

# Agitation and Mixing Processes

## Introduction

Mixing is a process where two or more substances enter a chamber where they are combined. The chamber can be a tank, hopper, length of pipe, or even an extruder barrel. Most often, stirring or agitation is the method to combine compounds. The stirring mechanism is a rotating arm that is often powered with a drive/motor. For a certain category of mixers, the chamber itself is rotated to achieve mixing. Different substances will require different levels of mixing, stirring speeds, and elapsed times. Because of these variables, drives can play a key role in the mixing process.

Almost anything can be mixed, and generally the type of mixer used depends on the nature of the substances to be mixed. Liquid-gas, liquid-liquid, and liquid-solid systems (suspensions) will generally be mixed in a vessel or tank with an impeller to provide the mixing energy. The end product is almost always a liquid, suspension, or slurry. A chemical reaction can often take place, and the tank can have accommodations for the addition or removal of the heat of mixing or heat of reaction.

A wide range of equipment can be used for the mixing of pastes, aggregates, viscous materials, or other solids. This is due to the wider variation in mixing properties for these different materials than for liquids. Typically, the agitating mechanism must be designed to extend very close to the walls of the vessel in these types of systems.

## Mixing Features and Properties

### 1. Liquids

The key to effective mixing for liquids is to create multiple flow patterns in the fluid being mixed. This motion is imparted to a fluid "pocket" as it contacts the blade on the rotating agitator. The momentum of this pocket will keep it in motion until it either contacts the wall of the vessel, or runs into another moving pocket.

## Application Solution

Three components for the motion are identified as radial flow (outward from an agitator), axial flow (parallel to the agitator arm), or angular flow (parallel to the vessel wall in a horizontal plane). The first two types are essential for effective mixing. Angular flow is undesirable, because it means that the fluid is orbiting around the agitator (pockets moving in parallel), but little mixing is occurring. Patterns are illustrated in figure 1.

Liquid flow can further be defined as either laminar or turbulent. Laminar flow is where layers of fluid molecules or "laminae" slide past one another (picture the sliding of a deck of cards at an angle). The flow is predictable and many formulas and studies for fluid mechanics are based on laminar flow.

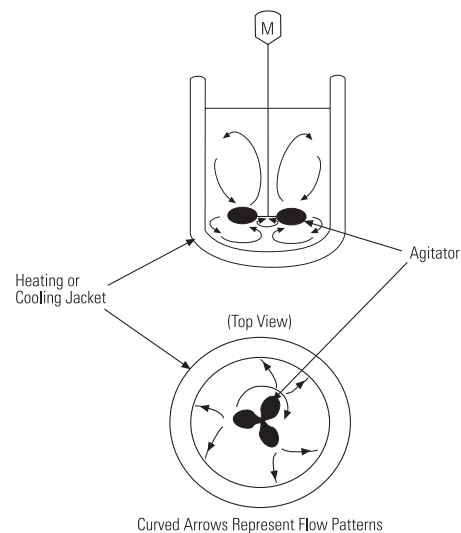


Figure 1. Liquids and Slurry Mixing Tank

Turbulent flow, on the other hand, is a random pattern where micro-pockets of fluid collide frequently with one another. New micro-pockets are continually formed from collisions, and random flow patterns result. This type of flow produces the most effective mixing, however in excess, can waste energy or produce unwanted entrainment of air.

The nature of the liquids and suspensions themselves affect fluid flow and mixing properties as well. Specific properties of concern are the fluid densities, viscosity, temperatures, pressures, and volatility. These properties have been related in a dimensionless formula called the Reynolds Impeller Number defined here:

$$N_{RE} = \frac{D^2 * N_I * \rho}{\mu}$$

Where: D = Impeller diameter (ft)

$N_I$  = Rotational speed of the impeller (Rev/Second)

$\rho$  = Fluid density (lb/ft<sup>3</sup>)

$\mu$  = Fluid viscosity (lb/ft-sec.)

