

Motionless Mixers: Can They Work In Your Application?

Static mixers are low cost, simple devices, which can provide a huge impact on mixing process results.

By Mughis R. Naqvi

Motionless mixers (also known as the static mixer, inline mixer and pipeline mixer) allow for the mixing of two or more fluids, and also enhance mass transfer in continuous operations. This eliminates the need for a tank vessel and a dynamic mixer (requiring a motor, drive, shaft and impellers), especially where residence time is not a factor. The motionless mixer can also enhance and improve mixing processes of existing dynamic mixing vessels, via the recycle loop, with the introduction of the chemicals prior to the motionless mixer, instead of having chemicals dumped directly into the vessel.

The motionless mixer is an effective answer to the end user's mixing requirements. Operating inline and continuously, the unique no moving parts mixer blends and disperses treatment chemicals into fluid streams. Consider these advantages: zero maintenance, low cost, energy savings and the ease of installation.

Motionless mixers, as compared to dynamic mixing devices, are maintenance free and have no external power sources to rely upon, except for the pump to overcome pressure losses in the mixer.

BACKGROUND

The spiral type motionless mixer geometry is based on the original and now popular design concept developed by Arthur D. Little back in 1965, and applied by Kenics. By

1988, the design was further improved by TAH, for disposable throw away uses to handle two component high viscosity applications specifically for the adhesives and sealant industry. TAH's baffle type Stata-tube design was created in the mid-70s for the low viscosity, water-like applications, commonly seen in many applications, including CPI and water/wastewater treatment industries.

Static mixers have been patented as far back as 1895. Even today, you will find in some processes, out of desperation, and due to quick-fix situations, where pipe is filled with bottle cap openers. One engineer stated he still goes out and buys dog chains and throws them in his pipe for mixing.

Chemical industrial companies, such as Dow Chemical, came up with their own designs to solve problems, such as efficiently dispersing titanium dioxide and silicates with a viscous polymer, prior to spinning it into textile fibers. Dow called their mixer the Interfacial Surface Generator (ISG). Other companies, such as Phillips Petroleum, Lightnin, Koch and TAH also began to market static mixers in the early 1970s. Presently, there are about a dozen companies involved in the manufacturing of static mixers in North America.

ELEMENTS OF MIXING

A particularly successful, yet simple mixer, is the spiral geometry. Metallic or composite strips are twisted, ma-

chined or injection molded through 180° twists to form helical elements of right-hand and left-hand rotation. Alternate right- and left-hand elements are joined so that their respective leading and trailing edges are mutually perpendicular.



Process streams entering the above-depicted mixer are divided into numerous sub-streams as they spiral through the mixer.

These sub-streams are progressively recombined and re-divided between opposing baffles in an overlapping manner. The number of flow divisions becomes very large, producing a mathematically predictable blend.

The assembly of elements is inserted into a tube, which has a bore diameter nominally equal to the width of the elements.

Two fluids, respectively designated *A* and *B*, are separately injected into the semicircular passage formed on either side of the first element. Then, the two streams rotate due to the physical constraint of the helix as they flow along the tube.

In the first element, therefore, half of the total channel cross section is filled with fluid *A*, and the other with fluid *B*. On entering the second element, each semicircular stream is split due to the perpendicular orientation of adjacent elements. So, two layers, one of *A* and one of *B*, flow in both passages of the second element. Also, note how the flow rotates in the opposite direction due to the left-hand orientation of the second helix.

This process is repeated at the interface between adjacent elements, so that the number of layers of both fluids in each semicircular passage is doubled by each element. Therefore, a mixer containing 10 elements would produce 2^{10} (1,024) alternate layers of fluids *A* and *B* in each semicircular passage at the mixer exit. These layers of fluid become sufficiently thin in practice, to produce virtually perfect plug flow mixing.

$$d = \frac{D}{2^n}$$

Where (*d*) is the striation thickness,



The above figure shows a spiral mixer, blending a black with white epoxy, in a series of 10 spiral-mixing elements. Note the striations.

and (*D*) is pipe I.D. over the number of splits in the stream, (2^n) to the power of (*n*) = number of elements.

Motionless inline mixing applications are numerous, and are required in all types of industrial applications. The baffle type mixer consists of a series of semi-elliptical baffles overlapped in a pipe. The unique geometry ensures effective inline mixing, virtually eliminating density, temperature and concentration gradients.

