The main factors to be considered when selecting equipment for crushing and grinding are:

1. The size of the feed.
2. The size reduction ratio.
3. The required particle size distribution of the product.
4. The throughput.
5. The properties of the material: hardness, abrasiveness, stickiness, density, toxicity, flammability.
6. Whether wet grinding is permissible.

The selection guides given by Lowrison (1974) and Marshall (1974), which are reproduced in Tables 10.12 (see p. 465) and 10.13, can be used to make a preliminary selection based on particle size and material hardness. Descriptions of most of the equipment listed in these tables are given in Volume 2, Chapter 2; or can be found in the literature; Perry *et al.* (1997), Hiorns (1970), Lowrison (1974). The most commonly used equipment for coarse size reduction are jaw crushers and rotary crushers; and for grinding, ball mills or their variants: pebble, roll and tube mills.

10.11. MIXING EQUIPMENT

The preparation of mixtures of solids, liquids and gases is an essential part of most production processes in the chemical and allied industries; covering all processing stages, from the preparation of reagents through to the final blending of products. The equipment used depends on the nature of the materials and the degree of mixing required. Mixing is often associated with other operations, such as reaction and heat transfer. Liquid and solids mixing operations are frequently carried out as batch processes.

In this section, mixing processes will be considered under three separate headings: gases, liquids and solids.

10.11.1. Gas mixing

Specialised equipment is seldom needed for mixing gases, which because of their low viscosities mix easily. The mixing given by turbulent flow in a length of pipe is usually sufficient for most purposes. Turbulence promoters, such as orifices or baffles, can be used to increase the rate of mixing. The piping arrangements used for inline mixing are discussed in the section on liquid mixing.

10.11.2. Liquid mixing

The following factors must be taken into account when choosing equipment for mixing liquids:

1. Batch of continuous operation.
2. Nature of the process: miscible liquids, preparation of solutions, or dispersion of immiscible liquids.
3. Degree of mixing required.
4. Physical properties of the liquids, particularly the viscosity.
5. Whether the mixing is associated with other operations: reaction, heat transfer.

For the continuous mixing of low viscosity fluids inline mixers can be used. For other mixing operations stirred vessels or proprietary mixing equipment will be required.

Inline mixing

Static devices which promote turbulent mixing in pipelines provide an inexpensive way of continuously mixing fluids. Some typical designs are shown in Figures 10.52*a*, *b*, *c*. A simple mixing tee, Figure 10.52*a*, followed by a length of pipe equal to 10 to 20 pipe diameters, is suitable for mixing low viscosity fluids ($\leq$50 mN s/m^2) providing the flow is turbulent, and the densities and flow-rates of the fluids are similar.

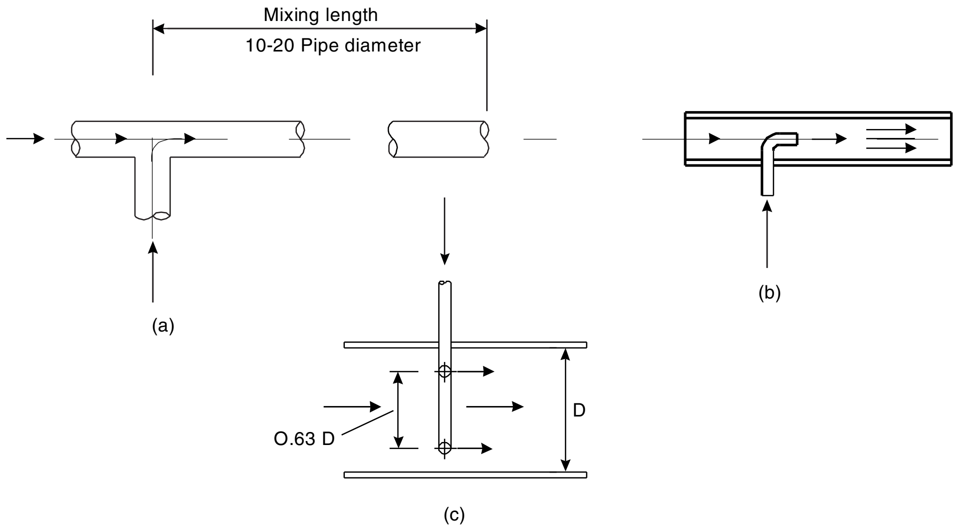

Figure 10.52. Inline mixers (*a*) Tee (*b*) Injection (*c*) Annular

With injection mixers (Figures 10.52*b*,*c*), in which the one fluid is introduced into the flowing stream of the other through a concentric pipe or an annular array of jets, mixing will take place by entrainment and turbulent diffusion. Such devices should be used where one flow is much lower than the other, and will give a satisfactory blend in about 80 pipe diameters. The inclusion of baffles or other flow restrictions will reduce the mixing length required.

