2 Basics of the Mixing Technology

2.1 Principles

Mixing / Stirring

The definition mixing and stirring is not quite clear. It might be stirring when the liquid component is the dominating factor, whereas, the border line between mixing and stirring is flowing.

Discontinuously / Continuously running mixers

Discontinuously working machines are in the majority. They mix a certain product quantity, depending on the bowl size, in a certain time. Continuous mixing systems are being used mainly for mixing low viscosity liquids; to mention for example static mixers.

Dynamic / Static Mixers

Dynamic mixers are systems with moving stirrer tools or moving vessels. Static mixers are continuous systems, in which the mixing process is initiated by using the hydrodynamic energy of a fluid (liquid / gas) passing through a pipe or canal with fixed fittings.

Kneading

Kneading is, when a high viscosity mixing product is being deformed by normal forces during the mixing process. A planetary mixer may be used as kneading machine when the respective stirring tools are inserted (for example Planetary Mixer Tool F5 in connection with a shearing or kneading frame / ”comb tool”).

Homogeniser

Herbst Homogenisers are so called gear rim dispersing machines, which consists of a rotor, rotating with high speed, and a stationary stator. Both have slits. Very often the rotor and stator have several incapsulated gear rims.

The fluid is sucked axially into the dispersion head and is being accelerated in a centrifugal way by the rotor movement. When passing through the slits of the rotor-stator-system the fluid is being accelerated several times in a tangential and radial way and slowed down. This results in high acceleration shear forces and turbulent stream velocities which cause the drop breaking up.

Attention! Rotor-stator-system is a correct name for the homogeniser, because in the proper sense the word homogeniser is already applied for high pressure homogenisers. These operate without movable parts; the liquid is forced through tight drillings under high pressure.

2.2 Basic Mixing Tasks

2.2.1 Homogenising

Homogenising in the mixing technology means mixing certain inter-soluble liquids up to a certain homogenising degree (mixing quality) or the up-keep of the homogenity for a certain reaction. The liquids to be mixed may differ for instance in concentration, colour or temperature. The time period needed for mixing is the homogenising time.

Attention! Homogenising is often used in connection with operating the homogeniser.

2.2.2 Suspending

Suspension = the even distribution of solid particles in a liquid (homogeneous mass). The mixer avoids sedimentation of the solid particles in the liquid. A mixture of solid particles and liquids subjects the mixing equipment to excessive wear, which is proportional to the third power of the circumferential speed (tip speed) of the mixing tool. It is therefore recommend that the speed be kept to the barest minimum. This is often also advantageous to the product.

2.2.3 Dispersing

Dispersing is the mixing process of two liquids which normally are insoluble. The drops ($\geq 1\,\mu m$) of the dispersing phase are spread over the continuous phase. Dispersions are unstable and demix when the power is too low or lacking totally. The actual task of dispersing is the enlargement of the phase border line so that for instance the process of chemical reaction is faster.

2.2.4 Gasification

The result of the gasification of liquids is the enlargement of the phase border line between liquids and gas. Generally the liquid is the continuous phase (=coherent phase) and the gas is the disperse phase (=divided phase). Basically one differentiates between self and uncontrolled gasification. With the practical application, which is foremost the uncontrolled gasification, the gas is pumped through a ring shower into the vessel; the stirring tool crushes the gas flow into small bubbles and divides them in the liquid.

2.2.5 Heat Exchange

A controlled heat transfer is very essential in many processes. Due to an unfavourable ration of heat transfer areas to the vessel volume only very little heat per time unit can be transferred.

Improved heat exchange can be obtained through a suitable mixing tool; it's function is to produce a flow along the heat transfer areas (vessel jackets) such as to improve the heat transfer coefficient and thereby the heat transit coefficient.

2.2.6 Emulsifying

One has to differentiate between dispersing and emulsifying. The latter is to initiate respectively to support the enlargement of the phase border line by adding surface active substances (Emulsifier). Emulsions consist of very fine drops ($< 1\,\mu m$) and remain stable for a longer period of time.

