Tackling Difficult Mixing Problems

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Some difficult mixing problems cannot be solved, but their impacts can be lessened. Here's how you can deal with difficult processes or products, misunderstandings about good mixing, and obstacles to improvements.

No matter how much you think you know about mixing, no matter how many people say they have already tried to fix a problem, no matter how much data have been collected — some mixing problems are so difficult that they seem virtually unsolvable. Yet, many problems that appear to be unsolvable can benefit from improvements.

Some of the most difficult mixing problems involve formulation (*i.e.,* the combining of two or more ingredients) rather than complicated chemical reactions. If chemistry is involved, it is rarely more complicated than pH adjustment. In many cases, the simpler a process sounds, the more problems that develop. In the case of formulation, those problems may be a result of assuming that the process should be simple and the products easy to mix.

Impeller Selection

This is the third article in a three-part series. The previous articles offered guidance on impeller selection:

- "Select the Right Impeller," by Julian B. Fasano of Mixer Engineering Co. (June 2015, Back to Basics, pp. 30–36), explains how an impeller functions, describes the various classes of impellers, and recommends which class of impeller to use for common mixing applications *(1).*
- "When Mixing Matters: Choose Impellers Based on Process Requirements," by Márcio B. Machado and Suzanne M. Kresta of the Univ. of Alberta (July 2015, pp. 27–33), points out that while power number is important when selecting an impeller, other factors, including bulk flow, turbulence at the impeller, and mixing conditions at the bottom of the vessel and at the liquid surface, must also be considered *(2).*

Most unsolvable problems are rooted in conflicts over objectives, understandings, and limitations. This article provides insight into common causes of problems and frequent misunderstandings about mixing, and offers guidance on how to identify potential difficulties and find opportunities for improvements.

Difficult products and processes

Some products have physical properties that make them difficult to mix. Because those properties might be what makes a product effective or desirable, the product cannot be made with different properties just to make it easier to mix.

Non-Newtonian behavior. One particularly difficult property is non-Newtonian viscosity *(3),* a characteristic of common everyday items like personal care products, paints, and foods (Table 1). Viscosity has the effect of resisting fluid motion, so the motion created by a mixer impeller in a viscous fluid may die out before it moves the entire contents of the tank. With all non-Newtonian fluids, the potential exists that a portion of a tank will remain unmixed because of inadequate fluid motion.

Non-Newtonian behavior generally becomes evident in fluids with viscosities higher than about 1,000 cP (1 Pa-sec). At that point, the viscosity alone makes mixing the fluid more difficult than mixing low-viscosity, water-like fluids. Small impellers may just bore a hole in the fluid, whereas large impellers can move an entire batch. One approach to mixing non-Newtonian and other viscous fluids is to use large impellers or multiple impellers, so the fluid does not have to travel as far from the mixer to reach other parts of the tank *(4).*

Non-Newtonian fluids exhibit shear dependence — *i.e.,* the viscosity changes as the fluid is sheared (moved) by the

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mixer. A fluid that experiences a decrease in viscosity when subjected to shear is called shear-thinning, while a fluid that experiences an increase in viscosity under shear is called shear-thickening. The magnitude of the shear that influences the apparent viscosity is proportional to rotational speed *(5)*.

Time-independent non-Newtonian fluids are influenced by the shear rate applied to them. Time-independent, shear-thinning fluids are often called pseudoplastics, because they behave like molten polymers. Shear-thickening fluids are sometimes called dilatant fluids, because many are high-concentration slurries that must expand (dilate) at the particle level in order to flow.

Time-dependent non-Newtonian fluids change apparent viscosity not only with shear rate, but also during and following the applied shear. Time-dependent, shear-thinning fluids are described as thixotropic. Latex paint is a common thixotropic fluid. The paint thins when it is sheared by the brush or roller as it is applied. While the paint is thin, it spreads evenly and the brush strokes disappear. After the shear of the application process ends, the paint begins to thicken again, so it does not run down the wall or off the painted item. This thixotropic behavior can make even mixing latex paint in preparation for use problematic. Some time-dependent, shear-thinning fluids experience a permanent reduction in viscosity, making mixing time an important factor in obtaining the desired product properties. Time-dependent, shear-thickening fluids are called rheopectic fluids. Printing ink can exhibit rheopectic properties.

