CHAPTER 2

CONCEPTUAL FRAMEWORK

2.1 STATIC MIXER

2.1.1 Classification

Mixers are classified according to different criteria. Classification of mixers according to the state of components in the operating zone and agitating force is considered to be more appropriate.

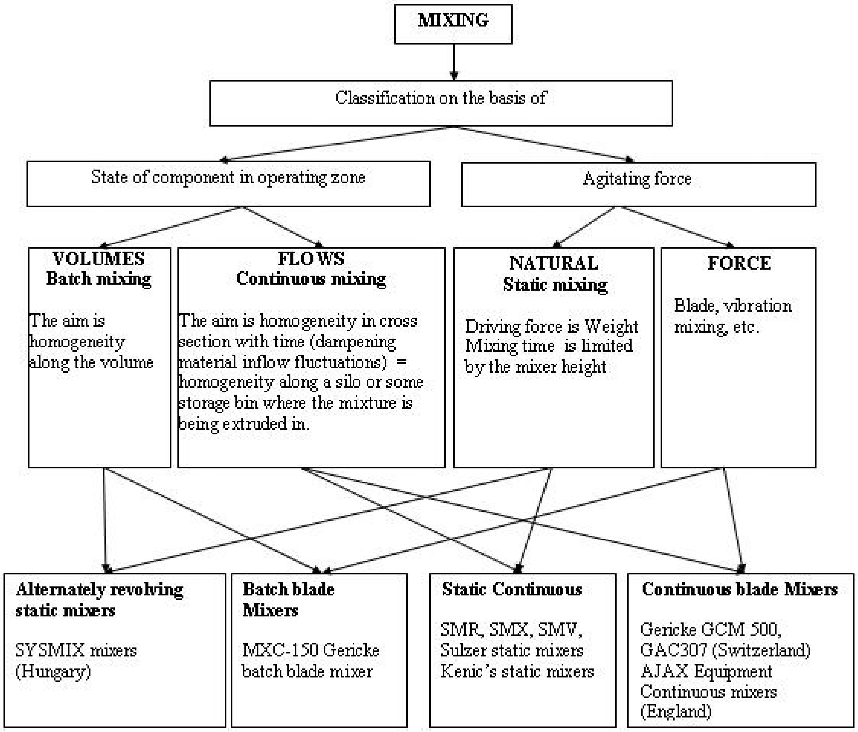

Figure 2.1 The Scheme of classification of static mixer

According to the Figure 2.1, mixing can be both batch and continuous. Each of these types can apply different agitation force. Therefore, particles can move naturally by gravity force or they can be agitated to move by vibrating, pushing, stirring, etc. Thus, any mixer can be related to some class according to these two principles. Some static mixer elements of different design are shown in Figure 2.2.

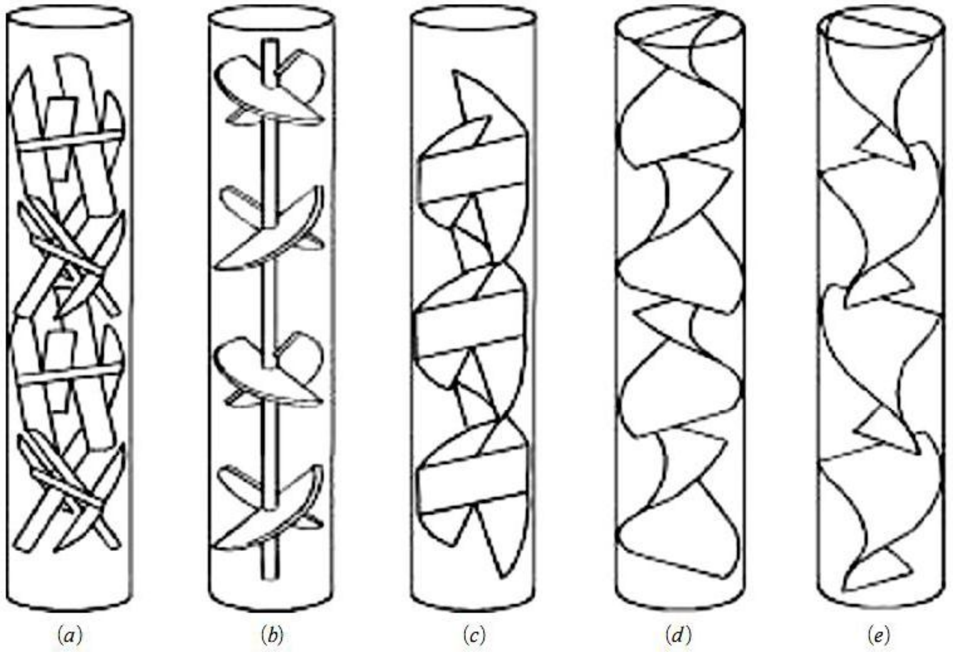

Figure 2.2 Static Mixing Elements; (a) lamellar (Sulzer SMX) mixer, (b) Ross LPD mixer, (c) Komax mixer, (d) Kenics static mixer, (e) FixMix mixer