2.3 Viscosity and Flow Property

The viscosity and flow properties of the products are of great importance in mixing technology; for example the required power requirements depends on it.

In the following some basic knowledge of the science of deformation and flow characteristics of products (Rheology) is provided.

Viscosity

Viscosity is a measure of internal friction. One differentiates between dynamic viscosity (generally known as viscosity) and kinetic viscosity. Kinetic viscosity ν is attained when the dynamic viscosity η is divided by density ϱ. The SI unit for the viscosity is the pascal second. The unit Poise (P) is still used, however not approved anymore. The conversion is simple:

$$1\,P = 0,1\,Pas \qquad \text{resp.} \qquad 1\,cP = 1\,mPas$$

The SI unit for the kinetic viscosity is m^2/s. The unit Stokes (St) is still used, however not approve anymore. The conversion is:

$$1\,St = 10^{-4}\,m^2/s \qquad \text{resp.} \qquad 1\,cSt = 10^{-6}\,m^2/s$$

Also other measurement for viscosity are being used in various industries, i. e. time, which is needed for a specific liquid volume to flow through a funnel with a defined outlet cross section.

Viscosity is a characteristic material property for every fluid (liquids / gases). Fluids, whose viscosity is independent of the shear forces (shear and time) and only dependent on temperature and pressure, are defined as Newtonian medias (i. e. water); in the mixing process the viscosity is independent of the mixing speed (temperature effects are ignored!).

By rising temperatures the viscosity of liquids is reduced and by gases lightly increased. In table 2 some examples for the viscosity of different products are shown.

Various liquid systems (solvents, emulsions and suspensions, ...) show variations from Newtonian behaviour, where the viscosity, by constant temperature and pressure is dependent on the shear strength and possibly also on the time. Transferring this to the mixing process this means that the viscosity is dependent on the revolutions of the mixing tools. This non-Newtonian flow behaviour is divided up as follows:

a) Independent of Time

- **Structural viscosity:** The viscosity diminishes with rising revolutions of the stirrer; this is a frequent happening.

Table 2: Viscosity of different products

Material	**Viscosity** $(mPas)$	**Material**	**Viscosity** $(mPas)$
Air	0,018	Gases, general	0,01 ... 0,02
Petrol	0,65	Water	1
Ethylalcohol	1,2	Mercury	1,5
Milk	2	Butter Milk	9
Cream	100	Motor Oil	150 ... 400
Gear Oil	300 ... 800	Joghurt	900
Pure Glycerine	1.500	Orange concentrate	2.000
Sour Cream	4.000	Sirup	1.000 ... 10.000
Cottage Cheese	20.000	Plastic Melts	10^4...10^8

- **Dilatancy (inverse plasticity):** The viscosity increases with rising revolutions of the stirrer; this is relatively infrequent.
- **Plasticity:** Below the boundary revolutions the stirred product behaves like a solid product and the structure will only be elastically deformed. After surpassing the flow limits (of certain revolutions of the stirrer) the stirred product behaves like a liquid.
- **Viscoelasticity:** By increasing mixer revolutions an intensified "rising up" the mixer shaft is noticeable (Weissenberg-Effect), whereas products without viscoelasticity would form a vortex (provided there are no baffle to avoid this).

b) Dependent of Time

- **Thixotropy:** A decrease in viscosity as a result of a constant mechanical stress (i. e. stirring) and an increase at the end of the stress source.
- **Rheopexy:** An increase in viscosity as a result of a constant mechanical stress (i. e. stirring) and a decrease at the end of the stress source.

Time dependent and independent effects may happen in combination.