Some more-difficult non-Newtonian fluids have viscoelastic, or yield-stress, properties.

Viscoelastic fluids have an elastic return, behaving like bread or pizza dough. As the dough is mixed or kneaded, it can stretch and move; when the applied force is removed, the dough tends to (at least partially) creep back to where it was before being stretched. Because of both the high viscosity and the elastic behavior, special equipment is often required for mixing viscoelastic materials. Dough mixing equipment, for instance, typically has blades that stretch and fold or cut the dough (*e.g.,* a paddle or dough hook in a kitchen mixer). Yield-stress fluids are most readily identified by their gel-like characteristics and their initial resistance to motion. Some common yield stress fluids include ketchup, mayonnaise, hair gel, and hand lotion (Table 2). A certain minimum force must be applied before a yield-stress fluid will flow. Yield-stress fluids can form a cavern *(6)* of moving fluid around the impeller, with stagnant fluid surrounding the volume that is moving (Figure 1).

Mixing non-Newtonian fluids may be doubly complicated when the mixing process creates the non-Newtonian properties. For example, a formulation process may start with a low-viscosity liquid, and mixing causes the viscosity to increase until the fluid becomes non-Newtonian. Sometimes mixer power may be used as an indicator of final fluid viscosity.

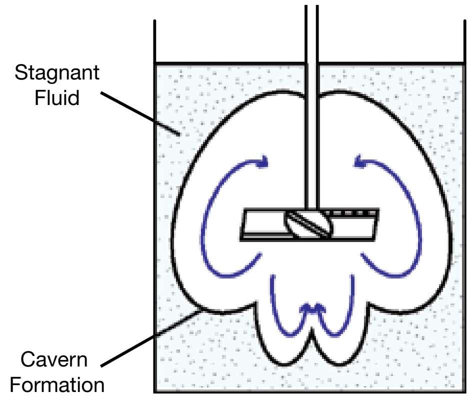
Two of the other difficult processes involving non-Newtonian fluids are powder addition and emulsification.

Table 1. Typical liquid viscosities (at 70°F/35°C).

Substance	Viscosity, cP
Acetone	0.3
Water	1
Gasoline	8
Kerosene	10
SAE 10 Oil	60
Olive Oil	81
SAE 30 Oil	175
Glucose	500
Caster Oil	1,000
Corn Syrup	1,400
Glycerol	1,500
Honey	5,000
Molasses	7,500
Ketchup	30,000
Peanut Butter	250,000
Caulk	5,000,000

Table 2. Common yield-stress fluids.

Substance	Yield Stress, Pa
Ketchup	15
Salad Dressing	30
Mayonnaise	100
Hair Gel	135
Yogurt	200



▲ **Figure 1.** Viscoelastic fluids can form a cavern of moving fluid around an impeller. The cavern is surrounded by stagnant fluid. The size and shape of the cavern depend on the impeller type and its torque.

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Powder addition. Powder addition is fraught with a variety of problems that are a function of whether the powder is soluble, insoluble, or hydrating.

Problems with soluble powder addition are often self-correcting as the powder dissolves, although extended mixing times may be needed. All dissolution requires some additional time; slowly dissolving particles may require mixing times from minutes to, in the extreme, hours. The time required to dissolve powders depends primarily on solubility and particle size, and less about mixing intensity, as long as the particles are suspended. Insoluble powders and hydrating powders may form agglomerates or lumps that require intense processing to break and disperse.

One powder-addition difficulty is getting the powder to wet thoroughly. Wetting involves both the surface properties of the particles and the surface tension of the liquid. The surface-electric characteristics of some powders make them hydrophobic, so they do not wet well with water. That may necessitate changing the material, if possible, or pretreating the material to alter its wetting properties. Altering the surface tension of the liquid, perhaps by adding a surfactant, may improve the liquid's wetting characteristics and make powder addition easier. Particle size also affects wetting. Larger particles are more likely to penetrate the surface than fine particles. Fine particles and low-density particles tend to float on the liquid surface, making powder addition extremely difficult *(7)*.