2.1.2 Application

Mechanical agitators are commonly used for batch mixing; static mixers are often preferred for continuous mixing applications. Helical mixers are used in a wide variety of applications. For example, they are used in a reactor to produce polymers and in a turbulent flow vessel to make liquid-liquid dispersions. In contrast, Koch-Sulzer mixers tend to be used for specific applications over a restricted range of flow rates. As an example, the SMV mixer is used for gas-liquid contacting and SMF is used for viscous flows where clogging is a concern.

Table 2.1 Applications of Static Mixers in Industries

Industry	Applications
Chemicals	Chlorination and oxidation Steam injection Acid and base dilution Fast reactions
Food processing	Acid washing of fats and oils Constituent blending Starch slurry cooking
Mineral processing	Slurry dilution Metal recovery by solvent extraction
Paints and resins	Coloring and tinting Solvent blending Color concentrate dilution
Petrochemicals and refining	Gaseous reactant blending Gasoline blending Emissions monitoring and control
Pharmaceuticals	Nutrient blending Sterilization pH control
Polymers and plastics	Reactant-catalyst blending Thermal homogenization Plug-flow finishing reactors
Pulp and paper	Chemical and coatings preparation Stock dilution and consistency control Addition of bleaching chemicals
Water and waste treatment	Rapid mixing and polymer dilution Disinfection and dechlorination Aeration

Helical static mixers are used for process applications, such as blending for pH control, polymer dilution, and gas- liquid or solid- liquid contacting. Helical static mixers have been used in wastewater treatment. They are used for high and low pressure spray applications. They are also used in order to increase the rate of heat transfer in heat exchangers. The radial mixing action rapidly eliminates temperature gradients, reduces fouling and thermal degradation. The main applications of static mixers are categorized and shown in Table 2.1.

2.2 REYNOLDS NUMBER

The Reynolds number (Re) of a flowing fluid is obtained by dividing the kinematic viscosity (Viscous force per unit length) into the inertia force of the fluid (Velocity x Diameter)

$$\text{Kinematic viscosity} = \frac{\text{Dynamic viscosity}}{\text{Fluid density}} \tag{2.1}$$

$$\text{Reynolds number} = \frac{\text{Fluid velocity x Internal pipe diameter}}{\text{Kinematic viscosity}} \tag{2.2}$$

2.3 VELOCITY PROFILES

Design of chemical reactors is no routine matter and great variety of designs can be proposed for a process. Especially, in case of actual reactors, the deviation from an ideal reactor type may be caused by the following environment at sectors

a. Non-uniform velocity profile,
b. Velocity fluctuation due to molecular or turbulent diffusion,
c. Short circuiting,
d. Bypassing and channeling,
e. Existence of dead zone due to reactor shape and internals.
f. Recycling of fluid as a result of agitation.

2.3.1 Flow Velocity Profiles

All fluid particles are not travelling at the same velocity within a pipe. The shape of the velocity i.e. the velocity profile across any given section of the pipe depends upon whether the flow is laminar or turbulent. If the flow in a pipe is laminar, the velocity distribution at a cross section will be parabolic in shape with the maximum velocity at the center being about twice the velocity in the pipe. In turbulent flow, a fairly flat velocity distribution exists across the velocity in the pipe, with the result that the entire fluid flows at a given single value.

2.3.1.1 Laminar Flow

When a fluid flows through a pipe the internal roughness of the pipe wall can create local eddy currents within the fluid adding resistance to flow of the fluid. Pipes with smooth walls such as copper, brass and polyethylene have only a small effect on the frictional resistance. Pipes with less smooth walls such as concrete, cast iron and steel will create larger eddy currents which will sometimes have a significant effect on the frictional resistance.

The velocity profile in a pipe will show that the fluid at the centre of the stream will move more quickly than the fluid towards the edge of the stream. Therefore friction will occur between layers within the fluid.

Fluids with a high viscosity will flow more slowly and will generally not support eddy currents and therefore the internal roughness of the pipe will have no effect on the frictional resistance. The condition is known as laminar flow and it is defined as a function of Reynolds number.

When the Reynolds number is less than 2300, laminar flow will occur and the resistance to flow will be independent of the pipe wall roughness. The friction factor for laminar flow can be calculated from 64/Re.