2.4 Performance Equation

An important requirement for the mixer design is the determination of the necessary power requirements. The power requirements are obtained by the use of the performance equation:

$$P = Ne \cdot \varrho \cdot n^3 \cdot d^5 \tag{1}$$

Included here are:

P	Performance
Ne	Newton-number
ϱ	Density of the product
n	Revolution of the mixing tool
d	Diameter of the mixing tool

The equation shows that the mixer revolutions and the diameter of the mixing tool (third and fifth power!) have great influence on the necessary performance requirements. A further important point in the power equation is the Newton-number Ne. Unfortunately this is not a constant, but is dependent on various inputs. This can be interpreted as a finger print of the mixer. The various values of the Newton number are dependent, among others, on the type of the mixing tool, of the flow characteristics, of the mixing bowl and of the properties of the product. Mechanical losses also need to be included in the power requirements (i. e. in bearings and seals).

The relationship between revolutions n, torque M and performance P can be obtained by the following equation:

$$P = M \cdot 2\pi \cdot n \tag{2}$$

So called performance characteristics can be obtained by the values of torque and revolutions. These are diagrams, which show the Newton-number Ne in dependence of the so called Reynolds-number Re (flow characteristics), which will assist in the choice of power requirements.

$$Re = \frac{n \cdot d^2}{\nu} = \frac{n \cdot d^2 \cdot \varrho}{\eta} \tag{3}$$

Figure 3 shows a Ne-Re-diagram for various mixing systems.

Performance requirements of electrical drives are obtained from the equation:

$$P = U \cdot I \tag{4}$$

By measuring the current strength I by the given voltage U the performance P may be obtained in the workshop trials, however, it is to be noted that these values are only partially usable (due to losses ...)!

2.5 Scale-up

To achieve the possible interpretation mixing tests should be carried out preferably with original products with technical mixers of bowl volumes of 15 to 100 litres in general. Several scale-up-criteria are known in order to project results to production standard, i. e. a constant specific production registration ($P/V =$ const.) or a constant tip speed ($u =$ const.).

