Mixing Technology - Review And Update

Dr V V Chavan

SYNOPSIS

Sophistication of the process industry has its impact on all the basic operations involved including on mixing. With computer aided tools, mathematical modelling, experimental and theoretical advances in fluid dynamics it's been possible to develop newer designs and concepts in mixers. The author has reviewed the physical processes involved and explained how a better understanding of these processes, availability of latest machining techniques led to the development of mixers with highly improved efficiencies.

Introduction

High scale operations and stringent quality requirements characterise the process industry today. Mixing which is an essential part of any process industry has also got sophisticated to meet these mentioned demands. Higher scale of operation required closer look at the efficiency both from the point of view of power consumption and process time. Other operational considerations such as easy maintenance, amenability to automation and computer control have also to be taken into account. Stringent quality standards have also led to the concept of Mixing being looked at in more scientific and quantitative terms.

The "Physical Processes" that are generally associated with mixing have undergone scientific investigations and some fundamental rules have been laid down. Fluid dynamics that is related to "Physical Process" is studied experimentally by sophisticated techniques using laser and theoretically with newer mathematical techniques and computers. Such investigations have led to improved designs. Engineering development in the techniques of manufacture have also helped to incorporate such designs in the process industries. A summary of such technological progress is sketched below:

Physical Process

Physical processes associated with Mixing are:

- Homogenisation (or Blending)
- Dispersion (deagglomeration, deflocculation)
- Emulsification (or aeration)
- Aggregation (Agglomeration, Flocculation)
- De-emulsification (Deaeration)
- Suspension
- Transfer (Heat or Mass)

One or more of these processes occur in any process situation at a time. In a multiple reactor, for example, there will be dispersion of a catalyst, aeration of reacting gas, mass transfer of gas to liquid and then to the catalyst particle surface. The reaction is then followed by transfer of reaction product to the bulk. The situation may be further complicated by exothermicity where heat has to be removed from the bulk to maintain the temperature. Quantification of such process should be achieved and weighed for a proper design.

a) Homogenisation

"Homogeneous" would mean as "composed of parts which are all of the same kind". The size of these parts has a special significance when quantifying homogeneity. It represents the scale at which we scrutinise the mixture (table 1).

In quantifying homogeneity, two terms are defined and used, these being:

- Scale of segregation, and
- Intensity of segregation

The scale of segregation is the dimension that characterises the clumps of an unmixed component in the mixture. The intensity of segregation really accounts for the distribution of these clumps. Physical significance is better explained by an example. In blending of two viscous liquids, the scale of

Table 1. Typical Scales of Scrutiny

Purpose of Mixing	Scale of Scrutiny
Mixing pigments in plastics, paints or soap.	Resolving power of eye
Mixing ingredients in detergent powder	Weight used for one wash
Mixing ingredients in a pharmaceutical drug	Weight of a tablet
Mixing active additives to rubber before vulcanization	Volume over which an individual grain can be active.

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segregation can directly be observed as the thickness of the striation of one liquid into another. Initially, when the two liquids are entirely separate, the intensity of segregation is equal to 'one'. Finally when they are totally mixed at the level of the "scale of scrutiny", the intensity of segregation is zero.

In order to define these quantities in precise mathematical terms it is convenient to approach the small and large scale segregations separately. In "small scale segregation", our "scale of scrutiny" is also small. Generally in the mass transport at the molecular level or in chemical reactor problem, we are associated with small scale segregation. In large scale segregation, the scale of scrutiny is larger (mostly greater than a micron). The problems associated with large scale segregation are thus physical, for example: dispersion of pigment in viscous liquids, blending of polymer melts or mixing of powders.

b) Dispersion

Here, we will consider the physical processes that are associated with dispersion of one phase into another. Often, these phases are insoluble in each other, for example: in dispersion of a pigment in liquid or forming an emulsion or aerating a liquid. Dispersion is also relevant when the phases are soluble in each other, since the contact area and hydrodynamics around these particles will determine the overall mass transfer coefficient. "Dispersion" involves two processes:

- Physically breaking one phase down to smaller size and
- Dispersing these small units in a continuum.

The second process is quantitatively governed by the same framework and criteria of homogeneity. In the first process, that is the process of breaking, the size of a unit (a particle, a droplet or a bubble) is the critical factor to watch.

