Mixing (or blending) is a unit operation in which a uniform mixture is obtained from two or more components, by dispersing one within the other(s). The larger component is sometimes called the *continuous phase* and the smaller component the *dispersed phase* by analogy with emulsions (Chapter 4), but these terms do not imply emulsification when used in this context. Mixing has no preservative effect and is intended solely as a processing aid or to alter the eating quality of foods. It has very wide applications in many food industries where it is used to combine ingredients to achieve different functional properties or sensory characteristics. Examples include texture development in doughs and ice cream, control of sugar crystallisation and aeration of batters and some chocolate products. In some foods, adequate mixing is necessary to ensure that the proportion of each component complies with legislative standards (for example mixed vegetables, mixed nuts, sausages and other meat products). Extruders (Chapter 14) and some types of size reduction equipment (Chapter 4) also have a mixing action.

Forming is a size enlargement operation in which foods that have a high viscosity or a dough-like texture are moulded into a variety of shapes and sizes, often immediately after a mixing operation. It is used as a processing aid to increase the variety and convenience of baked goods, confectionery and snack foods. It has no direct effect on the shelf life or nutritional value of foods. Close control over the size of formed pieces is critical (for example to ensure uniform rates of heat transfer to the centre of baked foods, to control the weight pieces of food, and to ensure the uniformity of smaller foods and hence to control fill weights). Extrusion (Chapter 14) also has a forming function.

### 5.1 Mixing

When food products are mixed there are a number of aspects that are different to other industrial mixing applications:

- mixing is often used primarily to develop desirable product characteristics, rather than simply ensure homogeneity
it is often multi-component, involving ingredients of different physical properties and quantities

it may often involve high viscosity or non-Newtonian liquids

some components may be fragile and damaged by over-mixing

there may be complex relationships between mixing patterns and product characteristics

The criteria for successful mixing have been described as first achieving an acceptable product quality (in terms of sensory properties, functionality, homogeneity, particulate integrity, etc.) followed by adequate safety, hygienic design, legality (compositional standards for some foods), process and energy efficiency, and flexibility to changes in processing (Campbell, 1995). A detailed review of mixing operations is given by Lindley (1991a–c).

5.1.1 Theory of solids mixing

In contrast with liquids and viscous pastes (Section 5.1.2) it is not possible to achieve a completely uniform mixture of dry powders or particulate solids. The degree of mixing that is achieved depends on:

• the relative particle size, shape and density of each component

• the moisture content, surface characteristics and flow characteristics of each component

• the tendency of the materials to aggregate

• the efficiency of a particular mixer for those components.

In general, materials that are similar in size, shape and density are able to form a more uniform mixture than are dissimilar materials. During a mixing operation, differences in these properties also cause unmixing (or separation) of the component parts. In some mixtures, uniformity is achieved after a given period and then unmixing begins. It is therefore important in such cases to time the mixing operation accurately. The uniformity of the final product depends on the equilibrium achieved between the mechanisms of mixing and unmixing, which in turn is related to the type of mixer, the operating conditions and the component foods.

If a two-component mixture is sampled at the start of mixing (in the unmixed state), most samples will consist entirely of one of the components. As mixing proceeds, the composition of each sample becomes more uniform and approaches the average composition of the mixture. One method of determining the changes in composition is to calculate the standard deviation of each fraction in successive samples:

$$
\sigma_m = \sqrt{\frac{1}{n-1} \sum (c - \bar{c})^2}
$$

where \( \sigma_m \) = standard deviation, \( n \) = number of samples, \( c \) = concentration of the component in each sample and \( \bar{c} \) = the mean concentration of samples. Lower standard deviations are found as the uniformity of the mixture increases.