Some observations regarding the Reynolds Impeller Number:

- A. If  $N_{RE} \leq 10$ , flow is laminar. If  $N_{RE} > 10000$ , flow is turbulent, and between 10 and 10000 there is a transition range where both laminar and turbulent flow elements exist.
- B. Doubling the impeller diameter will quadruple  $N_{RE}$ . This follows, as the impeller will sweep an area four times larger when the diameter is doubled.
- C. Temperatures and pressures are accounted for in  $N_{RE}$  as they affect both density and viscosity.

These factors are useful for sizing and selections of tanks, impellers, and the associated driving equipment.

Slurries and suspensions are similar to liquids in mixing properties. With suspensions, it is especially important to have sufficient agitation to prevent settling. However, excess agitation may cause particles to collide and break into smaller sizes which is equally undesirable in most cases.

## 2. Solids, Pastes, And Highly Viscous Materials

Solids, pastes, and other highly viscous materials cannot rely on internal flow momentum to help the mixing process, unlike liquids. Motion and therefore mixing must rely directly on contact with the agitating device. The designs of these will differ greatly from the propeller type agitators used for liquids, and more energy per unit is required to mix solids over liquids as well.

Other factors and properties of pastes and solids affect mixing. Bulk densities, particle shapes, and flow characteristics can affect energy requirements. In pure solids mixtures, particle size and abilities to hold static electricity charges must also be considered. A major objective of mixing solids can also be size reduction of particles, and/or the breaking up of lumps. Still, in other cases, size reduction is to be avoided in solids mixing due to the problematic dust that could result. The point of all this is that there are a wide variety of scenarios involved when mixing non-liquids, and a vast array of equipment and design solutions to address them.

Friction is an extremely important design consideration in the mixing of non-liquids. The heat produced by friction can either help a process as in an extruder, or is considered waste energy that must be removed. Excessive temperatures from friction can also cause product degradation and the creation of unwanted side products or off gases.

## Mixing Equipment

### 1. Liquids

See Figure 1 which shows a mixing tank and its components. Major equipment for this discussion is the vessel, agitator, and baffles.

A. Mixing vessels come in a variety of styles and sizes. They can be used for batch processing or on a steady-state flow basis where starting fluids enter the top and a mixed product is drawn from the bottom. Tanks typically have rounded bottoms to avoid stagnant areas that sharper corners could produce. A surrounding jacketed chamber holds steam or process water that might heat or cool the process depending on needs. Tanks could also be covered to prevent material losses due to volatiles, or heat losses that waste energy such as in a mixing tank reactor.

B. Agitators - Basically, an agitator is a shaft with a propeller attached. As mentioned earlier, the two components that provide for good mixing are radial and axial flow. A propeller with pitched blades promotes this behavior. The propeller speeds range from 350 to 1750 RPM with suspended matter being agitated at lower speeds and for rapidly dissolved solids or

chemical reactions at the higher speeds. Propellers typically work best at 3 HP or below and in tanks whose diameters do not exceed six feet.

Paddle type agitators come in both curved and flat-blade-turbine styles. (See figure 2). They operate in a wider range of horsepower and larger tank diameters than the propeller types. The blades extend farther than for propellers as well, so higher  $N_{RE}$  values are achieved at lower RPMs. Curved blade designs work well when starting up in a tank of settled solids. Another variation is multiple propellers set along the agitator arm to enhance mixing. These are especially advantageous with solid suspensions. (Example: Leaching of minerals from aggregates in a tank.)