The rate of addition and surface motion can either worsen or improve powder addition. Many powders need to be added slowly enough that they have time to be wetted and incorporated into the liquid. Some hydrating thickeners, such as cellulosic polymers, need to be added quickly, while the fluid is still low-viscosity and turbulent to aid the addition and dispersion of the powder. Thus, a balance must be struck between fast and slow addition to achieve the best and most-complete mixing. Controlling the rate of addition may require more than just an instruction that states "add slowly." Just because a specification for the rate of addition exists does not mean that the process is always carried out accordingly. To control the rate of addition, a portion of the powder might be added, followed by blending for an extended time, before more powder is added.

Surface motion must be sufficient to either wet the particles individually at the surface or rapidly take them from the surface to the region of intense mixing near the impeller. A modest vortex on the surface may help move liquid across the surface. A deep vortex will draw air into the liquid. A strong vortex is probably a sign of bad mixing (as discussed later).

Keep in mind that the spaces between particles of powder are filled with air. Adding any powder to a liquid has the potential to add air bubbles. Once air bubbles are in a liquid, especially a viscous liquid, they can be difficult to remove.

The best way to solve a problem of bubbles in a liquid is to limit their formation or avoid getting them into the liquid in the first place. To reduce air entrainment and bubble formation, avoid surface splashing by a partially submerged impeller, and ensure that a deep vortex does not reach an impeller. Some powder additions require special inline mixing equipment to rapidly combine and disperse powders into a liquid stream. Adding powders under vacuum is difficult, but may be the only way to reduce bubbles in a viscous product.

Emulsification. Emulsification is almost an art, since it involves both mixing intensity and the use of stabilization agents.

Most emulsions are a combination of an oil phase and an aqueous phase, one dispersed in the other. However, some emulsions involve more than two liquid phases or the presence of dispersed powders. If the dispersed phase droplets are small enough, the dispersion will not separate, especially if a surfactant is present to act as a stabilizer. Common products like mayonnaise, latex paint, and skin lotion are emulsions.

In general, more-intense mixing may reduce the amount of stabilizer needed, or more stabilizer may reduce the mixing intensity required to form an emulsion. Emulsion formation almost always requires high-shear mixing, often provided by special impeller blades. In some cases a sawtooth blade operating at high speed is sufficient to form an emulsion. In other cases, a rotor-stator mixer is necessary.

To form a stable emulsion, the dispersed phase must be prevented from coalescing, which requires creating enough surface area and surface tension between the immiscible droplets and the continuous liquid phase. Differences between the viscosities of the two phases can alter the

Axial Flow in a Baffled Tank

Mixing technology evolves slowly, perhaps because there are so many different types of mixing. Each new impeller design must be tested in different scenarios until its advantages and disadvantages are understood.

The first truly successful hydrofoil impellers were developed more than 30 years ago. Their primary advantage was extremely axial flow in a baffled tank. Some 30 years before the development of the hydrofoil, pitched-blade turbines were found to outperform straight-blade, radial-flow turbines. Axial flow creates a single recirculation loop instead of the double loop associated with a radial-flow impeller. Based on the demonstrated advantages of axial flow created by the early narrow-blade hydrofoil impellers, hydrofoil mixers have evolved to wider-blade designs capable of working well in viscous-fluid or gas-dispersion applications. Better axial flow provides greater and more-rapid uniformity in the liquid. In addition, hydrofoil impellers require less power and torque than a pitched-blade turbine for many process results.

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process and further complicate the formation of an emulsion. Because viscosity is a function of temperature and all the power added by a mixer eventually becomes heat, the temperature and viscosity may change during the emulsification process.

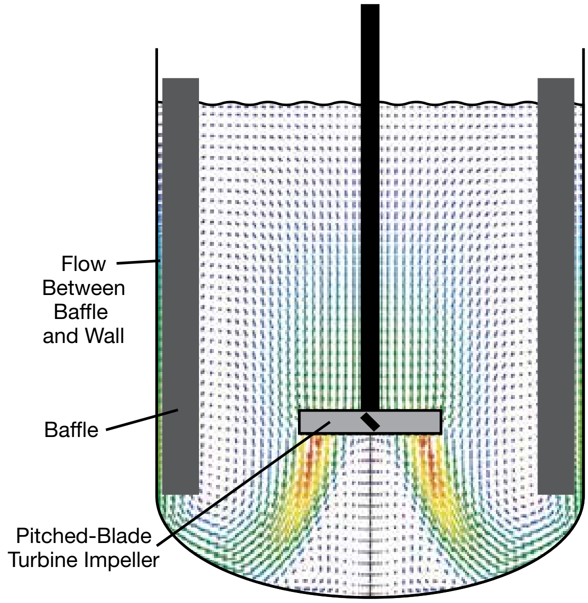
Careful observation and understanding of the factors that affect an emulsion are necessary to improve an emulsification process. The final emulsion will often have a viscosity higher than either of the two immiscible liquids. The emulsion properties and stability may be the desired process result.

