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INTRODUCTION

Scope

This guideline covers the basic elements of static mixer design in sufficient detail to allow an engineer to design a static mixer with the suitable size including diameter, length, media velocity, and pressure drop.

For static mixers, as with any process equipment, successful sizing and selection is always a combination of empirical observation/experience and analytical modeling. The best static 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.

The design of a static mixer may be influenced by factors, including process requirements, economics and safety. In this guideline, there are tables that assist in making these factored calculations from the various reference sources. Included in this guideline is a calculation spreadsheet for the engineering design. All the important parameters used in the guideline are explained in the definition section which helps the reader understand the meaning of the parameters or the terms utilized.

The theory section explains source, type of static mixer and its characteristic of moving, orientation and how to calculate pressure drop and selecting the static mixer. The application of the static mixer theory with the example assist the engineer to study the static mixer and be ready to perform the actual design of the mixer.

General Design Consideration

A static mixer or motionless mixer is a device inserted into a housing or pipeline with the objective of manipulating fluid streams to divide, recombine, accelerate/decelerate, spread, swirl or form layers as they pass through the mixer. As a result of these alterations in the fluid flow, mixture components are brought into intimate contact. Static mixers are therefore utilized not only for strictly mixing requirements but also reaction processes. Different designs are available, typically consisting of plates or baffles positioned in precise angles in order to direct flow, increase turbulence and achieve mixing.

Flow in an empty pipe produces some degree of radial mixing but in most cases, adequate mixing can only be achieved by an impractical length of pipe. Inserting a static mixer significantly accelerates inline mixing or reaction. This technique is essentially desirable wherever a continuous, inexpensive and fast operation is required. Since there are no moving parts in the static mixer, it is basically maintenance-free and can be installed as easily as any piece of pipe.

Energy for mixing is available in the form of pressure. Whether material is gravity-fed or forced through the mixer using external pumps, pressure loss is one consequence of static mixing and is sometimes the limiting factor in mixer selection.

The best static 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.

Since static mixers rely on external pumps to move product across the mixer elements, pressure drop often serves as a basis for selecting the appropriate static mixer. In many cases, the type and number of mixer elements are chosen so as to affect the best mixing possible without exceeding a maximum allowable pressure drop.

Over the years a large number of companies have produced static mixers all based on the principle of moving the streams radially by a series of metal baffles. These baffles may consist of twists of metal, corrugated sheets, parallel bars, small-diameter passages, or tabs sticking out from the wall. They are essentially plug flow devices with some small degree of back mixing, depending on the exact design.

Examples of the most commercially significant static mixers for pipelines are by type.

General Static Mixer K

The General K in-line mixer consists of a number of elements of alternating right and left-hand 180◦ helices. The elements are positioned such that the leading edge of each element is perpendicular to the trailing edge of the preceding element. The length of the elements is typically one and a half tube diameters. This type of static mixer is used for mixing under laminar flow conditions, such as the mixing of polymers or food products like peanut butter and chocolate.

In the General K, a set of twisted elements with left- and right-hand twists caused the material to move from the wall to the center and from the center to the wall. The flow in each channel circulates around its own hydraulic center causing radial mixing. After traveling through a number of these elements, the fluid is homogenized with respect to age, composition, and temperature. Since for each element the rotation is in the opposite direction than in the previous element the shear at the interface of the two becomes great (Paul et al, 2004).

1. KMS: twisted ribbon or bowtie type, with alternating left- and right-hand twists. An element is 1.5 or 1.0 diameter in length. The KME variation is edge sealed to the tube wall.
2. KMX: a series of inclined retreat curve rods forming an X lattice; alternating in direction every diameter an element is one diameter in length.
3. HEV: a series of four tabs spaced around the pipe. An element consists of four tabs symmetrically placed. Axially, the tabs are about 1.5 diameters apart. The traditional helical mixing element is used primarily for in-line blending under laminar and transitional flow conditions. The high efficiency vortex (HEV) mixer is used for turbulent blending of gases or miscible liquids. It consists of a series of tab arrays, which are placed along a length of pipe. The advantages of this design are that it is easily adapted to both cylindrical and square pipe cross-sections and that it has a relatively low pressure drop. HEV mixers have been in use in the process industries for several years now, for both liquid–liquid and gas–gas mixing. Applications include wastewater treatment, burners, exhaust stacks, beverage manufacturing, and many others.