The static inline mixer shown in Figure 10.53 is effective in both laminar and turbulent flow, and can be used to mix viscous mixtures. The division and rotation of the fluid at each element causes rapid radical mixing; see Rosenzweig (1977) and Baker (1991). The

Figure 10.53. Static mixer (Kenics Corporation)

dispersion and mixing of liquids in pipes is discussed by Zughi *et al.* (2003) and Lee and Brodkey (1964).

Centrifugal pumps are effective inline mixers for blending and dispersing liquids. Various proprietary motor-driven inline mixers are also used for special applications; see Perry *et al.* (1997).

Stirred tanks

Mixing vessels fitted with some form of agitator are the most commonly used type of equipment for blending liquids and preparing solutions.

Liquid mixing in stirred tanks is covered in Volume 1, Chapter 7, and in several textbooks; Uhl and Gray (1967), Harnby *et al.* (1997) and Tatterson (1991), (1993).

A typical arrangement of the agitator and baffles in a stirred tank, and the flow pattern generated, is shown in Figure 10.54. Mixing occurs through the bulk flow of the liquid and, on a microscopic scale, by the motion of the turbulent eddies created by the agitator. Bulk flow is the predominant mixing mechanism required for the blending of miscible liquids and for solids suspension. Turbulent mixing is important in operations involving mass and heat transfer; which can be considered as shear controlled processes.

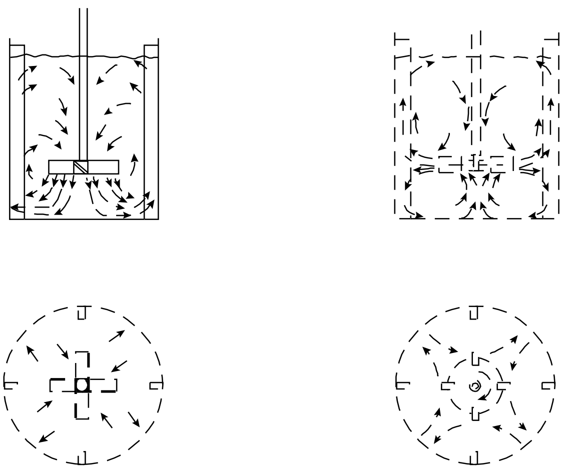

Figure 10.54. Agitator arrangements and flow patterns

The most suitable agitator for a particular application will depend on the type of mixing required, the capacity of the vessel, and the fluid properties, mainly the viscosity.

The three basic types of impeller which are used at high Reynolds numbers (low viscosity) are shown in Figures 10.55*a*, *b*, *c*. They can be classified according to the predominant direction of flow leaving the impeller. The flat-bladed (Rushton) turbines are essentially radial-flow devices, suitable for processes controlled by turbulent mixing (shear controlled processes). The propeller and pitched-bladed turbines are essentially axial-flow devices, suitable for bulk fluid mixing.

Paddle, anchor and helical ribbon agitators (Figures 10.56*a*, *b*, *c*), and other special shapes, are used for more viscous fluids.

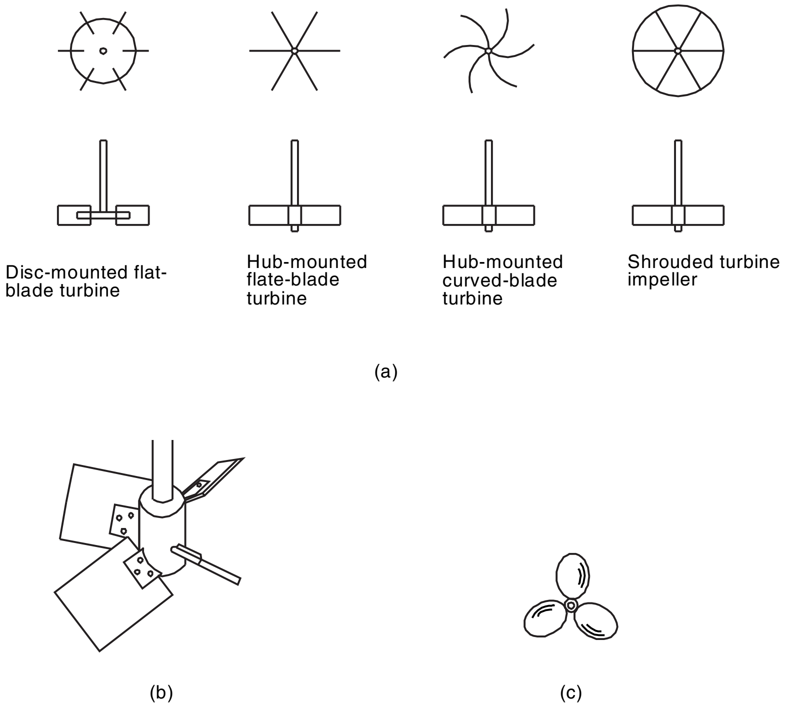

Figure 10.55. Basic impeller types (*a*) Turbine impeller (*b*) Pitched bladed turbine (*c*) Marine propeller