A number of mixing indices are available to monitor the extent of mixing and to compare alternative types of equipment:

$$
M_1 = \frac{\sigma_m - \sigma_\infty}{\sigma_0 - \sigma_\infty}
$$
Food processing technology

\[ M_2 = \frac{\log \sigma_m - \log \sigma_\infty}{\log \sigma_0 - \log \sigma_\infty} \]  
\[ M_3 = \frac{\sigma_m^2 - \sigma_\infty^2}{\sigma_0^2 - \sigma_\infty^2} \]

where \( \sigma_\infty \) = the standard deviation of a 'perfectly mixed' sample, \( \sigma_0 \) = the standard deviation of a sample at the start of mixing and \( \sigma_m \) = the standard deviation of a sample taken during mixing. \( \sigma_0 \) is found using:

\[ \sigma_0 = \sqrt{V_1 (1 - V_1)} \]

where \( V \) = the average fractional volume or mass of a component in the mixture.

In practice, perfect mixing (where \( \sigma_\infty = 0 \)) cannot be achieved, but in efficient mixers the value becomes very low after a reasonable period. The mixing index \( M_1 \) is used when approximately equal masses of components are mixed and/or at relatively low mixing rates. \( M_2 \) is used when a small quantity of one component is incorporated into a larger bulk of material and/or at higher mixing rates, and \( M_3 \) is used for liquids or solids mixing in a similar way to \( M_1 \). In practice, all three are examined and the one that is most suitable for the particular ingredients and type of mixer is selected.

The mixing time is related to the mixing index using:

\[ \ln M = -Kt_m \]

where \( K \) = mixing rate constant, which varies with the type of mixer and the nature of the components, and \( t_m \) (s) = mixing time.

**Sample problem 5.1**

During preparation of a dough, 700 g of sugar are mixed with 100 kg of flour. Ten 100 g samples are taken after 1, 5 and 10 min and analysed for the percentage sugar. The results are as follows.

<table>
<thead>
<tr>
<th>Percentage after</th>
<th>1 min</th>
<th>0.21</th>
<th>0.32</th>
<th>0.46</th>
<th>0.17</th>
<th>0.89</th>
<th>1.00</th>
<th>0.98</th>
<th>0.23</th>
<th>0.10</th>
<th>0.14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage after</td>
<td>5 min</td>
<td>0.85</td>
<td>0.80</td>
<td>0.62</td>
<td>0.78</td>
<td>0.75</td>
<td>0.39</td>
<td>0.84</td>
<td>0.96</td>
<td>0.58</td>
<td>0.47</td>
</tr>
<tr>
<td>Percentage after</td>
<td>10 min</td>
<td>0.72</td>
<td>0.69</td>
<td>0.71</td>
<td>0.70</td>
<td>0.68</td>
<td>0.71</td>
<td>0.70</td>
<td>0.72</td>
<td>0.70</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Calculate the mixing index for each mixing time and draw conclusions regarding the efficiency of mixing. Assume that for 'perfect mixing' there is a probability that 99.7% of samples will fall within three standard deviations of the mean composition (\( \sigma = 0.01\% \)).

**Solution to Sample problem 5.1**

Average fractional mass \( V_1 \) of sugar in the mix

\[ V_1 = \frac{700}{100 \times 10^3} \]

\[ = 7 \times 10^{-3} \]

From equation (5.5),
\[\sigma_0 = \sqrt{[7 \times 10^{-3} (1 - 7 \times 10^{-3})]} \]
\[= 0.08337 \]
\[= 8.337\% \]

After 10 min

mean \(\bar{c}\) of the samples = 0.703

Using equation (5.1), after 1 min,

\[\sigma_m = \sqrt{\left[\frac{1}{10-1} \sum (c - 0.703)^2\right]} \]

(that is subtract 0.703 from \(c\) for each of the ten samples, square the result and sum the squares):

\[\sigma_m = \sqrt{(0.11 \times 1.837)} \]
\[= \sqrt{0.2020} \]
\[= 0.4495\% \]

After 5 min,

\[\sigma_m = 0.0772\% \]

and, after 10 min,

\[\sigma_m = 0.0125\% \]

Using equation (5.3), after 1 min,

\[M_2 = \frac{\log 0.4495 - \log 0.01}{\log 8.337 - \log 0.01} \]
\[= 0.566 \]

After 5 min,

\[M_2 = 0.304 \]

and, after 10 min,

\[M_2 = 0.0326 \]

Interpretation: if the log \(M_2\) is plotted against time, the linear relationship indicates that the mixing index gives a good description of the mixing process and that mixing takes place uniformly and efficiently.

