and the batch quickly comes together; the different crumbs and pieces fuse into a single mass. In 10 minutes, the 2-gallon batch is completely and thoroughly mixed. The finished product is a high-viscosity white putty.



A scraper arm is not used in this application. In fact, most viscous products made on double planetary mixers do not require scrapers. Any material that temporarily sticks to the walls during mixing is often reincorporated into the batch by the planetary stirring action without the need for additional scraping assistance. There are applications however wherein non-sticky products can benefit from a scraper arm to promote thorough mixing and maintain uniform temperature. This arm is affixed to the planetary gearbox and is typically removable. A cove cut plug on the mix can is ideal for high viscosity dough-like materials. It is completely flush with the sidewall and bottom of the vessel. There are no dead spots in the mixing zone where batch materials can stagnate.

Planetary Stirrer and Disperser (PowerMix)

Some highly filled and highly viscous formulations require a two-step approach to assure a properly dispersed batch. For example, after mixing all ingredients in a double planetary mixer, if the level of dispersion still comes up short, the entire batch may be transferred to a high speed disperser to provide the extra shear needed for completion. (At this point, the batch has been let down so that the disperser is able to generate an acceptable turnover.) This cumbersome, two-step process is highly labor intensive and time consuming.

In a different scenario, when a product that is batched in a multi-shaft mixer causes frequent overloading of the motors or requires multiple scrape-downs and long cycle times/reworks, it can be a sign that the batch undergoes a viscosity peak outside of the mixer's range.

The recommended solution to mixing requirements similar to the above is a hybrid planetary mixer such as the Ross PowerMix (US Patent No. 4,697,929). This system combines the traditional thorough mixing action of a planetary stirrer with the added benefit of a high speed disperser. Both the planetary blade and the high speed disperser rotate on their own axes while revolving around a central axis. The planetary blade orbits through the mix can in a circular manner, continuously sweeping the vessel walls, as well as the vessel bottom, and carrying material toward the high-speed disperser. The close tolerance sweeping action of the planetary blade also insures that heat created by the disperser blade is evenly distributed throughout the batch. For even faster powder wet-out and dispersion, the high speed shaft can be fitted with two saw-tooth blades. Variable speed allows precise control of shear rates to minimize the degradation of any shear-sensitive components.

Sample applications include adhesives, sealants, molding and potting compounds, fiber-filled composites, plastisols, conductive inks, topical creams, softgels, medical pastes, etc.

Multiple Planetary Stirrers and Dispersers

A mixer configuration with two planetary stirrers and two disperser shafts is chosen for more demanding applications. In this system, large amounts of solids are quickly incorporated into the viscous bulk material and stubborn agglomerates are dispersed regardless of product flow characteristics. This style mixer also offers processing flexibility – both disperser shafts are removable, allowing the mixer to be operated as a classic double planetary mixer. Proven applications include fine pigment dispersions, thermal interface materials, electrode pastes used in advanced batteries, engineered composites, etc.