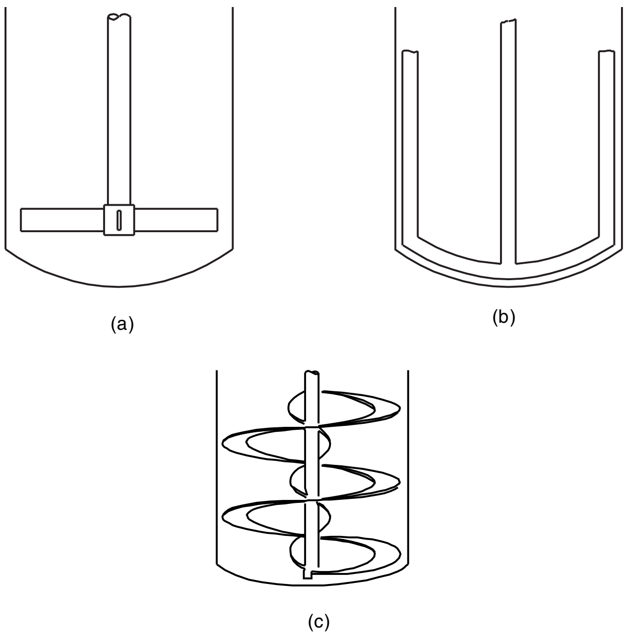

Figure 10.56. Low-speed agitators (*a*) Paddle (*b*) Anchor (*c*) Helical ribbon

The selection chart given in Figure 10.57, which has been adapted from a similar chart given by Penney (1970), can be used to make a preliminary selection of the agitator type, based on the liquid viscosity and tank volume.

For turbine agitators, impeller to tank diameter ratios of up to about 0.6 are used, with the depth of liquid equal to the tank diameter. Baffles are normally used, to improve the mixing and reduce problems from vortex formation. Anchor agitators are used with close clearance between the blades and vessel wall, anchor to tank diameter ratios of