Enhanced mixing by the motionless mixer suggests improvement in heat and mass transfer characteristics. Keeping in mind as you increase flow rate, or decrease mixer diameter or increase the number of elements in a string, the pressure drop will increase.



TAP's baffle type static-tube mixer design was created in the mid-70s for multiple flow divisions.

MOTIONLESS VS. STIRRED TANK

Analogous to dynamic impeller/shaft mixers, more commonly seen in the process industries, we can relate mixedness to blend times and tank turnover rates.

In a stirred tank vessel, we can take the volume of the fluid (gallons) in the tank, and divide by the fluid pumping capacity (gallons per minute), exiting the impeller to calculate the time (minutes) required for one tank turnover. Typically, in a majority of the cases, the time required to achieve 12 tank turnovers is considered a good blend time.

Some applications may require more or less turnovers, depending on process, residence times and the types of impellers used. In this mixing system, random motion occurs, as well as hydraulic instability. The number of striations is difficult to predict, as well as what fraction of flow exerted by the impeller actually goes into, pumping verses shear energy.

In the end degree of mixedness is qualitative, and in recent years with advances in technology, mixing has arrived at a scientific approach for both dynamic and static mixers.

Ask yourself these questions, when using a mixing device:

- Did you get a mixer to perform the mixing required in your process?
- How do you measure mixedness, or degree of mixing in your particular process?
- You may have too much mixing or maybe too little mixing — can you tell by how much?

A static mixer fits right into the pipeline, and consists of flanged ends, a piece of pipe and some twisted metal configurations inside to direct flow for mixing. The static mixer requires no external power, and has a lower capital cost, lower maintenance cost, as well as lower operating cost, as compared to the dynamic mixer.

The theoretical HP of a static mixer = $0.262 \times \text{pressure drop (psi)} \times \text{flowrate (cfs)}$.

Being a plug flow device in a continuous operation with very little retained volume, the static mixer also has a lower residence time than the typical vessel dynamic mixer. The static mixer has the potential to plug up when mixing sludge, certain slurries and most fibers. Then again, the impeller in stirred tank vessels can also wrap around fibers and rags, causing considerable damage to shafts and gearboxes, if not properly sized to handle overloading.

A static mixer has a uniform controlled degree of flow and shear, where the dynamic mixer has some backmixing, with variations of flow and shear throughout the vessel, near to and far from the impeller.

When mixing low viscosity fluids (turbulent flow) in a static mixer, the degree of mixing is dependent on flow rate through the mixer. In a dynamic mixer, you can always increase or decrease impeller RPM, and change impeller diameters to adjust for change in process conditions, as long as the existing motor allows for increased amp draw.

MIXER FUNDAMENTALS

Static mixers work on the principles of diffusion, convection and shear to achieve homogeneous blends. Blending as depicted by the following... is a function of...

$$\text{Blending} = f \left\{ Re, \mu, \frac{\mu_1}{\mu_2}, \frac{\rho_1}{\rho_2}, \frac{V_1}{V_2}, v, n, \frac{L}{D}, Inj \right\}$$

Where Re = Reynolds Number
 μ = Absolute viscosity
 μ_1/μ_2 = Viscosity ratio of unmixed streams
 ρ_1/ρ_2 = Density ratio of unmixed streams
 V_1/V_2 = Volumetric ratio of unmixed streams
 v = Shear rate
 n = Number of elements
 L/D = Element length to diameter ratio
 Inj = Injection method of additive stream

The Reynolds number can be calculated by the following...

$$Re = 3157 \frac{Q \cdot sg}{\mu \cdot D}$$

Q = Flow rate (us GPM)
 sg = Specific gravity
 μ = Viscosity (cps)
 D = Pipe inside diameter (inch)

As a rule of thumb, at higher Reynolds number (turbulent flow), we will need less mixing elements than at lower Reynolds. Typically, for spiral mixers, a majority of applications require two to six mixing elements for Reynolds numbers greater than 5,000. Anywhere from 12 elements and higher will be needed for laminar flow with a Reynolds number a lot less than 5,000.