Misunderstandings about mixing

Vortex. Perhaps the greatest misunderstanding about mixing is that a vortex on the surface is necessary for good mixing. In fact, the opposite is closer to the truth.

A strong central vortex on the surface of a stirred tank usually means that the entire tank contents are moving in solid-body rotation. If all of the liquid is rotating together, almost no mixing occurs in the radial or axial directions. Just as race cars moving around a track do not collide if they follow each other or move along parallel paths, radial mixing cannot occur if all of the liquid is moving in coherent rotation.

Vertical motion is even more critical. Consider the addition of either a liquid or solid on the surface of a rotating batch. In rotational flow, the added material must circle the tank many times before diffusion and local turbulence carry it to the bottom and distribute it throughout the tank. Although a vortex on the surface may appear to carry some of the material spiraling down the center, that flow is only a result of the sloped surface leading to the center of the tank. Once the moving liquid reaches the center of the tank, the limited downward flow may take a long time to achieve uniform blending throughout the tank.



▲ **Figure 2.** Baffles extending from the vessel wall redirect the rotational flow from the impeller to a vertical direction.

The most effective way to control a vortex and excessive swirling is the use of baffles. Baffles are typically three or four vertical plates that extend out from the wall of the tank to redirect the rotational flow from the impeller into a vertical direction (Figure 2). To avoid a stagnant zone, most baffles are mounted with a gap between the baffle and the tank wall. Only a small amount of the rotational flow passes through that space and around the baffles — most of the flow is directed vertically. Vertical flow also creates radial flow, which is necessary for recirculation. Vertical flow can drastically improve batch uniformity, solids suspension, gas dispersion, and other mixing results.

Baffles are necessary for nearly all turbulent mixing applications. Turbulence is usually defined in terms of an impeller Reynolds number (N_{Re}):

$$N_{Re} = \frac{D^2 N \rho}{\mu} \qquad (1)$$

where D is impeller diameter, N is rotational speed, ρ is fluid density, and μ is fluid viscosity.

Mixing conditions with Reynolds numbers greater than 20,000 are usually considered to be turbulent. Large mixer applications with fluid viscosities as high as 5,000 cP (5 Pa-sec) or more may be turbulent enough to require baffles. Without baffles, high-intensity mixing of low-viscosity fluids is impossible.

Miscibility and viscosity. Another common misunderstanding is that adding one liquid to another is easy, as long as the liquids are miscible.

Combining liquids with different viscosities can be much more difficult than combining liquids with similar physical properties. Adding a high-viscosity liquid to a low-viscosity liquid is usually easier than adding a low-viscosity liquid to a high-viscosity liquid. A low-viscosity liquid that is well-agitated can become turbulent, and the turbulence can act to disperse the high-viscosity liquid. Once the more-viscous liquid is dispersed, it can dissolve in the other liquid, eventually achieving a uniform blend.

A simple kitchen test — adding corn syrup to water — demonstrates the difficulty of blending liquids of different viscosities. To see the effect of yield stress on mixing, try adding ketchup to water — rather than dissolving, the ketchup forms undispersed filaments in the water. Other examples of mixing fluids of different viscosities in food processing are the addition of honey to tea and fruit juice concentrate to water.

Mixing miscible fluids with different viscosities usually requires only extending mixing times, but the times can vary from many minutes to an hour or longer, depending on the

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viscosity difference. Combining liquids of different viscosities also requires controlled addition rates.