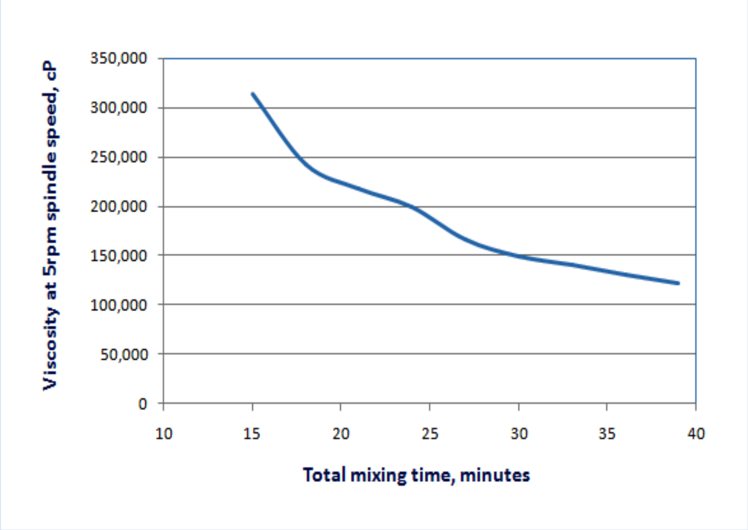
Application Snapshot

A producer of specialty ceramics was using a 40-gallon double planetary mixer with rectangular blades to produce a plug cement material. Their set-up was able to achieve an adequate mixture but they wanted to improve the quality of their product and investigated more vigorous mixer systems that could also shorten cycle time.

The nature of the ceramic cement is that viscosity goes down as the level of dispersion increases. A lower viscosity slurry is advantageous as it allows for easier application and more uniform coating on the substrate.

In the double planetary mixer, viscosity drops to around 210,000 cP after 50 minutes of mixing. Simulation trials on a PowerMix system proved that the level of dispersion can be dramatically improved.

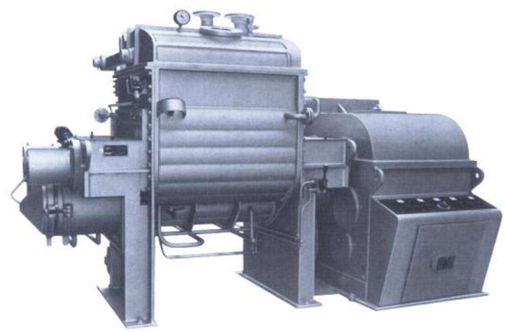
Powders consisting of talc, kaolin clay, silica, graphite, etc. are loaded into the PowerMix, followed by the liquid component. The combination of high speed mixing and planetary stirring produces the same dispersion quality as the control sample in less than half the time it takes in the double planetary mixer. In under 40 minutes, a better quality slurry is completed in the 40-gallon PowerMix with a final viscosity of ~120,000 cP.



Horizontal Kneaders

At the end of the spectrum of high viscosity mixing equipment are double arm sigma blade mixers and kneader extruders that can muscle through solid blocks of hard rubber. A sigma blade mixer is composed of two z-shaped blades that rotate toward each other at differential speeds. Mounted on a horizontal trough, each blade moves the material in opposite directions providing excellent cross mixing of all raw materials. The blades pass the trough walls and each other at close clearances, providing a shearing and tearing action on the product being mixed. At the end of the cycle, the trough of the mixer is tilted and the finished product is discharged for transfer to a downstream operation.

The kneader extruder combines the efficiency of a double arm - sigma blade mixer with the convenience of an extrusion screw for discharging heavy viscous materials. This discharge screw is located in a separate cavity just below the z-blades. During the mixing cycle the blades rotate toward each other while the mixing screw rotates in a reverse direction, constantly feeding new materials into the mixing blades. Once the mixing/kneading cycle is complete, the screw is reversed and it transports the product out through a discharge die.



The kneader extruder remains to be the most powerful high viscosity mixing equipment and many manufacturers have relied on this machine since the beginning. It is highly recommended however to reevaluate your own application's mixing requirements. In particular, it is worth investing if a heavy-duty double planetary mixer with helical blades can replace an existing sigma blade mixer. Switching from a horizontal kneader to a vertical change-can mixer offers numerous benefits including lower capital cost, smaller footprint, reduced energy consumption and easier maintenance.

Conclusion

High viscosity mixing has evolved over the years and many of today's mixing technologies overlap in use and function like never before. If the opportunity is present, try out your own formulation on several mixer configurations and experiment with different methods and order of ingredient addition. Find out if mixing under vacuum can improve your product or if automating the discharge operation can increase yield. Compare cycle times, ease of cleaning, energy costs, etc. You may find that your current mixing process only needs a few tweaks here and there or that a full equipment upgrade is completely justified. Whatever the case, gathering the necessary technical and financial information is easier done in partnership with a reliable and experienced mixer supplier.

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