General G

The General G mixer is constructed of corrugated panels with the corrugation at a 45^o angle to the linear axis. Separate panels, all one diameter long, are welded together lengthwise, with each panel having the corrugations running in a perpendicular direction to its neighbor. This set of panels, defined as one element, cause a two dimensional mixing pattern. Successive elements are rotated 90^o forming one long unit as well as a third mixing dimension.

1. SMV: several stacked sheets of corrugated metal running at 30 or 45◦ to the pipe axis. Each element is 0.5 to 1.0 diameter in length and adjacent elements are rotated 90◦ relative to each other. Mixer hydraulic diameter is determined by the height of the corrugation or the number of stacked corrugated sheets.
2. SMX: guide vanes are intersecting bars at 45◦ to the pipe axis. Each mixing element is 1.0 diameter length. Adjacent elements are rotated 90◦.
3. SMXL: similar to the SMX but with intersecting bars at 30◦ to the pipe axis. Typically, fewer bars per element, and the element length is variable, depending on application.
4. SMR: guide vanes are hollow tubes through which heat transfer fluid circulates. The tubular bundle is arranged similar to the shape of the SMX design.
5. KVM: single inclined tab mounted off the tube wall. Axially, tabs are about 2.5 diameters apart.
6. KHT: twisted ribbon with alternating right- and left-handed twists.
7. SMF: three guide vanes project from the tube wall so as not to contact each other. This is a special design for high plugging applications. Element length is approximately 1.0 diameter.
8. KFBE: special version of the SMX/SMXL design with guide bars for exclusive application in gas fluidization of solid particles.

General M

1. General M mixer: crossed elliptical plates with a flat at the centerline. Adjacent mixing elements are rotated 90◦.

General R

1. ISG: solid tube inserts with shaped ends so that adjacent elements form a tetrahedral chamber, each with four holes drilled at oblique angles.

   ISG Sample Applications
   - Color blending
   - Delustering of polymer dopes
   - Water/fuel oil emulsions
   - Blending of viscous fluids
   - Injection molding and extrusion applications (mounted in the nozzle)
   - Submicron emulsions
   - Resin-catalyst mixtures
   - Fiber-reinforced composites
   - Sanitary emulsions

2. LPD (Low Pressure Drop): Static Mixer consists of a series of semi-elliptical plates discriminately positioned in series. As the product moves through each element, flow is continuously split into layers and rotated 90 degrees in alternating clockwise and counterclockwise directions.

3. LLPD: LLPD mixer is constructed of semi-elliptical panels. Two panels are connected together in the middle at a 120^o angle (one element). Each element is fitted in a pipe with each neighboring reversed and rotated 90^o along linear axis.

   LPD and LLPD static mixers are used in many processes including:

   - Blending different grades of oil or gasoline

- Mixing two or more liquid resins
- Dilution of concentrated solutions
- Water and wastewater treatment
- Gas-liquid dispersions
- Pipeline reactions
- Oil/water and water/oil emulsification
- Biodiesel production
- Blending anti-oxidants and other additives
- Chlorine dioxide bleaching of pulp
- Inline addition of flocculants
- Homogenizing process streams for sampling
- Adjusting viscosity
- Chemical suspensions
- pH control

Table 1 provides rough guidelines for applications in the laminar and turbulent flow regimes. Equipment selection and sizing should be based on application engineering to meet specific process requirements.