Blend time measurements for liquids with similar densities and viscosities have been correlated and reveal that blend time is inversely proportional to mixer rotational speed in geometrically similar situations. Blend time correlations for turbine mixing typically take the form:

$$\Theta_{Blend} = \frac{N_\Theta}{N\left(D/T\right)^{\sim 2.3}} \quad (2)$$

where Θ is blend time, N_Θ is a dimensionless turbulent blend number, and T is tank diameter.

The blend time number is a dimensionless constant characteristic of the type of impeller. The ratio of impeller diameter to tank diameter (D/T) usually has an exponent between 2.0 and 2.5; its value within that range depends on the type of impeller. Liquid level also has an effect on blend time, which differs with impeller type and other factors.

Scale-up. Many other misunderstandings about mixing are a result of the relatively limited direct experience most engineers and scientists have with industrial-scale mixing. All mixing technology has its roots in empirical study — learning by observation.

Seeing industrial mixing from the surface may not reveal much about the flow pattern below the surface and around the impeller. In a laboratory beaker, uniform blending may appear easy, rapid, and complete. That same mixing process may take a much longer time in a production-scale mixer, and, in that additional time, other processes may be important. The amount of power required to achieve the same small-scale mixing time in a large tank is usually beyond economic and mechanical feasibility. Blending in larger tanks takes longer, simply because fluid velocities and pumping rates do not increase enough to overcome the longer distances in a large tank.

An understanding of dimensional analysis and similarity may help in scaling up a mixing process. However, scale-up criteria are usually based on keeping a process variable constant. Keeping a dimensionless variable, such as Reynolds number, constant may not provide useful scale-up guidance or may give unsatisfactory results. The correct tests, range of conditions, and problem identification are necessary before scale-up is attempted.

Successful scale-up involves two important, but often overlooked, steps: small-scale testing to identify the key process variable(s), and careful and accurate measurement of conditions to identify those that yield successful results.

First, small-scale testing needs to identify which mixing variable or combination of variables needs to be held constant or controlled for successful scale-up. Testing should be done at different mixing speeds, and sometimes must be done with impellers of different diameters or with different types of impellers. Other process variables may be measured or calculated to help you understand what processes are taking place, and their effects on mixing results.

Although equal blend time might seem to be a good criterion for a mixing application, it is almost never a practical scale-up objective. Not only do larger tanks take longer to mix, but larger mixers typically rotate more slowly. Blend time in geometrically similar tanks is inversely proportional to rotational speed, as shown by Eq. 2. Effective blending requires a certain number of revolutions to achieve the desired degree of uniformity.

The second requirement for successful scale-up is careful and accurate testing. Some of the most overlooked small-scale observations are the effects of mixer dimensions and rotational speeds. Noting and explaining process failures can be extremely important, especially if the failures can be avoided in production situations.

Even in the laboratory, knowing the diameter of a beaker, volume of a material, and length of a stir-bar can help in defining or duplicating mixing intensity. The relationship between impeller power and mixing variables shows the importance of accurate measurements:

$$P = N_p \rho N^3 D^5 \quad (3)$$

where P is impeller power and N_P is the impeller power number.

Under turbulent conditions in a baffled tank, the impeller power number is essentially constant, and power is proportional to fluid density. Viscosity influences power only in transitional and laminar conditions, as defined by the impeller Reynolds number (Table 3).

Mixer speed and impeller diameter should be measured

Nomenclature

D = impeller diameter
N = impeller rotational speed
N_P = turbulent power number
N_Θ = turbulent blend number
P = power
T = tank diameter

Greek Letters

μ = dynamic viscosity (kg/m-sec)
Θ = blend time (sec)
ρ = density (kg/m^3)

Table 3. Reynolds number characterizes the mixing regime.

Regime	Reynolds Number
Turbulent	> 20,000
Transitional	10–20,000
Laminar	< 10

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and recorded in the laboratory and pilot plant, and at the production scale. Rotational speed is important, because it has an inverse effect on blend time and a cubed effect on power in turbulent mixing. However, rotational speed is often not measured and recorded in laboratory studies because most magnetic stirring plates and small mixers do not have a speed reading. At a minimum, the number scale on the laboratory stirrer needs to be correlated to mixing speed and recorded as part of the experimental observations.