In processes such a break down of agglomerates or flocculates or formation of a droplet or bubble, several physical aspects become important. For example, it would be the interaction forces between the particles or it would be the colloidal forces like van der Waal attraction force or electrostatic repulsive force or it could be forces due to the absorbed macromolecules on to the particles. In any case, in breaking down of agglomerates or formation of droplet, hydrodynamics plays an extremely important role. It is well known now that by certain type of flow (illustrated in Fig 1) you can break an aggregate or form an emulsion with less effort. This thought provoking figure should make one think on two aspects:

- How to design the impeller and
- Where to introduce the second phase

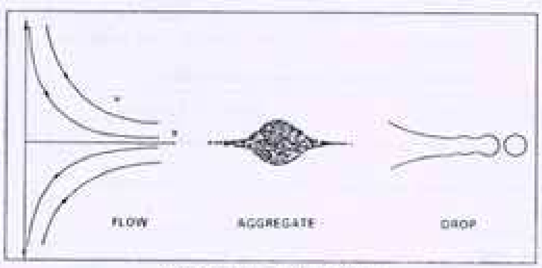


Fig.1 Effects of stretch flow

When the applied shear on aggregate becomes larger than the strength of the aggregate it will naturally break down. This simple law should determine the average size of an aggregate that will be present in an agitated vessel provided the hydrodynamics is known. Based on this hypothesis simple scale-up rules could be derived. And it will be shown that aggregate size is related to power per unit volume. Just to illustrate the use of such arguments, a plot of aggregate size against the power per unit volume is shown in Fig 2.

Emulsification and aeration processes are also governed by similar hydrodynamic phenomena although the forces associated with particles are different. Here, it is the interfacial forces and the physical properties of these interfaces that dominate the physics. The importance of hydrodynamics, however, cannot be underestimated as illustrated in Fig 3. Empirical equations are available in the published literature for:

- the critical speed above which a dispersion could be formed, and
- the diameter of a droplet or a bubble.

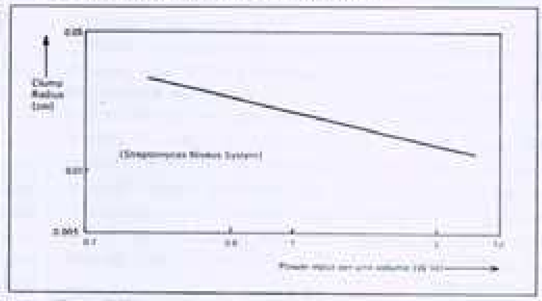
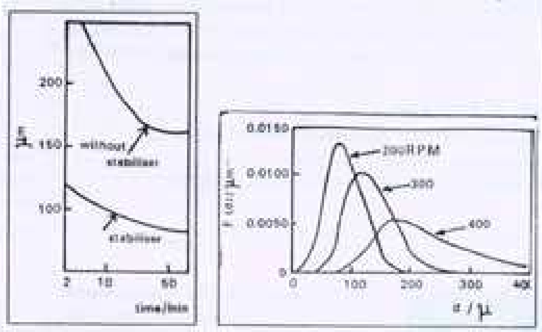


Fig.2 Effect of power input on size of bacteria clumps.

c) Aggregation

This is precisely the opposite phenomenon. Here the particles are required to be brought closer to each other. Situations are several, for example: Water treatment, oil recovery from oil/water emulsions and deaeration. Again,



a) Mean drop size as a function of time.(Paraffin/water at 60°C,in 1.5 lit vessel with a turbine, PVA as the stabilizer).

b) Drop size distribution of a dispersion of kerosene in aqueous glycerol at various impeller speeds (μ_c = 3.6 cP, μ_d = 1.4 cP, σ = 31.8 dyn/cm)

Fig.3 Typical emulsification results

here the interaction forces and the interfacial forces become important. Now the particles are to be brought closer to each other and thus the repulsive forces need to be overcome. The time needed for the particles to come closer to each other is also an important factor. Thus, the impeller tip velocity and shear rate are important factors in laminar (slow) flows, which is a common mode of operation for this purpose. In turbulent flows, the power per unit volume provides a useful scale criterion.