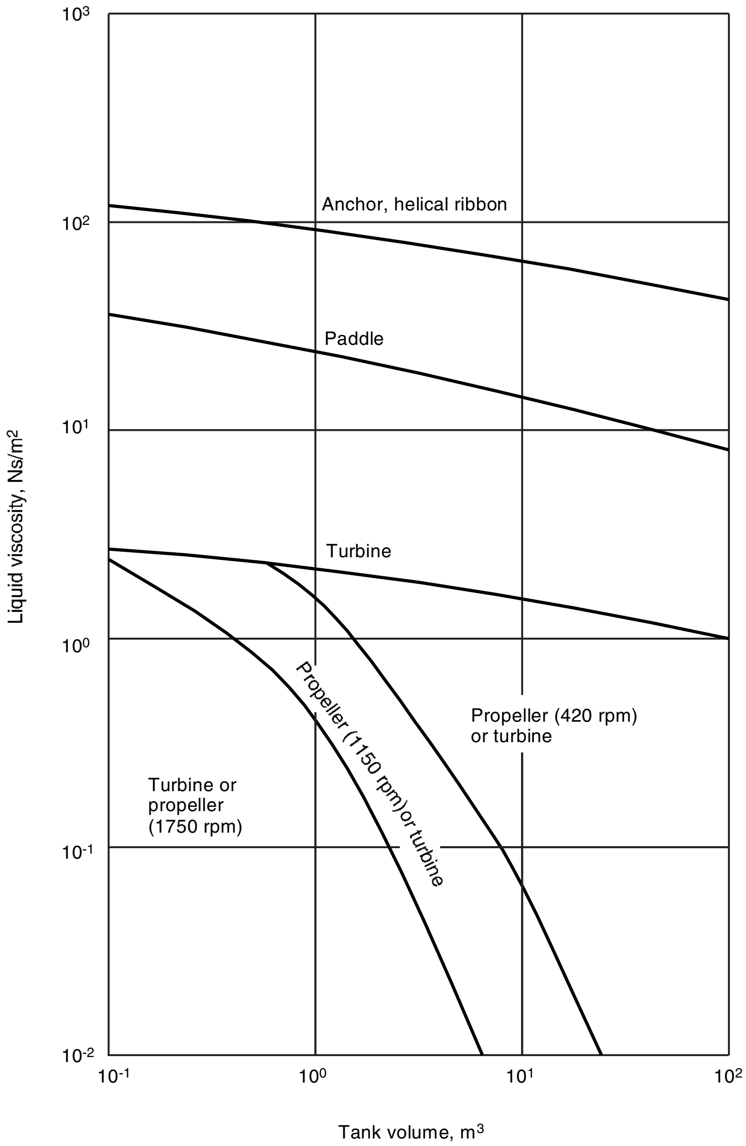

Figure 10.57. Agitator selection guide

0.95 or higher. The selection of agitators for dispersing gases in liquids is discussed by Hicks (1976).

Agitator power consumption

The shaft power required to drive an agitator can be estimated using the following generalised dimensionless equation, the derivation of which is given in Volume 2, Chapter 13.

$$N_p = KRe^b Fr^c \tag{10.11}$$

where N_p = power number $= \dfrac{P}{D^5 N^3 \rho}$,

Re = Reynolds number $= \dfrac{D^2 N \rho}{\mu}$,

Fr = Froude number $= \dfrac{DN^2}{g}$,

P = shaft power, W,

K = a constant, dependent on the agitator type, size, and the agitator-tank geometry,

ρ = fluid density, kg/m^3,

μ = fluid viscosity, Ns/m^2,

N = agitator speed, s^{-1} (revolutions per second) (rps),

D = agitator diameter, m,

g = gravitational acceleration, 9.81 m/s^2.

Values for the constant K and the indices b and c for various types of agitator, tank-agitator geometries, and dimensions, can be found in the literature; Rushton *et al.* (1950). A useful review of the published correlations for agitator power consumption and heat transfer in agitated vessels is given by Wilkinson and Edwards (1972); they include correlations for non-Newtonian fluids. Typical power curves for propeller and turbine agitators are given in Figures 10.58 and 10.59. In the laminar flow region the index "b" = 1; and at high Reynolds number the power number is independent of the Froude number; index "c" = 0.

An estimate of the power requirements for various applications can be obtained from Table 10.14.

Table 10.14. Power requirements — baffled agitated tanks

Agitation	Applications	Power, kW/m^3
Mild	Blending, mixing	0.04–0.10
	Homogeneous reactions	0.01–0.03
Medium	Heat transfer	0.03–1.0
	Liquid-liquid mixing	1.0–1.5
Severe	Slurry suspension	1.5–2.0
	Gas absorption,	1.5–2.0
	Emulsions	1.5–2.0
Violent	Fine slurry suspension	>2.0