Table 1: Rough Guidelines for Applications in the
Laminar and Turbulent Flow Regimes[a]
(Paul & Friends. 2004. Handbook of Industrial Mixing Science & Practice)

Flow Regime	Static Mixer Design									
	KMS	KMX	HEV	SMV	SMX	SMXL	SMR	KVM	SMF	ISG
Laminar										
Mixing/blending	c	a			c	c			a	a
High–low viscosity		a			c	a				a
Dispersion	a	a			c	a				a
Heat transfer	c				b	c	c			
Plug flow	b				c	b	c*			
Turbulent										
Mixing/blending										
High turbulence	a		c	c’				c		
Low turbulence	c			c	a	a			a	
Dispersion										
Liquid–liquid	c			c	a	a	c*		a	
Gas in liquid	c			c	a	a	a*		a	
Liquid in gas	a			c	a					
Fluidized beds					c”					

a, Applicable; b, typically applied; c, best design choice. *, Where temperature control is required; ‘, especially for very large diameters and nonround cross-sections; “, gas fluidized solid particles, specialized design

Basic Unit Operation Fluid Application Mixer

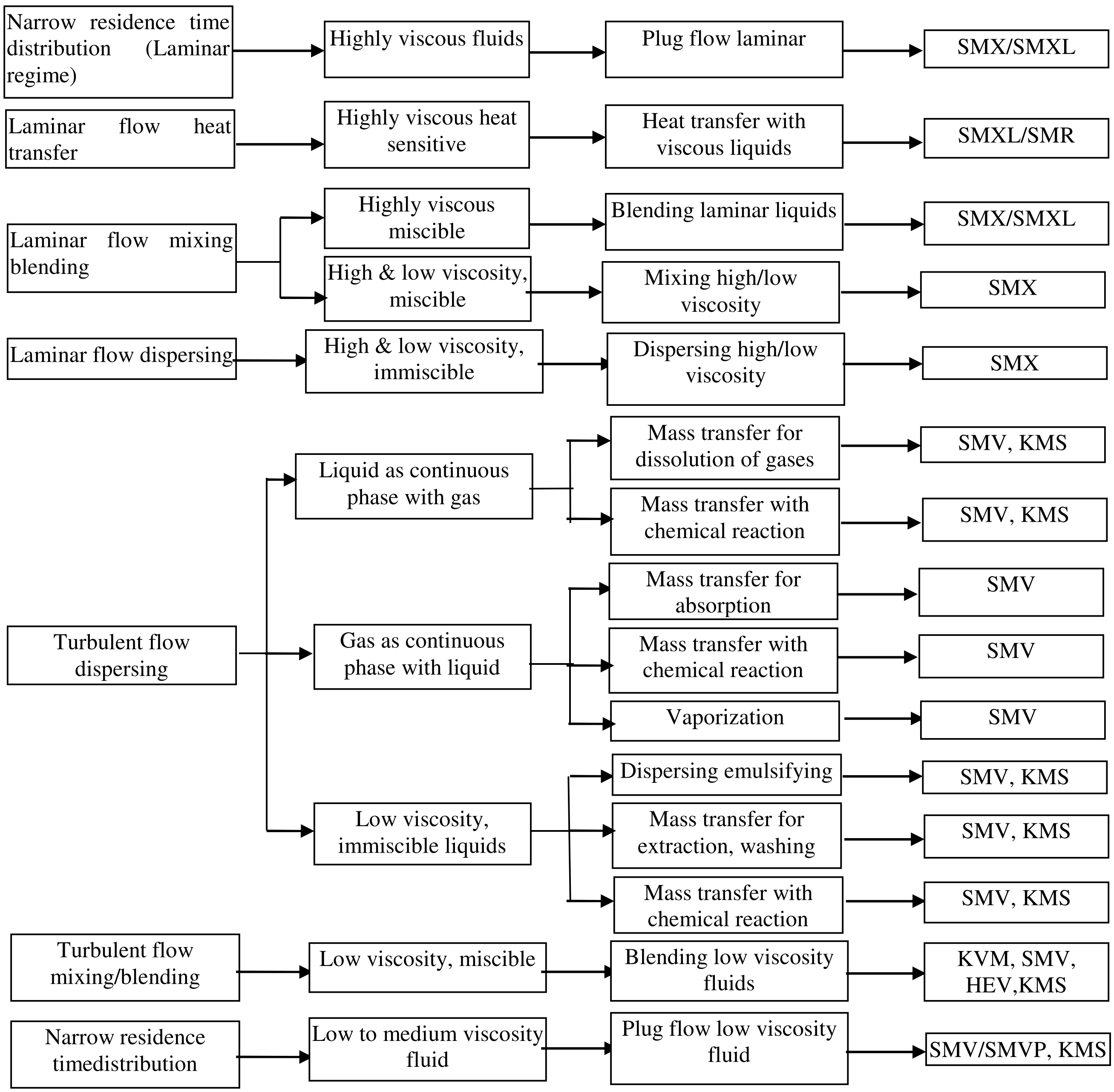


Figure 9: Correct static mixer design: applications
(Paul & Friends. 2004. Handbook of Industrial Mixing Science & Practice)

Static mixer in turbulent flow

Static mixers are well established in multiphase turbulent flow and meet industrial requirements for absorption, reaction, extraction, and heat transfer/phase change. Designs are engineered to achieve specific results at minimum cost and energy expenditure. The mixers are very compact, making them very attractive for single-stage contacting applications versus countercurrent flow options such as packed, tray, or mechanically driven towers.

Static mixers are recommended for multiphase flow applications with a continuous liquid phase and a dispersed gas or immiscible liquid phase. Turbulent shear is applied efficiently to the additive liquid or gas to create a dispersion or droplets or bubbles. The mean drop size depends on the energy expenditure. Also important is the drop or bubble size distribution. Static mixers are designed specifically for the application to create uniform drop size distributions with the interfacial surface area required for reaction or extraction. Uniform size distribution also facilitates downstream separation of the phases in some type of gravity or inertial separator. In addition to creating interfacial surface area, the static mixer performs bulk homogenization, ensuring that all flow components are distributed uniformly in the cross-section and exposed to similar levels of turbulent energy dissipation in the fluid surrounding the droplet or bubble.