USEFUL CALCULATIONS

The mixing and shear rates are determined by calculating the pressure drop across the static mixer

$$\Delta P_f = \frac{1.125 \times 10^{-3} \cdot f \cdot l \cdot Q^2 \cdot \rho}{D^5}$$

ΔP_f = pipe pressure drop (psi)
 f = Darcy friction factor
 l = Element length (inch)
 Q = Flow rate (gpm)
 sg = Specific gravity
 D = Pipe inside diameter (inch)

Knowing the pressure drop across an empty pipe, and the coefficient of friction caused by the static mixer elements, we can determine the pressure drop across the mixer.

$$\Delta P_{\text{StaticMixer}} = \Delta P_{\text{Pipe}} \cdot C_{\text{friction}}$$

Velocity Gradient (G), is a common value calculated to compare mixer performance in shear sensitive applications that involve polymer flocculants, especially in the water treatment industries.

$$G = \sqrt{\frac{\Delta P \cdot v}{\mu \cdot l}}$$

Where (G) is the average shear rate; μ is the viscosity; l is the mixer length; (v) is the velocity and ΔP is the mixer pressure loss.

THE MIXER INDUSTRY

The static mixer industry is predicted to be worth about \$100 million/year worldwide, as compared to the one billion U.S. dollar worldwide dynamic mixer market. While the dynamic mixer market is relatively stable and growing in a single digit percentage, static mixer demand is growing in the seven to 15 percent/year range. One reason could be accredited to the fact that every day, new applications are being found where the static mixer has been found to have some beneficial use.

As engineers become more and more knowledgeable about and comfortable with the static mixer, the usage of static mixers in continuous applications rises.

Static mixers are used widely in the CPI industry, which includes polymerization processes, followed by the use in the water/wastewater sector, pulp and paper, petroleum, food, mining and other related industries.

Some typical application uses in the static mixer industry, along with rough

sizing guidelines, are shown in the table on page 63.

Static mixing is partially based on velocity and pressure drop values.

Some application suggestions include:

- Raw water blending: Two to four mixing elements, at a velocity of one to three fps.
- Flash mixing: Two to four elements, at a velocity of three to five fps.
- pH control: Four to six elements, at a velocity of three to five fps.
- Chemical premixing: Two to four elements, at one to three fps.

Other common uses for static mixers are in shell and tube heat exchangers for heating and or cooling viscous materials. Injection molding and the extrusion industry also commonly use static mixers for heat transfer, as well as uniform color dispersion.

DISPOSABLE STATIC MIXER MARKET

Another growing industry where static mixers are used, is the dispensing of two component epoxy, adhesives and sealants.

To avoid recycling costs of the solvent used to clean the static mixers, the mixers are thrown away after each usage. Static mixers are used in the solid surface counters industry.

The automotive industry is a heavy user of disposable static mixers, with the use of sealants and adhesives in the assembly of automobile components. The same goes for the aircraft industry, and any industry that uses two component glues during assembly.

The dental and hearing aid industries use static mixers to mix impression ma-

Process	Recommended Minimum Velocity Through the Static Mixer*	Recommended Minimum Number of Elements
Liquid-Liquid Dispersions ^b		
Drop size = 1,000 microns	2 ft/sec	4
100 microns	5 ft/sec	4
10 microns	7-8 ft/sec	4
Liquid emulsions	10 ft/sec	4
Multiphase dispersion	5-10 ft/sec	4
Dissolved air separation	10 ft/sec	4
Flash mixing (waste water treatment)	3 ft/sec	2
Chlorine bleaching of paper pulp	2-3 ft/sec	8
Simple blending applications	1-5 ft/sec	2

*It is recommended that a minimum fluid velocity of 1.0 ft/sec be maintained for turbulent flow applications.

terials.

Typical applications:

- Reynolds number less than 500: 12 to 40 elements
- Adhesives and sealants: 16 to 40 elements

CONCLUSION

Static mixers are an intelligent option for continuous mixing solutions. They are used commonly in conjunction with stirred tank mixers, to enhance mixing process results. Overall, the static mixer is a low cost, simple device, which can provide a huge impact on mixing process results.

About the Author

Mughis Naqvi graduated in 1989 from

McGill University, with a bachelor's degree in chemical engineering. He has over 10 years of practical mixing experience with the stirred tank mixer market in Canada and United States for various industries. Currently, he works for TAH Industries. He is a member of the North American Mixing Forum, a subgroup of AIChE, and a licensed professional engineer in Canada.

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