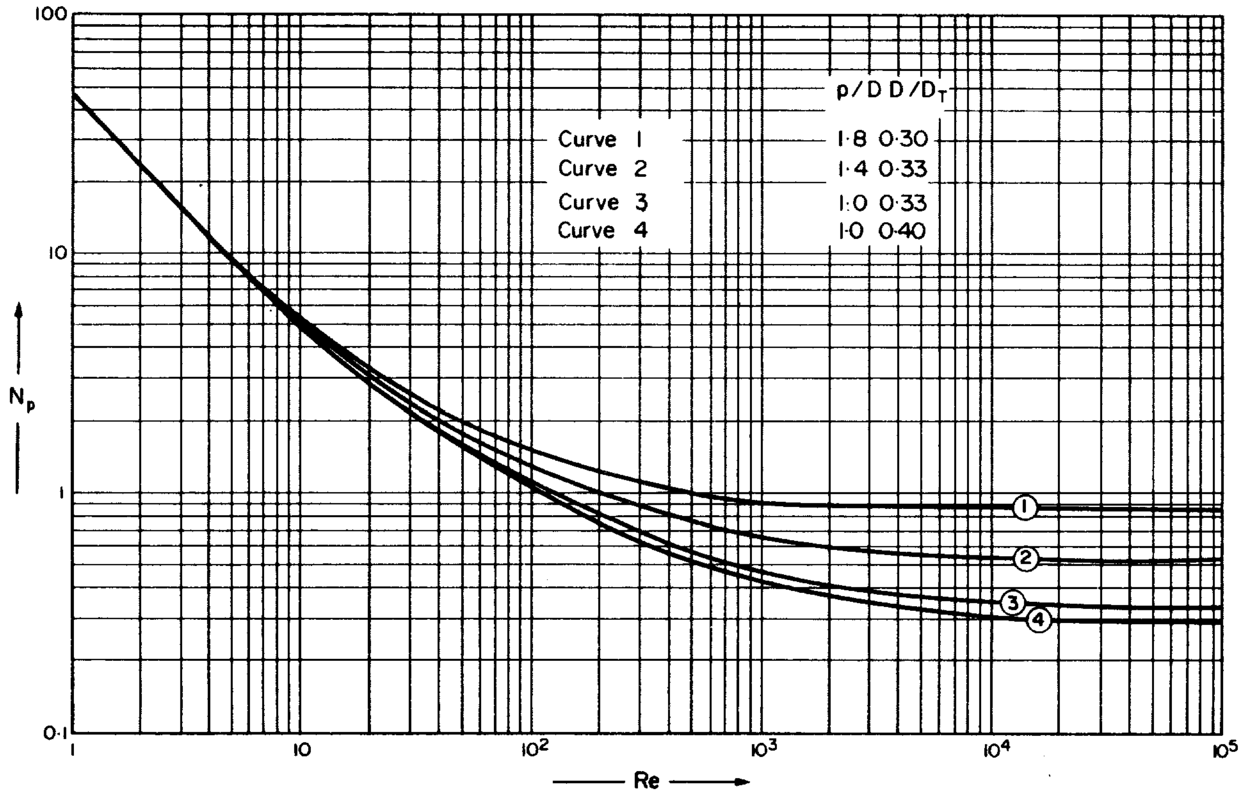

Figure 10.58. Power correlation for single three-bladed propellers baffled, (from Uhl and Gray (1967) with permission). p = blade pitch, D = impeller diameter, D_T = tank diameter

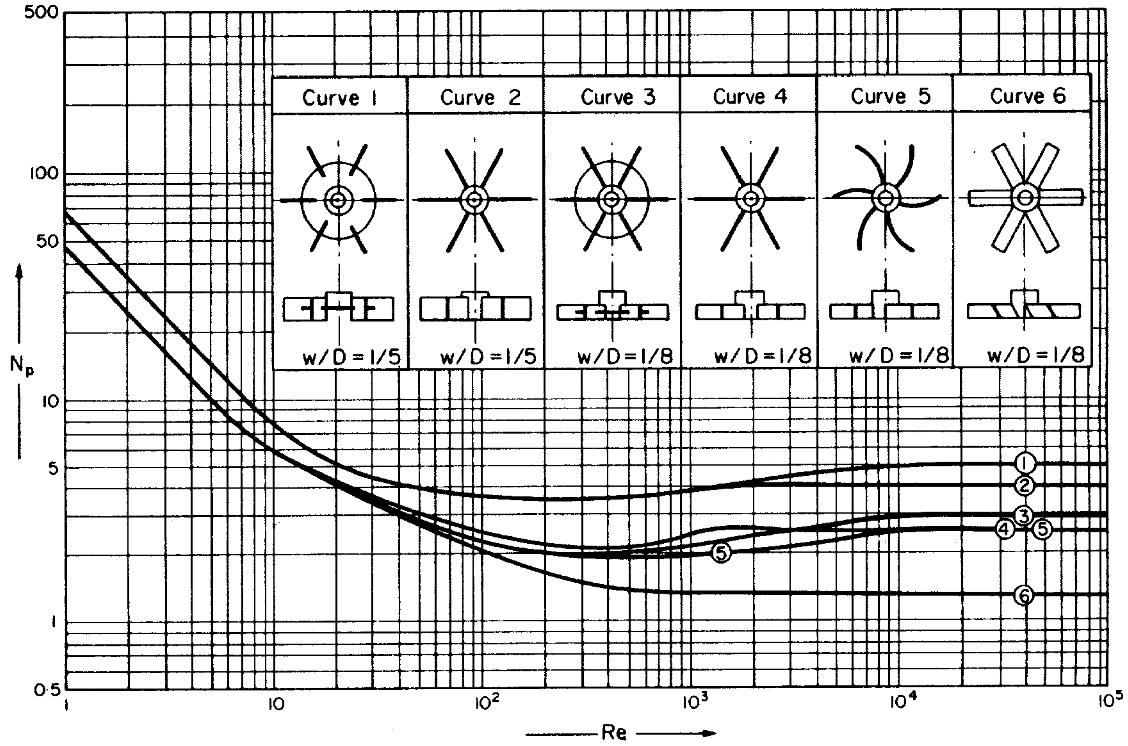

Figure 10.59. Power correlations for baffled turbine impellers, for tank with 4 baffles (From Uhl and Gray (1967) with permission). w = impeller width, D = impeller diameter