The required mixer pressure drop or energy dissipation depends on the amount of interfacial surface area required for mass transfer-limited and reaction rate-limited applications as well as the required residence time when reaction rate is limiting. Surface area generation varies with power input per unit mass, and consequently, there are turndown limitations that must be considered when designing static mixer processes for multiphase applications. Scale-up criteria are well established for the static mixer designs that are used in turbulent multiphase flows. This is a very important consideration since many processes are lab scale or pilot scale tested prior to commercialization.

Static mixers in multiphase applications where the gas is continuous are typically highly structured designs, providing large surface area per unit volume. Surface area is needed for absorption of gas phase components, stripping of components from the liquid, condensation, or vaporization. The properly selected mixer is a compact, highly efficient phase contactor. Turbulent flow energy is used to break up the liquid feed, achieving some equilibrium droplet size and corresponding total surface area. Flow turbulence is maintained uniformly over the pipe cross-section in individual interconnected flow channels. Liquid that wets the mixer surfaces is continuously stripped off and re-dispersed in the gas stream.

Flow stability is maintained over a greater range of gas–liquid flows versus what would occur in an empty pipe, an important factor considering that liquid- and gas phase mass and volume flow rates could change significantly during the process as a result of phase change of all or part of the streams. As with all multiphase processes the initial drop (or bubble in the continuous liquid analog) size is an important design factor. Spray nozzles (with or without an atomizing fluid) are often used to create the initial drop size distribution utilizing additive stream energy and designing for relatively low mixer pressure drop.

In turbulent conditions, complete mixing is typically accomplished in just 4 or 6 elements with relatively minor loss in pressure. For low flow and/or high viscosity requirements, however, the number of static mixer elements of the design that is required to achieve a homogenous blend increases significantly. If the process set-up is limited in length, a move to a different style static mixer is recommended.

