SPECIFYING MOTIONLESS MIXERS

The operating cost for the energy necessary to mix fluids with a motionless mixer is usually far lower than for any competitive mixing technique. An extruder which melts, mixes and pressurizes polymer chips uses up to 0.1 kWh per pound of plastic processed. A motorized rotary in-line mixer uses 0.01 kWh per pound of material mixed. A motionless mixer operating with 10 psi pressure drop uses only 0.00001 kWh per pound more energy than is normally required to transfer the fluid through the pipe.

Motionless mixing means the mixing device has no moving parts. Conduits, plates or baffles within the device manipulate the fluids to divide, recombine, spread, rotate, eddy, swirl or jet the fluids such that they are mixed with the least expenditure of energy and time possible. The fluids are transported by pump or gravity. While most motionless mixers are constructed from carbon steel or stainless steel, they can be built from almost any construction material. The best motionless mixer is the one that delivers the mixing quality desired at the lowest pressure drop, for lowest installed cost and fits in the space available. Ideally, it would be useful to test the mixing ability of each of the various types available with the actual materials to be processed. However, in a practical sense, that is not possible. It is necessary to rely upon recommendations and the literature of the various mixer suppliers.

The mixing quality desired needs to be defined. It is never enough to specify “good” mixing. It must be specified as to sample size, sample frequency, sampling technique, test method and the average concentration and distribution of that concentration. The desired distribution of concentration must be meaningful in view of the use of the product. A mixing line for bottling shampoo and a mixer for catalyst and epoxy resin have very different mixing requirements. The specified end results must be determined and provided to the mixer supplier. The motionless mixers commercially available are of four general types: a series of semi-elliptical baffles, a series of directed channels, a series of helixes and a series of parallel corrugated plates. In order to design a motionless mixer, it is essential to define the properties of each component and the mixture.

Flow rate: It is necessary to know the average flow rate of each component to be mixed, the variation above and below the average and the time period of the variation. A pulse flow that has a cycle time longer than the residence time in the mixer will not be mixed properly. A flow leveling device such as a surge tank may be required to effectively mix a pulse flow. Special care needs to be taken that a minor stream doesn’t collect at the wall, in a “T” connection, or the flow momentum of the major stream doesn’t pulse a minor stream. A minor stream needs to be added from a centrally located injection nozzle. The nozzle should have enough pressure drop to prevent the major stream from influencing its flow. The major stream should wipe the minor stream away smoothly from the injection nozzle. The location of the injection nozzle should be close (less than half the mixer diameter, if possible) to the upstream entrance of the motionless mixer to preclude resegregation of the streams.

Physical state: Motionless mixers mix gases, liquids and solids. Mixing gases with gases is usually an easy mixing task, but the mixers are most often relatively large due to low pressure drops available. Applications range from simple tasks such as preventing hot/cold segregation in laminar flow air conditioning systems to premixing reactants before use in large gas reactors. Contacting liquids and gases is a very useful application of motionless mixers. Calculating pressure drop can be difficult due to the two-phase flow regime. If the system is also near the boiling point or saturation point for the gas in the liquid, the pressure drop calculation can be complicated by the increased boiling or degassing as the fluid goes through the mixer. Cavitation erosion is a potential problem. Liquid/liquid mixing is the most common process used with motionless mixers. All the liquid properties have an impact on the design of the motionless mixer. Especially important are the relative flow rates, viscosities and viscosity ratios, surface tensions and specific gravities. In solid/solid mixing, the unit is usually vertical with the flow being by gravity only. The material is removed below the mixer with a star wheel, auger or other solids moving device. It is important to maintain the mixer full. Ingredients should be added in the correct ratio as the level drops. The mixer must be kept full because whenever there is a free area to form a flow cone or moving surface, resegregation can occur. The solids being mixed usually have different aspect ratios (length to width or other significant geometric shape difference), size, density, surface characteristic (slippery or sticky), or static charge. The exit of the mixer must be connected as closely as possible to the use location such as a package filling operation, extruder, liquid resin contact injection molding, or powder metallurgy forming step. The mixed materials should never be shaken, have free surface, vibrated, or stored for later use, as resegregation is always a probability. The angle of repose of the solid is a significant design parameter. The design of the motionless mixer must be that no surface inside the mixer is within 5-10 degrees of the angle of repose. Otherwise, the material will hang up or build up areas that are segregated rather than flow through the mixer.