Dispersion and aggregation are the two processes that generally go on simultaneously till an equilibrium is reached. Several other physical processes are also involved in making the situation extremely complex. The suggestion is, therefore, that one should always carry out a pilot plant trial, while physics could be used for scaling up. Further, it should be noted that the empirical equations should be used with extreme caution.

d) Suspension

Keeping particles or emulsion droplets in suspension is another important job of an agitated system. Generally, the suspension is required for an efficient mass transfer operation. Simple physics leads to relevant equations that may be found in any of the text books.

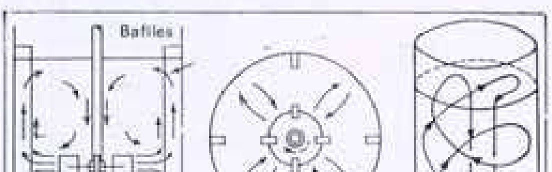
e) Heat and Mass Transfer

Heat and mass transfer rates could be expressed by -
(rate of transfer) = (transfer coefficients) x (contact area) x (driving force)

Our requirement obviously is of higher transfer rates. This will be achieved by higher transfer coefficients and/or higher contact area.

Together with such quantities as thermal and molecular diffusivities, transfer coefficients will also be dependent on hydrodynamics in the agitated vessel especially as the flow around the particles will determine the coefficients.

When heat transfer is either from the vessel walls by means of a jacket or from the walls of coils and pipes inserted in the vessel, the contact area can be easily computed. In the mass transfer operations, such as gas absorption from bubbles, liquid extraction from the immiscible drops or extraction from solid particles, the contact area is not easily known. Generally, the smaller the particle (drops or bubbles) size, the higher is the contact area per unit volume.



a) In baffled tank with turbine positioned on centre.

b) Produced by a ribbon mixer

Fig.4 Typical flow patterns

Fluid Dynamics and Rheology

Industrial mixing generally occurs in a confined space such as tanks, vessels, or pipe lines. The design of the contraption that makes the liquid, solid and gas flow in particular way is indeed critical. Fig 4 (see typical flow patterns).

Investigations on flow very close to an impeller of agitators have also led to better designs from point of emulsification, aeration and dispersion. Newer concepts for including the high shear impeller have been developed.

a) Rheology

Rheology specifically means science of flow. This science deals with the interactions between flow and the physical characteristics of the material. For example a polymer material when subjected to flow reacts due to its elastic character to give rise to a force (called "Normal" force). The interaction between this normal force and centrifugal force gives rise to flow patterns not known to a liquid like water (see Fig 7). In many polymer liquids or dispersion the viscosity is also dependent on flow (or shear rate in a viscometer) Fig 8 gives illustration with respect to some materials.

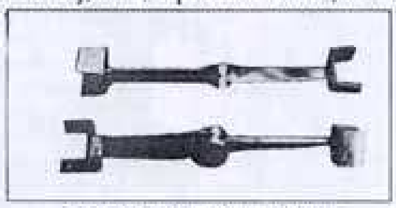


Fig.5 Modern Turbine Impellers

Fig.6 High Shear Impeller

b) Gross Parameters

On several types of agitated vessels, empirical data have also been collected over the past few years. Integral quantities such as:

- Discharge rates
- Circulation capacities
- Power consumption and
- Mixing times

have been measured and efficiency of various impellers calculated to categorise their use depending on the viscosity of liquid.

Design Improvements

On the design front there has been tremendous developments. Some examples are discussed below:

a) Powder/Paste Mixing

Progress here is three fold:

- Reduction in mixing time
- Mixing under known shearing conditions
- Continuous mixing

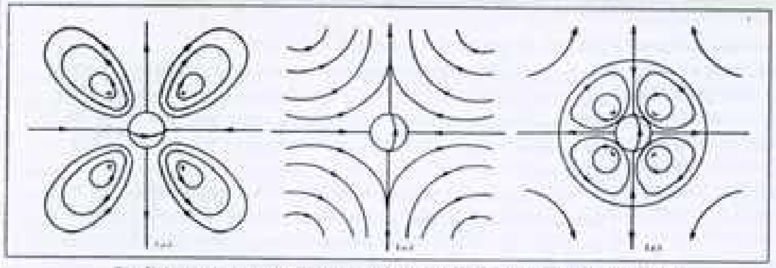


Fig.7 Secondary flow around a sphere rotating in a viscoelastic liquid.
a) Normal forces dominating. b) Centrifugal forces dominating
c) Normal and centrifugal forces comparable