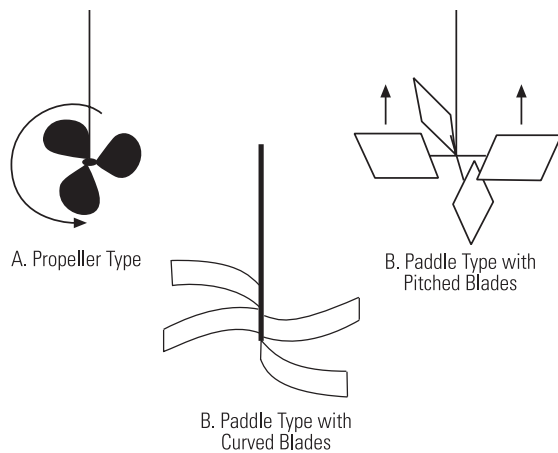


Figure 2. Impeller Types

Circular (tangential) motion in fluids will still occur with propeller or paddle agitators. Given the disadvantages cited earlier, there are a few ways to minimize this.

A relatively easy solution is to set the agitator in an off-center position. Figure 3 shows some possible configurations. This solution is generally limited to low (<3 HP) energy applications because flow patterns would apply excess stress loads to the agitator arm at higher power levels.

C. Baffles - Baffles are obstacles or barriers that are positioned parallel to the agitator arm at the edge of a tank wall as shown in figure 4. They inhibit tangential flow without affecting the radial component. (See figure 1). Typically, four baffles are adequate unless the tank has an unusually large diameter.

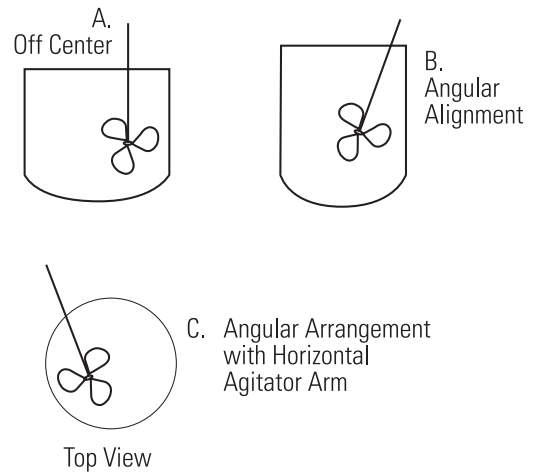


Figure 3. Agitator position solutions to reduce swirling.

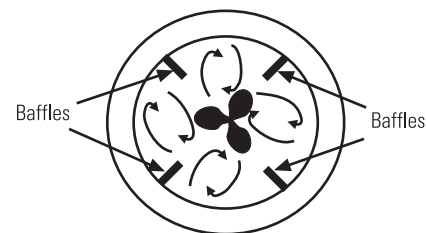


Figure 4. Flow patterns with baffles.

## 2. Solids, Pastes, and Viscous Materials

As previously mentioned, mixing of non-liquids opens application considerations to a wider choice of equipment and many more challenges due to the varying nature of these types of substances. Another consideration is the actual objective for mixing in the first place. Some typical ones are listed here.

- Heating, cooling, or drying operations
- Size reduction
- Homogeneity of aggregates
- Coating of particles
- Kneading

What they all have in common is that the agitator must be designed so as to physically contact all of the substance in the mixer. Mixing occurs due to the shearing action of the blades as no momentum from flow can be depended upon as with liquids.

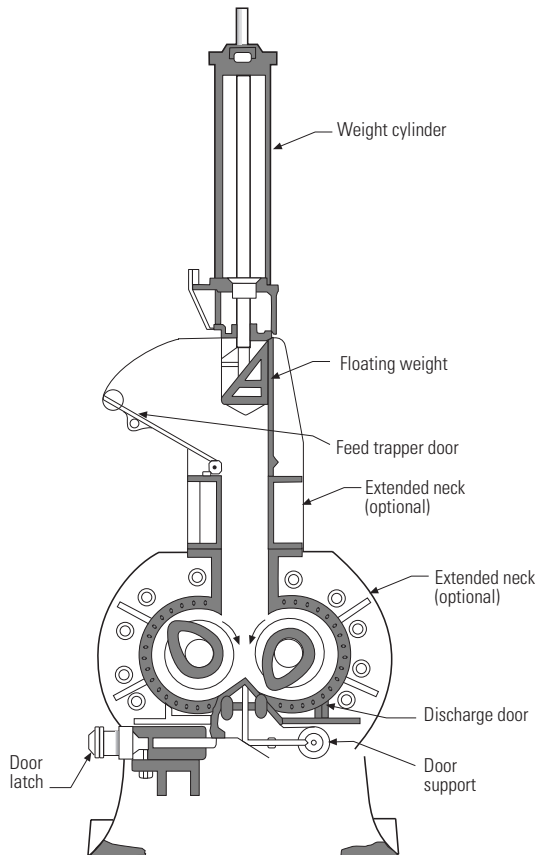


Figure 5.