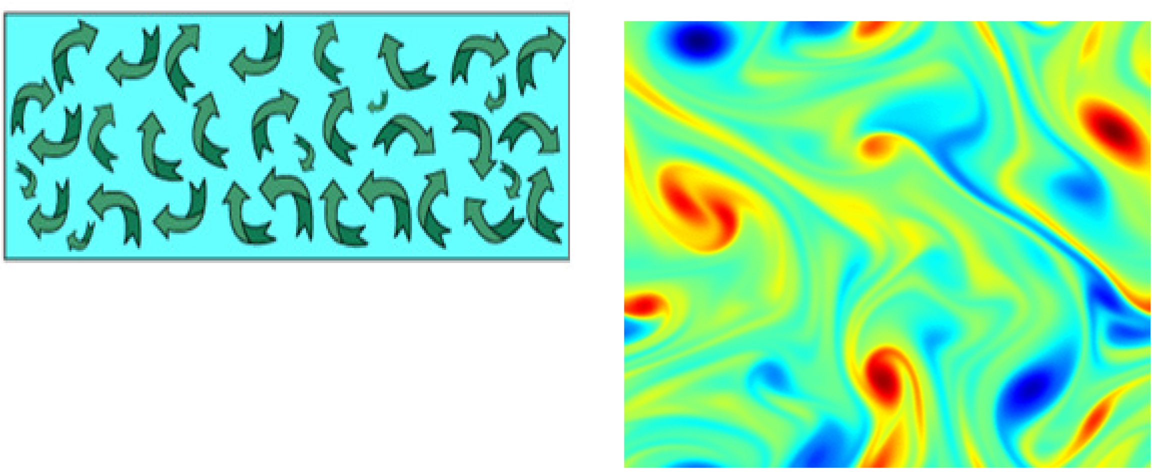


Figure 10: 2D turbulent flow regime (wiki.palabos.org)

Static mixer in laminar flow

When the flow is laminar, either single or multiphase, there is only one design class option: static or motionless mixers. Static mixers are proven in a broad range of laminar flow processes involving both Newtonian and shear thinning fluids. Some processes are more complicated than others. Very often, commercial installations follow laboratory or pilot scale evaluations, and success is dependent on proper scale-up. Scale-up methodology is well established for the predominant static mixer designs used in the laminar flow regime. In addition to mixing applications there is value in the use of static mixer packings to enhance laminar flow heat transfer and for creating plug flow in laminar tubular reactors.

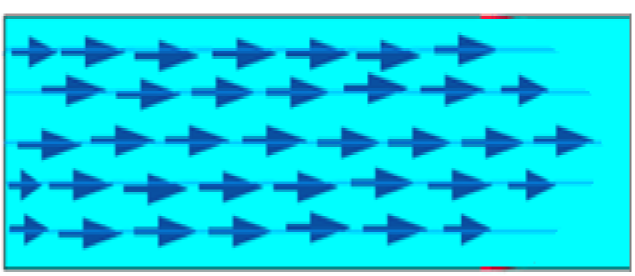
The mixer is designed to achieve the desired degree of homogeneity. The time required for diffusion may influence the mixer design. The optimum static mixer from the perspective of equipment design would be the one most compact and operating at the lowest pressure drop. The optimum mixer design would be the one that is the most efficient generator of fluid surface, or a high division rate device.

When laminar distributive mixing is complicated by viscosity differences, static mixer design options are limited. Elongational flow static mixers are required. When there is a resistance at the interface, the static mixer must be one that operates at uniform shear stress. Additionally, when there is some degree of immiscibility and a significant difference in viscosity, elongational shear has been demonstrated to be more effective then rotational or simple shear

Mixing efficiency is strongly dependent on elongational flows within the mixer structure. Mixing of higher viscosity material into a lower viscosity but laminar stream is not as common but equally difficult, requiring controlled elongational flows. Shear stressing of the additive gas or liquid results in it being extended to the point where it becomes unstable and breaks to smaller size. This process continues until the droplet or bubble is reduced to a size that is stable under mixer flow conditions. In addition to creating this dispersion, the mixer must also distribute the additive phase uniformly over the pipe cross-section. The structured X or cross-bar design is at this point in time, the only significant commercially available design for this very difficult application.