2.3.1.2 Turbulent Flow

When the Reynolds number is less than 4000, turbulent flow will occur. Eddy currents are present within the flow and the ratio of the internal roughness of the pipe to the internal diameter of the pipe needs to be considered to be able to determine the friction factor. In large diameter pipes the overall effect of the eddy currents is less significant. In small diameter pipes the internal roughness can have a major influence on the friction factor. Between the Laminar and Turbulent flow conditions (Re 2300 to Re 4000) the flow condition is known as critical. The flow is neither wholly laminar nor wholly turbulent. It may be considered as a combination of the two flow conditions.

Turbulence has several characteristics:

- Presence of “non-deterministic” fluctuations in flow properties. This means that one cannot precisely predict the value of a flow property at a future instant by any known means, since the precise relationship is not known.
- Examples: In the boundary layer over a large wing in flight, the velocity at a given point cannot be predicted for every instant, because it keeps fluctuating. We can watch the fluctuations for as long as we care, we will not be able to predict the exact value for a future instant.
- Counter-example: Consider the flow in the wake of a helicopter rotor. Every time the blade comes around, the flow velocity undergoes sharp fluctuations. It looks “chaotic”, but only until one realizes that exactly the same thing is happening every time the blade comes by. Once this realization occurs, we see that we can indeed predict the value

of, say, velocity associated with a particular position of the rotor blade during its cycle: it is a “periodic” process, with a predictable period and therefore a frequency.

- Turbulent fluctuations occur over many frequencies. “Broadband”, as opposed to the single frequency is seen when vortices are shed from a circular cylinder, or the processes in the wake of a flapping wing or a rotor or propeller, or a sound wave.
- Turbulence is 3-dimensional: When turbulent fluctuations occur, they occur in all 3-dimensions. There is no such thing as“2-d turbulence”. Fluctuations occur in properties along all directions.
- Cascade of scales. If one asks: “How big are the turbulent eddies?” the answer is: “all kinds of sizes, ranging from eddies as large as the stream width (or boundary layer thickness), to very small eddies. The lower limit on eddy size can be estimated.

Many scholars have researched the turbulence problems of non-compressible fluid. Mellado et al (2005), Zheng Yonggang (1997) have presented the turbulent motional differential equation of variable density and variable viscosity fluid in open channel, related the density turbulence with the concentration turbulence and presented the concept of concentration turbulence stress. But the turbulence variation of viscosity has not been taken into account.

In turbulence, the viscosity of fluid is continuously variable. For aeration water flow, the concentration of gas is the function of position and time, which makes the viscosity of mixture fluid become a continuously variable turbulence quantity. Therefore, while deriving the basic equations of turbulent flow for variable density and variable viscosity fluid, the turbulence variation of viscosity must be taken into account, and the viscosity turbulence stress resulting from that.

2.4 ADVANTAGES OF PLUG FLOW REACTORS

Based upon the above criteria, many reactions are usually conducted in tubular flow reactors. Levenspiel (1974) summarises the advantages of plug flow reactors over the stirred tank reactors. They are:

a. The volume of backmix reactor is always greater than the plug flow reactor for all positive orders of reaction rates. The ratio of the reactor volumes v_B/v_p increases with the order of reaction. For zero order reaction, the reactor size is independent of the type of flow.

b. When conversion is small, the reactor performance is only slightly affected by flow type for all reactions. The volume ratio viz., volume of backmix reactor/volume of plug flow reactor tends to unity as conversion approaches zero. The ratio increases very rapidly at high conversions. Consequently the knowledge of the type of flow system becomes very important to the design in this range of conversion.

c. Density variation during reaction as measured by expansion factor affects the design procedure. However, it is generally of secondary importance compared to the difference in flow type. Volume expansion or density decrease during reaction increases the volume ratio. In other words, this results, in decrease in the effectiveness of the backmix reactor with respect to plug flow reactor. Density increases during the course of reaction has the opposite effect.

Ease of control, labour saving, mechanical simplicity, adaptability to heat transfer and high pressure, uniform product quality, high capacity – are some of the salient features of the plug flow reactors. As defined previously, the plug flow reactor is centered on a fact that the movement of each fluid element is always forward, and no backmixing takes place. The residence time of the each element is always the same, which is essentially an ideal situation. This can be arrived at only if the fluid elements flow through the tube under turbulent conditions, which is possible at high flow rates. Introduction of turbulence inducing fins or baffles inside the tube, does not permit the near parabolic velocity profile typical for the laminar flow of Newtonian fluid, to be established for the turbulence. For example, Hoverka et al (1960) reported that the conversion in the tubular reactor with baffles is higher, than the reactor without any baffles.