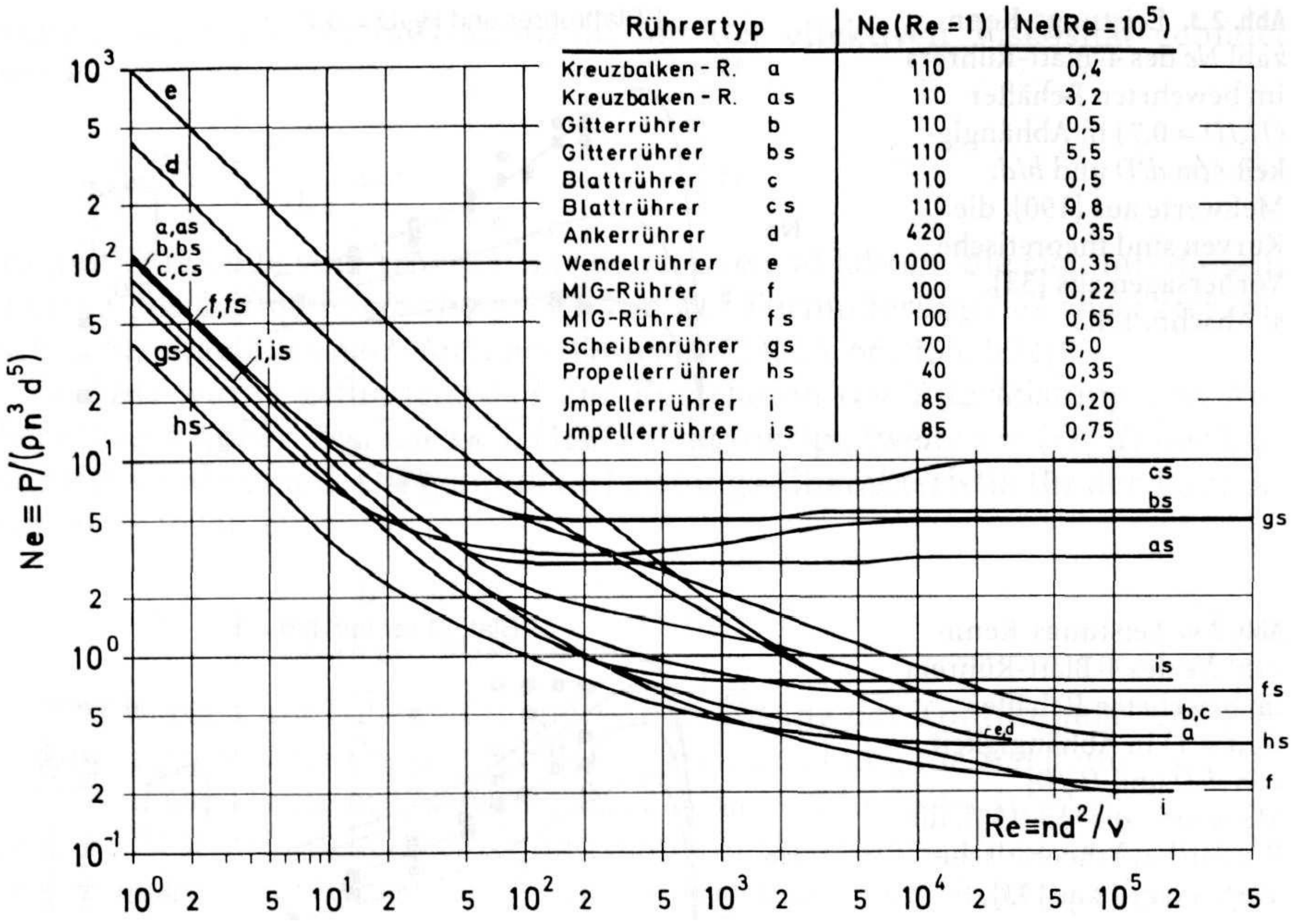

Figure 3: *Ne*-*Re*-Diagram for various mixing systems [1]

$$u = \pi \cdot n \cdot d \tag{5}$$

Selecting the correct scale-up-criteria is not always easy and depending on many factors (mixing task, mixing product, ...).

2.6 Machinery

The different mixing systems are as manifold as the mixing products. Basically one differentiates between continuous and discontinuous machines (for batch processes).

Discontinuous batch mixers are frequently used in industrial mixing processes. A **semi-continuous operation** can be achieved by using a number of mixing bowls and/or a number of mixers in parallel operations.

Continuous mixers have a steady in- and output. Examples are screw conveyor mixers, static mixers and extruders.

Furthermore one differentiates between **dynamic** and **static mixing systems**. Static mixers as opposed to dynamic mixers have no moving machine parts. The simplest static mixer is a pipe-line. Turbulences in the pipe result in the mixing of liquids. This mixing process is generally supported by an additional installation of baffles in the flow channel, which, however, result in a pressure drop.

Central mixers are used to mix liquid of low and medium viscosity. The simple case would be a drive, a mixing shaft and a mixing tool. For more sophisticated requirements additional components are needed (bearings, seals, ...). The three bladed propeller or the dissolver disc are often used as a mixing tool. Besides these high speed mixing tools the slow moving anchor mixers are also in use. The choice of mixing tools is specially dependent on the mixing task and the specific product properties.

Central mixers reach their limits in the area of high viscosity, for which so called **coaxial mixers** provide help by the combination of a slow speed anchor mixer with a fast speed straight-arm paddle agitator.

Magnetic mixers represent a special form of central mixers. The torque here is transmitted by a magnetic field and thereby no shaft penetration into the mixing bowl is necessary.

Solids are not suitable to be mixed in central mixers. In these cases specific mixers are used.

Planetary mixers cover a large operational area due to their application ranging from mixing materials of medium to high viscosity to mixing of solids. Generally they are delivered as a complete system as the mixing tools have to be built to suit the mixing bowl.