Table 2. Comparison of Static Mixers for Equivalent Homogeneity in Laminar Flow (Paul et al, 2004)

Mixing unit	Measured values		Comparison				
	L/D (CoV=0.05)	$Ne.Re_D$	Volume	Holdup	Diameter	Length	Pressure drop
SMX	9	1237	1	1	1	1	1
SMXL	26	245	1.8	1.8	0.84	2.4	0.6
SMV	18	1430	4.6	4.5	1.3	2.7	2.3
General	29	220	1.9	1.8	0.84	2.7	0.6
HV	32	190	2	2	0.84	2.7	0.6
K	38	620	8.9	8.2	1.3	5.4	2.1
L	100	290	29	27	1.4	15.3	2.6
PMR	320	500	511	460	2.4	86	14.5
T	13	1150	1.94	0.88	1.1	1.5	1.35
N	29	544	4.5	3.8	1.1	3.6	1.40
ISG	10	9600	9.6	3.4	2.1	2.3	8.6



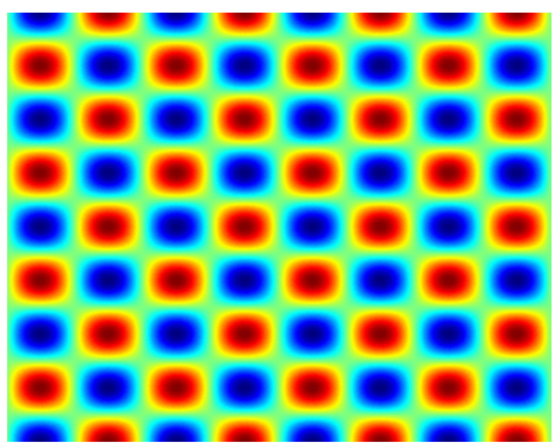


Figure 11: 2D laminar flow regime (wiki.palabos.org)

Static mixer in transition flow

Transition to turbulence is a process by which a flow passes from a regular (laminar) to an irregular (turbulent) regime as the Reynolds number is increased. Understanding the transition to turbulence is important for flow control and design optimization.

The transition between these flow regimes is set by the Reynolds number based on the pipe diameter. For a simple pipe the traditional number is 2100, but there is a large transition range. For static mixers the Reynolds number is usually much lower based on pressure drop. This is due to the much higher rates of energy dissipation due to the internals. The exact value depends on the mixer design but is in the 500 range for many. However, this transition is based on the change measured by pressure drop. There is very limited test work showing that the quality of turbulent mixing is poorer at low Reynolds number, due to these turbulence changes. Care should be taken in this region.

The General HEV mixer, which consists of tabs, shows a transition in mixing performance at a very high Reynolds number. This is believed due to the change in vortex structure off the tabs at a specific tab Reynolds number rather than a pipe Reynolds number. Since the tab/diameter ratio is kept constant, this occurs at a higher pipe Reynolds number.

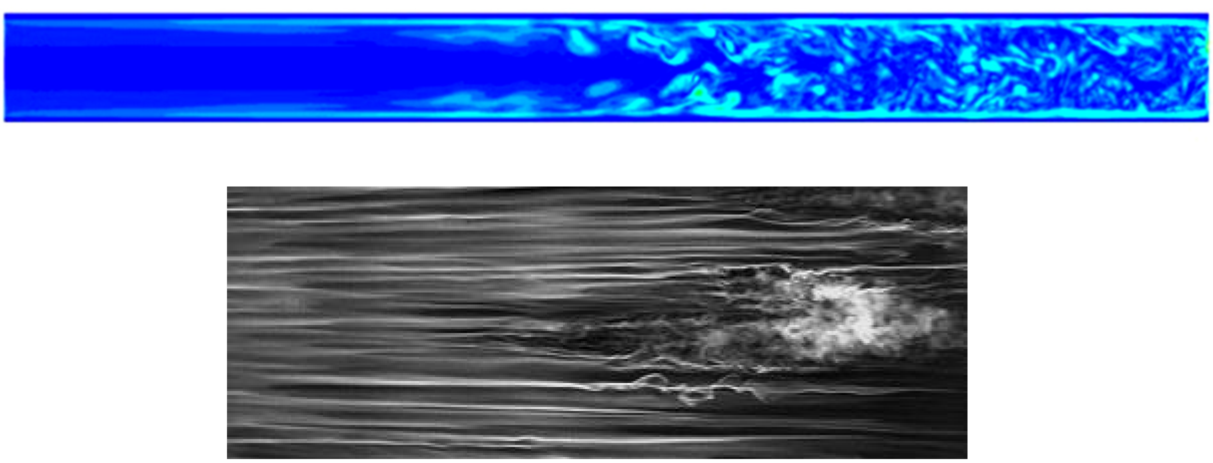


Figure 12: Transition flow regime (www.frontierlattices.ch)