Shearing, is defined as the application of force via the mixing blade. As a result, the energy required per unit volume is greater for solids and pastes than for liquids. Equipment for pastes, doughs, and solids mixers are described here.

#### A. Tumblers

One notable exception to the above described shearing action is a tumbler-type mixer. Here, the vessel itself is either rotated or oscillated back and forth. A cement mixer is a good example of this. Tumbler-types are useful when the objective is to break up clumps or agglomerates of material. They can have baffles to enhance mixing and are used for batch processing. They are generally low maintenance, low wear devices that are suited for dry solids and low-adhesion pastes.

One variation is to add inert ceramic spheres in the mixer. These serve the purpose of helping to break up chunks. The tumbler becomes a ball mill in these cases. One example where this is useful is in mixing certain types of paint.

#### B. Agitators for Non-liquids

- i. Ribbon mixers consist of helical or spiral mixing blades that sweep across nearly the entire surface of the vessel. There are many variations to handle a wide variety of compounds. When pastes adhere to vessel walls, the tank may be aligned vertically so that the blades vertically lift the material as it is sheared. Heat transfer operations use this type of design. The main design criteria for ribbon mixers are the blade thickness, number of spirals, wall clearances, and spiral pattern.
- ii. Twin-rotor mixers use two parallel rotors with intermeshed flights along their axes. There is a tight clearance to the vessel walls, so high shearing action between the rotors and between rotors and wall occurs. This design is similar to a twin-screw extruder, except that the product is not forced through a die, nor is it normally melted. These, as well as single rotor mixers are useful for continuous mixing processes, and will produce a high degree of mixing for homogeneity.
- iii. Kneading mixers consist of two kneading arms that intermesh as well as form a close tolerance to the mixer wall. These are effective for pastes such as adhesives, toothpaste, and flour-based doughs. Mixing is accomplished via a combination of stretching, squeezing, folding, and shearing in between kneading arms and walls. This multiple action makes kneading mixers effective for heat transfer as well.
- iv. Rubber and plastic compounds present unique mixing challenges because of their high elasticity. High shearing forces are required, and a common solution is the Banbury® mixer (See figure 5). This high-torque, low RPM mixer shears material between two thick blades and the mixer wall. It typically has thick shafts and requires very high HP per unit volume for mixing. As the friction is very high, temperatures of the materials will rise. Potential for off-product or degradation can occur unless there is a cooling jacket. Shear forces are not especially high, however mixing is usually done under pressure as a mechanical ram forces material to the blades. These mixers are great for granular dispersions in plastics and for other compounding operations.

C. One final note on the mixing equipment in operations where liquids are processed or gases injected into liquid streams. For these situations, an in-line static mixer can be used. These have no moving parts, but consist of a cylindrical length (usually right inside a process pipe) that has a series of short elements that split fluid and make a 90° twist. The fluid is then recombined with half of the other stream, split again, and another twist occurs. (See figure 6). As flow progresses, split streams recombine and twist again repeatedly. Between eight and 20 such splits will provide adequate mixing. This is a low-maintenance way to achieve mixing, but the corresponding pressure drops in the pipe will require additional upstream pumping to overcome the friction from the twisting elements.