Using equation (5.6), after 10 min,

\[\ln 0.0326 = -k \times 600 \]

Therefore,

\[k = 0.0057 \]
The time required for $\sigma_m = \sigma_\infty = 0.01\%$ is then found:

$$\ln 0.01 = -0.0057 t_m$$

$$t_m = 808 \text{ s}$$

Therefore

remaining mixing time $= 808 - 600$

$= 208$

$\approx 3.5 \text{ min}$

### 5.1.2 Theory of liquids mixing

The component velocities induced in low viscosity liquids by a mixer are as follows (Fig. 5.1a):

A. a longitudinal velocity (parallel to the mixer shaft)
B. a rotational velocity (tangential to the mixer shaft)
C. a radial velocity which acts in a direction perpendicular to the mixer shaft.

To achieve successful mixing, the radial and longitudinal velocities imparted to the liquid are maximised by baffles, off-centre or angled mixer shafts, or angled blades (Fig 5.1b). To mix low-viscosity liquids adequately, turbulence must be induced throughout the bulk of the liquid to entrain slow-moving parts within faster moving parts. A vortex should be avoided because adjoining layers of circulating liquid travel at a similar speed and mixing does not take place. The liquids simply rotate around the mixer.

![Diagram of component velocities in fluid mixing](image)

**Fig. 5.1** (a) Component velocities in fluid mixing: A, longitudinal; B, rotational; C, radial; (b) Position of agitators for effective mixing of liquids.
In high-viscosity liquids, pastes or doughs, a different action is needed. Here, mixing occurs by:

- **kneading** the material against the vessel wall or into other material
- **folding** unmixed food into the mixed part
- **shearing** to stretch the material.

Efficient mixing is achieved by creating and recombining fresh surfaces in the food as often as possible. However, because the material does not easily flow, it is necessary either to move the mixer blades throughout the vessel or to move the food to the mixer blades.

Most liquid foods are non-Newtonian and the most common types are pseudoplastic, dilatant and viscoelastic. These properties are described in detail by Lewis (1990) and in Chapter 1 (Section 1.1.2). The design of equipment should enable thorough mixing without overloading the motor or reducing the mixing efficiency.

**Pseudoplastic** foods (for example sauces) form a zone of thinned material around a small agitator as mixing proceeds, and the bulk of the food does not move. The higher the agitator speed, the more quickly the zone becomes apparent. Planetary or gate mixers or roller mills (Section 5.1.3) are used to ensure that all food is subjected to the mixing action. **Dilatant** foods (for example cornflour and chocolate) should be mixed with great care. If adequate power is not available in the mixer, the increase in viscosity causes damage to drive mechanisms and shafts. A folding or cutting action, as for example in some planetary mixers or paddle mixers, is suitable for this type of food (Section 5.1.3). **Viscoelastic** foods (for example bread dough) require a folding and stretching action to shear the material. Suitable equipment includes twin-shaft mixers and planetary mixers with intermeshing blades.

The rate of mixing is characterised by a mixing index (Section 5.1.1). The mixing rate constant (equation 5.6) depends on the characteristics of both the mixer and the liquids. The effect of the mixer characteristics on $K$ is given by:

$$K \propto \frac{D^3 N}{D_t^2 z}$$

where $D$ (m) = the diameter of the agitator, $N$ (rev s$^{-1}$) = the agitator speed, $D_t$ (m) = the vessel diameter and $z$ (m) = the height of liquid.