Viscosity: The viscosity and the flow rate are the most important parameters for the design of the physical size of the mixer. The ratio of the viscosities of the various streams is the most significant for mixing efficiency. The motionless mixer does an ideal, absolutely predictable mixing job for a system with two miscible liquids with equal viscosity, density, no interfacial surface tension, flowing at equal flow rates with no pulses. The designer of a system incorporating a motionless mixer needs to take into account the influence of all the parameters which deviate from the ideal case.

Pressure drop: Before calculating the pressure drop through a motionless mixer, it is necessary to know if the regime is generally laminar or turbulent. The Reynolds number (N-re) is used to make the determination. (*formula)*

For motionless mixers, if N-re is less than 500, the flow is probably turbulent. The pressure drop (DP1) for laminar flow can be estimated by DP1 = *(formula)*

Similarly, the pressure drop (DP1) for turbulent flow can be estimated by *(formula)*

With these formulas, it is possible to take a motionless mixer manufacturer's design and pressure drop and estimate the pressure drop for a different diameter or flow rate. The number of elements necessary to obtain the desired level of fluid mixing is a strong function of the ratio of the viscosity of the primary and minor streams.

As a practical matter, the greater the pressure drop allowed to force the material through a motionless mixer, the better the resulting mix. This is especially true in turbulent systems where the excess energy input shows up as increased eddy turbulence, backflow eddies, shear forces and rotational flow. Likewise, there is an improvement in laminar systems as the pressure drop increases. Gravity forces on the materials with different densities are increasingly negated as the pressure drop increases. The shear spreading forces of droplets of different viscosities are enhanced to begin layer generation. As more pressure drop is allowed, a smaller diameter mixer can be used and the time period from when a catalyst is injected into a resin until it is completely mixed is reduced. Unwanted concentration-dependent side reactions are suppressed. As the pressure drop across the mixer increases, it is necessary to ensure that the structural rigidity of the motionless mixer is sufficient to withstand the force. One failure mode for some motionless mixers is crushing.

It is necessary to specify the working or system pressure to design the pipe housing and end connections. The mixing operation of the motionless mixer itself is independent of the system pressure. Motionless mixers fit in any pipe schedule or tubing. All common end fittings are available; i.e., slip-on, weld neck and lap joint flanges, and threaded ends.

Design features available as system add-ons include injection nozzles, heating and cooling jackets, removable and non-removable elements. Jacketing a motionless mixer can be valuable in many cases. A motionless mixer can increase the heat transfer rate of a viscous material flowing in laminar flow from two to five times that of the same material flowing in the empty pipe. If the material is exothermic (or endothermic) or very hot or cold relative to the surrounding conditions, the heat exchange through the jacket can be used to effect the desired temperature.

The fundamental reason that motionless mixers are used is that, in many applications, the required level of mixing can be predicted, obtained and maintained at lower cost and more reliably than with motorized mixers. Many motionless mixers are used in conjunction with motorized mixers. For example, the first part of a preparation may require a high energy or high shear motorized mixer to prepare a pumpable liquid. The next step may be the metering of the preparation to a continuous process. A motionless mixer may be used to blend the liquid with the process stream. In this case, use of a motionless mixer complements use of a motorized mixer.

Specifying Motionless Mixers

A. Material properties

1) Flow rate
2) Physical state
3) Viscosity
4) Specific gravity
5) Surface tension
6) Temperature
7) Name of material
8) Hazard classification

B. System properties

1) Allowable pressure
2) Working pressure
3) Preferred material of construction
4) End connections
5) Injection nozzles
6) Jacketing Required
7) Removable or non-removable elements
8) Space limitations
9) Desired diameter

C. Process requirements

1) Exothermic reaction (or endothermic)
2) Setup time for reactive polymer systems

A statistical description of the mixing required