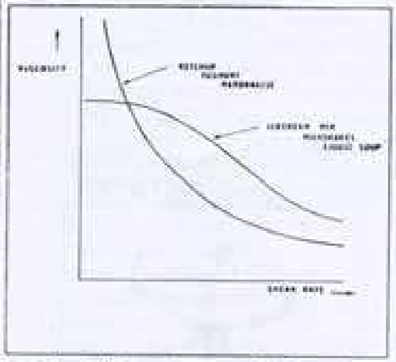


Fig.8 Typical viscosity curves of food products.

Typical example of improvement in a horizontal ribbon blender is the well-known 'Patterson Blender', where the principle of horizontal helical ribbon are used in such a way that the mixing time is greatly reduced.

High Shear Paste/Powder mixing is also attempted regularly these days in industry. For example, one such design Lodige is regularly used in Pharmaceutical Industry. Continuous Powder/Paste mixing is also a common feature of an industry with large production capacity.

b) High Speed/Shear Mixing

Advent of improved and accurate machining has made it possible for impellers to rotate at speeds higher than 1000 and upto 6000 ppm. Impellers of various sorts are used. There are basically two types of impellers:

- Open Impellers
- Stator/Rotor type of impellers

Open impellers are Cowler type and the closed ones are Silverson and Ultra turrox. As one can imagine there are several well defined designs possible. These designs are extremely useful for emulsification and dispersion of polymeric or non-abrasive materials.

c) Pressure Mixing

Pressure mixing is so called because it uses pumping pressure to achieve mixing. Such type of mixing is implemented in two ways:

- Macro mixing using jets and
- Micro mixing using jets and/or constriction

Macro Mixing is achieved by using jets to create high velocities. Such jets are suitably placed in a tank to create the required flow pattern to achieve mixing (see Fig 9).

Micro Mixing is employed for processes such as fine emulsification/dispersion. Either by microfine jets or by creating constriction high level turbulence is developed. In such high level turbulence size of eddies is submicrons. Thus droplets or particles to this level may be created. These are generally known as high pressure homogenisers.

d) Inline Mixing

Inline mixing is in principle a combination of high speed mixing and pressure mixing. It is however done mainly in pipe lines. These types of mixers replace large mixers and mixing tanks by providing instantaneous mixing.

Inline mixing may be achieved by introducing a carefully designed high speed mixer in the pipe line or by using the well known static mixing concept. Static mixing can definitely save capital cost, maintenance expenditure and will give a homogenous product.

In the last few years the Static Mixer Concept has definitely been accepted in the Indian Industry because of:

- Low capital cost
- Low maintenance and
- Low operating cost

The Static Mixer is employed for the following applications:

- Dilution of acids and alkalies
- As reactors both liquid-liquid and gas-liquid; applications have been already found in Sulphonation, Chlorination, Nitration and Ammonia reaction.
- Viscous heat transfer or heat transfer where rise in temperature leads to polymerisation and choke up, application is in edible oil industry.
- Effluent treatment for oxygen-contacting, acid

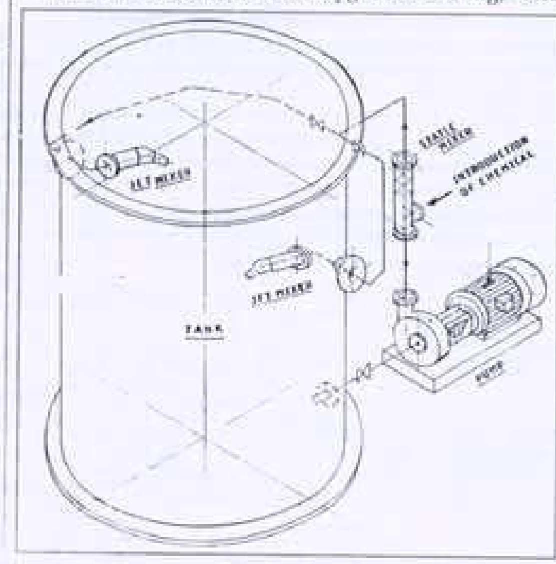


Fig.9 Mixing System with jet and static mixer