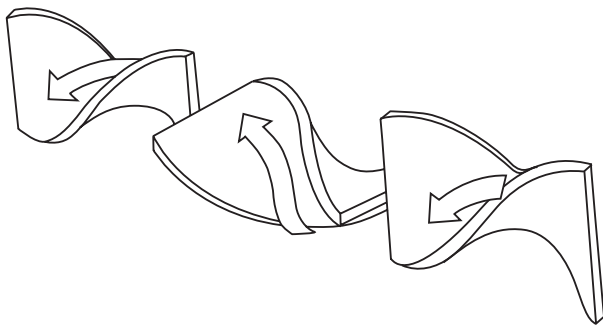


Figure 6. Static Mixer Elements (Arrows indicate fluid flow).

## Power Transmission Equipment

Unless static mixers are being used, all agitators and tumblers must somehow be driven, and this usually means at least a motor. With variable speed mixing, a drive is involved as well. Typically, a dedicated mixer that operates under constant flow, residence time, and product composition can be run adequately with an across-the-line motor and starter. All other cases will require variable speed drives or at least a multi-speed motor.

1. For mixing tanks with liquids, AC variable speed drives are well established and recognized for features such as:

- A. Energy savings from adjustable speeds.
- B. Soft starting, which reduces equipment wear, is easier on bearings, seals, etc.
- C. Ability to easily change speeds without having to change belts and gears. This is also an advantage when foaming,

cavitation, and vortex formations are a concern.

D. AC motors do not have brushes or commutators, therefore are lower maintenance. Furthermore, they can be operated in severe environments where mixing corrosives or volatile materials takes place.

2. Recent AC drives developments have also made them "smarter" in a variety of ways. Some of these smart features are:

A. Frequency avoidance bands to help eliminate the harmful effects of resonance.

B. Ability to operate at current limit even if this is below desired speed. Instead of causing a fault, the mixing will occur at reduced speeds. This may be useful where solutions start out at high viscosity, which lowers as mixing proceeds. This is a typical advantage of "trip-free" operation.

C. High starting torque occurs when, for example, the mixing process for a settled suspension is started. AC vector drives can provide this necessary starting torque.

D. Starting into a rotating load without an enormous current draw will prevent trips. Plus, it will be easier on the equipment. Again, AC drives that have this feature will be successful here.

E. In the course of mixing, some end product may have properties that change with time and are different than the initial charge. Some measurable variables such as viscosity, which will also change current requirements at a given speed, can be monitored so that its change signals the completeness of the process. By way of current detection in drives, they can be used to determine when a batch is complete and initiate the next action in a process. When used this way, drives can save on energy and optimize product quality.

3. Mixing of pastes, solids, and doughs has historically been the domain of DC drives. Starting up a charged kneader-mixer for example will follow a much different torque profile than a stirred tank with liquid. Typical DC advantages have been:

A. High starting torque capabilities and wide constant-load speed changes.

B. Good mixing and adequate speed control in voltage regulation.

C. Response to changes in loads (example: the addition of water to a dry flour mixture to make dough will increase torque as the flour particles interact with the water.)

D. Motor designs that feature high overload capabilities and can be designed for individual applications.

Recent advances in AC drive technology, notably AC vector control, have allowed them to become viable candidates in situations described above as well. High dynamic response, active torque control, and constant torque speed ranges of 120 or more are key features with newer AC designs. Furthermore, the suitability of AC motors in harsh environments and their lower maintenance needs also help make the case for AC drives for pastes, and solids mixing.

Regardless of the choice between AC and DC for a mixer, Reliance Electric has the right products and technologies to provide good solutions.

- Microprocessor-based regulators.
- Easy-to-configure drives with quick-start capabilities.
- Control from any number of sources: local, remote, network, serially to a PC.
- AC and DC motors that are specifically designed for severe duty environments and applications that can be typical for mixing processes.
- Easily modified with a wide variety of optional kits available for those extra special applications.

When it comes to mixing and its application technology, Reliance Electric has the answers.

NOTE: This material is not intended to provide operational instructions. Appropriate Reliance Electric Drives instruction manuals precautions should be studied prior to installation, operation, or maintenance of equipment.

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