It is well documented that the velocity profile for the flow of Newtonian fluid elements through an annulus under laminar conditions is not parabolic and is given by (Bird 1960).

$$V(r) = \frac{\Delta p R^2}{4\omega\mu L}\left[1 - \left(\frac{r}{R}\right)^2 + \frac{1-k^2}{\ln\left(\frac{1}{k}\right)}\ln\left(\frac{r}{R}\right)\right] \tag{2.3}$$

The presence of certain elements like fins or baffles as turbulence creators inside an annulus enable the turbulence to be generated even at low flow rates. Thus an annulus operating under low flow rates can be converted into a plug flow reactor by inserting some ‘turbulence promoters’ in the form of fins or baffles.

Static mixers with multiple passage of material through the mixing zone are a very interesting subject of research and mathematical simulation. They have a position between continuous mixers and batch mixers in a closed volume so that static mixers combine advantages of both operation principle types. The mixers bring a good deal of technological interest while mixing segregating materials because while rotating the mixer, components change their place. It is possible to search for the number of material passages through the mixing zone giving better mixture quality, and to stop the process if the necessary quality is achieved. Absence of rotating parts inside the mixing zone improves their technological reliability. Although batch loading reduces the throughput, it significantly improves the feeding precision. However, research on these mixers is oriented towards the direct experimental investigation of the mixture quality (Wang 1977, 1976, Fan 1975, 1972, 1990, 1995), but not on the conditions of obtaining such quality. The majority of the models built for this purpose, do not allow direct experimental identification of their parameters which could be found only on the basis of independent experiments. This circumstance does not make it possible to reduce the experimental information while keeping reliability on prediction of mixture parameters.

2.5 MATHEMATICAL MODELING

Process industries include all those operations where the feed materials undergo chemical or physio-chemical changes during the manufacture of end products. The majority of unit operations that serve these material transformations are basically mixing or separation in nature. Chemical treatment steps are conducted in vessels known as reactors, which are stirred tank reactors (backmix reactors) and plug flow reactors. Actual reactors deviate from these idealized concepts. The discrete (stagewise) backmixing model was considered as the best model representing residence time behaviour in the small-scale tube (Reis 2004). Mathematical modelling coupled with rigorous statistical methods has been of great assistance in understanding and quantifying the flow in a reactor as it is critical for predicting performance of the reactor.

As mentioned earlier, the plug flow reactor having many advantages over backmix reactor is centered on a fact that the movement of each particle is always forward in the form of a ‘file’ and no backmixing is allowed. The residence time of each fluid element flows in the form of a ‘file’. To establish such a situation in actual reactors, the fluid flow through the tube must be under turbulent conditions.

As the flow of fluids through a static mixer undergoes three type mechanisms, namely: (a). flow division, (b). flow reversal and (c). Flow combination, due to continuous flow division, flow reversal and flow combination at every element of the mixer the parabolic velocity profile cannot get established and therefore ideal plug flow conditions are approached. Hence the static mixer can be utilised for any process application of tubular chemical reactors where the provision of narrow residence time is important.

In the literature there exist many mathematical models for the hydrodynamics in static mixer whereby the model parameters are verified or obtained from residence time distribution data of the liquid phase in a static mixer reactor.

Methods to estimate RTD from observations are not unique and can be subjected to strong criticism. The efficient method to estimate the RTD and the sole means of achieving this is through detailed Ricker modelling. Such theoretical estimates need, however, always to be thoroughly checked against observations in Static mixer. The RTD was calculated numerically by the Ricker model.

William Edwin Ricker (1954), regarded as the father of fisheries science, developed a simple population model to predict the expected number of fish as a function of time which is known as Ricker equation. The restocking effects on a discrete growth population are considered in relation to Ricker (Watanabe Seiichi 1987). Ricker model is also used for the study and analysis of microbial growth dynamics as influenced by environmental conditions in an extensive experimental data set (Jose´ Miguel Ponciano et al 2005). The Ricker model has a long history in population ecology modelling and has been used as a discrete version of the well-known Verhulst logistic differential equation. Also, modifying the Ricker simulates the effect of immigration to, and emigration from, the population (Ruxton 1995). The Ricker equation expresses the one-step-ahead population size as a function of the current population size and includes a density-dependent effect.

In this research, the results of the Ricker model and the predicted RTD are presented in terms of different volumetric flow rate to illustrate the complicated flow patterns that drive the mixing process in helical static mixers. The computed results are also used to determine the amount of mixing that occurs within a mixing device.