In order to design a static 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.

Physical state

Static mixers mix gases, liquids and solids. Mixing gases-gases is usually an easy mixing task. Due to low pressure drops available, the mixers are most often relatively large. Contacting liquids and gases is a very useful application of static 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 static mixers. All the liquid properties have an impact on the design of the static 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. Below should be taking attention for solid-solid mixing.

1. It is important to maintain the mixer full.
2. Ingredients should be added in the correct ratio as the level drops.
3. Resegregation can occur if there is a free area to form a flow cone or moving surface, that's why the mixer must be kept full.
4. 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.

5. 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.
6. The mixed materials should never be shaken, have free surface, vibrated, or stored for later use, as resegregation is always a probability.
7. The design of the static 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 static 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.

Pressure drop

As a practical matter, the greater the pressure drop allowed to force the material through a static 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 static mixer is sufficient to withstand the force. One failure mode for some static 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 static mixer itself is independent of the system pressure.

Design features available as system add-ons include injection nozzles, heating and cooling jackets, removable and non-removable elements. Jacketing a static mixer can be valuable in many cases. A static 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 advantages which these static mixers boast over dynamic mixers are following:

1. Narrow residence time distribution
2. Use of a wide range viscosities (gases to highly polymer melts) as well as use for varied continues to dispersed phase viscosity ratios (10^{-2} to 10^{6})
3. Ready adaptation to existing pipe systems
4. Smaller place requirements
5. Negligible maintenance and wear, due to absence of moving parts
6. Low capital investment, operating cost, and energy requirement.
7. Availability in many types of material from aluminum to teflon.

DEFINITIONS

Axial Flow - Fluid flow directed axially along the mixer shaft from top to bottom (down-pumping), or from bottom to top (up-pumping) is called axial flow.

Baffles - A separator found in a reservoir, tank or other chamber to divert fluid flow in specific direction(s) for de-aeration of moving fluid. Plate or vane used to direct or control movement of fluid or air within confined area.

Cavitation - A localized gaseous condition within a liquid stream that occurs where the pressure is reduced to the vapor pressure.

Cavitation erosion - Progressive loss of original material from a solid surface due to continuing exposure to cavitation.

Endothermic. Pertaining to a chemical reaction which is accompanied by an absorption of heat.

Energy dissipation - The transformation of mechanical energy into heat energy. In fluids, this is accomplished by viscous shear. The rate of energy dissipation in flowing fluids varies with the scale and the degree of the turbulence. Baffles, the hydraulic jump, and other damping methods are used to dissipate energy.

Exothermic - Gives off heat. A process is said to be exothermic when it releases heat.

Flow rate - The volume mass, or weight of a fluid passing through any conductor per unit of time. Actual speed or velocity of fluid movement .

flow regime - The pattern of how water levels change in a stream.

Fanning friction factor - a dimensionless number used in fluid flow calculations. It is related to the shear stress at the wall

Friction factor - express the ratio of total momentum transferred to momentum transferred by turbulent mechanisms. Friction factor is a function of Reynolds number

Froude number - Used in hydraulics as an analog to the Reynolds number. It is the ratio of inertial forces to gravitational forces.

Homogenized - cause to become equal or homogeneous as by mixing; "homogenize the main ingredients"

Housing - A rigid casing that encloses and protects a piece of moving or delicate equipment.

Immiscible - The inability of two or more substances or liquids to readily dissolve into one another, such as soil and water. Immiscibility The inability of two or more substances or liquids to readily dissolve into one another, such as soil and water.