Doubling the rotational speed will reduce the blend time by half and increase power by a factor of eight (2^3). Most small-scale tests need to be run with speed change increments of no more than 10% (30% power difference) or 15% (50% power difference). If those speed changes have little effect, then mixing intensity is not important in that range of conditions.

At a constant rotational speed, doubling the impeller diameter will increase the power input by 32 times (2^5), as shown in Eq. 3. Extremely accurate measurements, often to within 0.1 mm or 0.01 in., of small-scale impeller dimensions are necessary, as minor dimensional differences can create large changes in mixing intensity.

Process failure is also often overlooked. Mixing intensity is easy to observe in laboratory glassware, so poor mixing is rarely allowed to develop. Even a failed test can be important if the reason for the failure can be identified. Sometimes the best, most cost-effective scale-up criteria are just avoiding conditions that caused a small-scale failure.

A simple example of a mixing failure is the situation where some of the fluid on the surface or in a bottom corner of a beaker or flask does not move. Good mixing requires complete motion. So scale-up always needs to avoid stagnant regions in production equipment. Scale-up with a minimum of equal fluid velocity, often represented by equal impeller tip speed in geometrically similar equipment, will usually avoid fluid motion failures.

Other applications, such as those involving chemical reactions, may have different limitations. A good philosophy is that failures should be made on the small scale in order to make product and money on a large scale.

Obstacles to improvement

The biggest obstacle to improving mixing in many cases is the requirement to use existing equipment. This stipulation becomes an even bigger obstacle when the equipment is more than 25 years old, which is common, or when used equipment is purchased. In either case, the equipment was likely not selected to match the process requirements. Old equipment probably was not designed for current process conditions or products. Used equipment is often chosen because of price or availability over performance.

A requirement to use existing equipment is not much different than the need to mix products with difficult properties. Both situations require making the best of a difficult situation and a focus on making improvements, rather than attempting to solve all of the mixing problems.

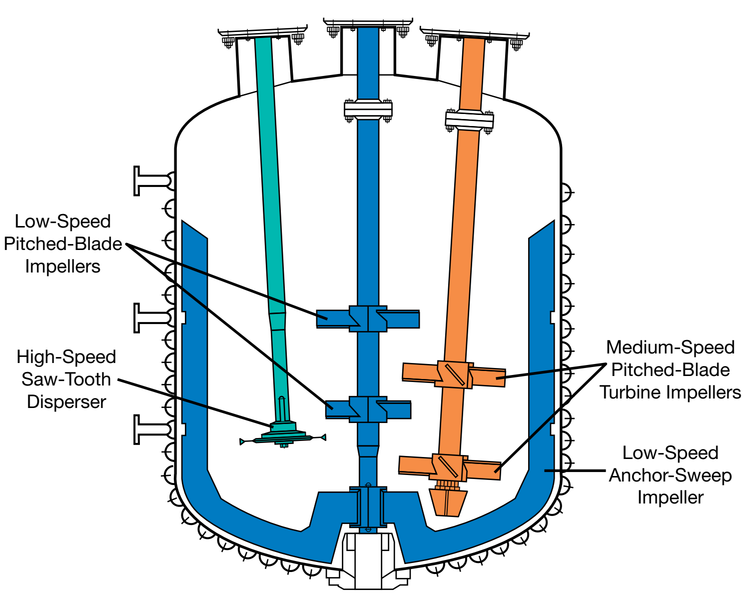
Making improvements to a process in existing mixing equipment requires some creativity. For example:

• *Change the order of addition.* A viscosity difference may pose less of a problem with a different order of addition — adding a more-viscous material to a less-viscous one is usually easier than mixing the materials in the other order.

• *Add minor ingredients to the less-viscous material.* If viscosity is expected change, for example, after a change in pH, adding all of the minor ingredients to the lower-viscosity fluid first (*e.g.,* before making the pH change) may yield better results.

• *Use different ingredients.* The same raw material from a different source or with slightly different specifications might make mixing easier. A liquid with a slightly different concentration or a powder with a different particle-size distribution might be easier to add and disperse.

• *Reduce the batch size.* Mixing intensity depends to some degree on the amount of material being agitated — a given impeller produces more-



▲ **Figure 3.** A multi-shaft mixing vessel with different types of impellers can perform several kinds of mixing. The three mixers can be operated separately or in various combinations, depending on the conditions in the tank and the process requirements.