Impeller - The device responsible for the actual mixing action in a process. The rotating impeller is responsible for flow and shear imparted to the fluid as it rotates.

Laminar Flow - Laminar flow occurs when adjacent layers of fluid move relative to each other in smooth streamlines, without macroscopic mixing. In laminar flow, viscous shear, which is caused by molecular momentum exchange between fluid layers, is the predominant influence in establishing the fluid flow. This flow type occurs in pipes when Re < 2,100.

Miscible - Able to be mixed. Two liquids are said to be miscible if they are partially or completely soluble in each other. Commonly, the term miscible is understood to mean that the two liquids are completely soluble in each other.

Multiphase flow - In fluid mechanics, multiphase flow is a generalisation of the modelling used in two-phase flow to cases where the two phases are not chemically related (e.g. dusty gases) or where more than two phases are present (e.g. in modelling of propagating steam explosions).

Physical state - Those properties familiarly discussed in physics, exclusive of those described under mechanical properties; for example, density, electrical conductivity, co-efficient of thermal expansion.

Pressure drop - Decrease in pressure from one point in a pipe or tube to another point downstream. Pressure drop occurs with frictional forces on a fluid as it flows through the tube.

Radial Flow - Impellers that draw from above and below the impeller and discharge it toward the tank wall, perpendicularly from the mixer shaft, are radial flow impellers. This type of flow is called radial flow.

Reynolds Number, Re - A dimensionless number which expresses the ratio of inertial to viscous forces in fluid flow

Specific gravity - Is a relative measure of weight density. Normally pressure has not significant effect for the weight density of liquid, temperature is only condition must be considered in designating the basis for specific gravity.

Static mixer or motionless mixer - A static mixer or motionless mixer is a device inserted into a housing or pipeline with the objective of manipulating fluid streams to divide, recombine, accelerate/decelerate, spread, swirl or form layers as they pass through the mixer.

Transition Flow - Flow regime lying between laminar and turbulent flow. In this regime velocity fluctuations may or may not be present and flow may be intermittently laminar and turbulent. This flow type occurs in pipes when 2,100 < Re < 4,000.

Turbulent Flow - Turbulence is characterized by velocity fluctuations that transport momentum across streamlines; there is no simple relationship between shear stress and strain rate in turbulent flow. Instantaneous properties cannot be predicted in a turbulent flow field; only average values can be calculated. For engineering analyses, turbulent flow is handled empirically using curve-fits to velocity profiles and experimentally determinate loss coefficients. This flow type occurs in pipes in industrial situations when Re > 4,000. Under very controlled laboratory situations, laminar flow may persist at Re > 4,000.

NOMENCLATURES

Ap	Pipe area (m^2)
D	Internal diameter of pipe (m)
f	Fanning friction factor
Fr	Froude number
KL	Pressure drop ratios for static mixers in laminar flow
KT	Pressure drop ratios for static mixers in turbulent flow
L	Element length (m)
L/D	Ratio element length with diameter
L_{pipe}	Pipe length (m)
L_{pipe}	Pipe length (m)
ΔP	Total pressure drop (Pa)
ΔP_g	Gas pressure drop in empty pipe (Pa)
ΔP_l	Liquid pressure drop in empty pipe (Pa)
ΔP_{pipe}	Empty pipe pressure drop (pa)
ΔP_{sm}	Static mixer pressure drop (pa)
Q	Flow rate (m^3/s)
Q_g	Gas flow rate (m^3/s)
Q_l	Liquid flow rate (m^3/s)
R	Scale,
R_e	Reynolds Number with symbol
v	Mean velocity of flow (m/s)
v_g	Gas velocity
v_l	Liquid velocity
X	Liquid/gas pressure drop ratio=

Greek Leters

μ	*A*bsolute viscosity (Pa.s)
ρ	Weight density of fluid (kg/m^3)
σ	Interfacial or surface tension

Superscript

A	Pipe area (m^2)
D	Internal diameter of pipe (m)
Q	Flow rate (m^3/s)
R	Scale,