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intense mixing in a smaller batch than in a larger batch. Greater productivity does not always come with bigger batches, especially if the products of large batches are of poor quality and must be reworked.

• *Modify the equipment.* This might be the best option if process modifications do not improve the mixing. Perhaps the existing mixer drive and shaft will give better process results with a different type of impeller. For instance, a three-blade hydrofoil impeller may require a shorter blend time and/or produce more uniformity, better solids suspension, or other desirable process results than an existing pitched-blade turbine. If the mixer makes the difference between good product and bad product, the cost of improving the mixing equipment may pay for itself quickly.

Some equipment attempts to improve mixing by performing several different kinds of mixing in the same vessel. The multi-shaft mixer shown in Figure 3 consists of: a center-mounted mixer with a low-speed, anchor-shaped, sweep impeller and two pairs of pitched blades attached to the shaft; a medium-speed, off-center, angle-mounted mixer with two pitched-blade turbines (PBTs); and an off-center, angle-mounted, high-speed disperser with a saw-tooth disk impeller.

The three shafts can be operated separately or in various combinations, depending on the conditions in the batch and the process requirements. The large sweep impeller rotates slowly to provide motion near the tank wall. The pair of pitched blades attached to the central shaft contribute almost no mixing because of their small diameter and low speed. The two medium-speed PBTs operate at the intermediate speeds typical of turbine impellers. The turbine mixer provides circulation and blending. The high-speed mixer with a saw-tooth blade provides liquid dispersion capability.

This type of multi-shaft mixing tank or kettle is designed to provide "good" mixing for a wide range of products, viscosities, and batch levels. However, the mixing is not always optimal, because some compromises are necessary. At low to intermediate viscosities, the mixer with two PBTs should be able to do effective mixing, even though it is not centered in the tank. The pitched blades can create vertical and radial motion, because the anchor blades and center shaft act as moderately effective baffles. The high-shear, saw-tooth mixer may be capable of creating an emulsion, which might increase the product viscosity. Once the viscosity increases, the sweep impeller is expected to provide mixing. The multiple impellers may give satisfactory results over a range of different batch sizes or changing liquid levels during batch preparation, filling, and emptying.

Unfortunately, the vertical arms of the anchor impeller create almost no vertical movement in the bulk material. At high viscosity, pitched-blade (*i.e.,* mixed-flow) impellers cease to create axial flow and act more like radial-flow impellers, especially with respect to recirculating flow patterns. The pitched blades on the center sweep shaft are almost useless, because at the slow speed at which the sweep shaft operates, they add almost no power or motion beyond what the anchor sweep creates. Impeller power and pumping in laminar flow are proportional to the cube of the impeller diameter, so the small pitched blades make almost no contribution to fluid motion. The ultimate result is that this multi-shaft mixer does a poor job of creating batch uniformity in laminar flow. Anything that is added to the surface of a viscous liquid will require a long time — many minutes to hours — to be uniformly blended.

A variation on the multi-shaft mixer is shown in Figure 4. The elimination of the off-center PBT mixer may reduce blending effectiveness in low- to intermediate-viscosity fluids. The high-speed shaft with dual saw-tooth impellers may still provide effective dispersion, or perhaps even better dispersion than the other mixer.

The most-significant difference in performance comes from the modified sweep impeller. Although it may be a bit difficult to visualize in this two-dimensional drawing, the two angled blades that connect the opposite corners of the anchor follow the curve of the tank wall. Each blade is a flat plate with its outer and inner edges cut to an ellipse that follows the wall of the cylindrical tank. The benefit of these angled arms on the anchor is that they create vertical fluid motion.

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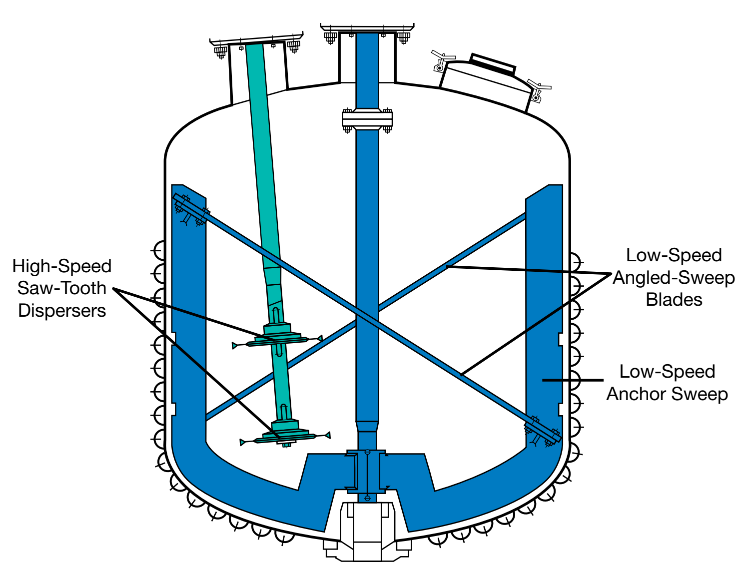

▲ **Figure 4.** The angled, elliptical blades connecting the corners of the anchor impeller improve blending by creating vertical motion.

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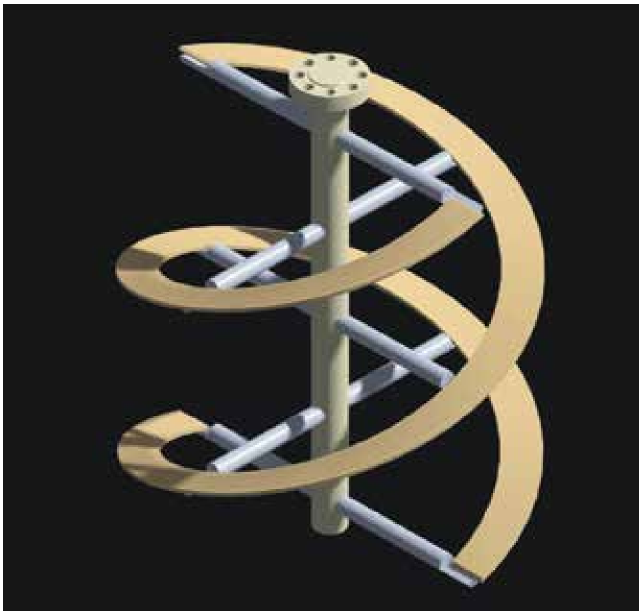
The most-effective impeller design for blending high-viscosity fluids is a helical ribbon, shown in Figure 5. A helical-ribbon impeller can blend fluids with viscosities in excess of 1,000,000 cP (1,000 Pa-sec). Although rarely applied in low-viscosity applications because of its higher cost, it works remarkably well at low viscosities, too.

The angled, elliptical blades attached to the anchor impeller in Figure 4 are a cost-effective substitute for a helical ribbon. Such angled blades could be added to almost any anchor impeller to improve vertical blending. The increased power required by the additional blades may be within the capability of the existing mixer drive; if not, a minor reduction in speed may keep it within the motor's power range.

Several other construction variations are possible for angled sweep blades. The critical factor in improving the performance of any sweep impeller is creating vertical motion, especially in viscous fluids. Motion at the tank wall is not sufficient to create concentration and temperature uniformity.

Another way to improve high-viscosity mixing may be to use a lower rotational speed. High-viscosity fluids need time to flow, and a high rotational speed may cause the fluid to rotate as a solid body or be cut by the rapidly moving blade.

Pharmaceutical manufacturers may face an extreme "use existing mixing equipment" requirement. U.S. Food and Drug Administration (FDA) regulations restrict changes to existing processes and equipment. The hardest mixing problem to solve is the one where no changes can be made. Product and process development testing should establish a range of conditions that will produce a successful product. Some improvements to production processes may be possible within that range.



▲ **Figure 5.** A helical-ribbon impeller is the most-effective design for mixing high-viscosity fluids.

Final thoughts

Remember that mixing always obeys physical laws. Just because you want something to happen does not mean it will happen in the real world.

The technical literature can provide background on how physical laws apply in mixing. Not all improvements can be found in the scientific literature, though — some improvements must be developed for the specific application. Further investigation may reveal ways to at least improve even difficult mixing applications *(8)*. CEP

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