The power requirements of a mixer vary according to

- the nature, amount and viscosity of the foods in the mixer
- the position, type, speed and size of the impeller.

Liquid flow is defined by a series of dimensionless numbers: the Reynolds number $Re$ (equation 5.8), also Chapter 1), the Froude number $Fr$ (equation (5.9)) and the Power number $Po$ (equation (5.10)):

$$Re = \frac{D^2 N \rho_m}{\mu_m}$$

1. The viscosity changes with rate of shear.
2. The viscosity decreases with increasing shear rate.
3. The viscosity increases with shear rate.
4. Materials which exhibit viscous and elastic properties including stress relaxation, creep and recoil.
where $P$ (W) = the power transmitted via the agitator, $\rho_m$ (kg m$^{-3}$) = the density of the mixture and $\mu_m$ (N s m$^{-2}$) = the viscosity of the mixture. These are related as follows:

$$Po = K(Re)^n(\text{Fr})^m$$  \hspace{1cm} (5.11)

where $K$, $n$ and $m$ are factors related to the geometry of the agitator, which are found by experiment (for example Rushton et al., 1950). The Froude number is only important when a vortex is formed in an unbaffled vessel and is therefore omitted from equation (5.11).

The density of a mixture is found by addition of component densities of the continuous and dispersed phases:

$$\rho_m = V_1 \rho_1 + V_2 \rho_2$$  \hspace{1cm} (5.12)

where $V$ = the volume fraction. The subscripts 1 and 2 are the continuous phase and dispersed phase respectively.

The viscosity of a mixture is found using the following equations for baffled mixers and for unbaffled mixers:

$$\mu_m(\text{unbaffled}) = \mu_1^{V_1} \mu_2^{V_2}$$  \hspace{1cm} (5.13)

$$\mu_m(\text{baffled}) = \frac{\mu_1}{V_1} \left( \frac{1 + 1.5 \mu_2 V_2}{\mu_1 + \mu_2} \right)$$  \hspace{1cm} (5.14)

(Jackson and Lamb, 1981).

Characteristic changes in power consumption $Po$ of propellers at different Reynolds numbers are shown in Fig. 5.2.

![Fig. 5.2 Changes in power number (Po = $P/\rho_m N^3 D^5$) versus Reynolds Number (Re = $D^2 N/\rho_m$) for propeller agitator. (30 cm propeller in 137 cm diameter tank, liquid depth 137 cm, propellor 30 cm above base. (A) viscosity = 0.189 N s m$^{-2}$, (B) viscosity = 0.028 N s m$^{-2}$, (C) viscosity = 0.109 N s m$^{-2}$. (Propeller speed varied from 100–500 rpm). (After Rushton et al. (1950).)](image-url)
5.1.3 Equipment

The selection of a correct type and size of mixer depends on the type and amount of food being mixed and the speed of operation needed to achieve the required degree of mixing with minimum energy consumption. There are a very large variety of mixers available, due to the large number of mixing applications and the empirical nature of mixer design and development.
<table>
<thead>
<tr>
<th></th>
<th>Tumbling mixer</th>
<th>Simple vertical screw</th>
<th>Orbital screw</th>
<th>Double ribbon mixer</th>
<th>Pan mixer</th>
<th>Z-blade mixer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Will it mix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>free-flowing powders</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cohesive powders</td>
<td>✖</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>damp powders</td>
<td>✖</td>
<td>✖</td>
<td>✔</td>
<td></td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>pastes</td>
<td>✖</td>
<td>✖</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>slurries</td>
<td>✖</td>
<td>✖</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>materials having varying shape</td>
<td>✖</td>
<td>✖</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>materials having varying density</td>
<td>✖</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>materials of varying size</td>
<td>✖</td>
<td>✖</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Is it prone to de-mixing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>high shear</td>
<td>✖</td>
<td>✖</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>low shear</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>self-cleaning</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>self-emptying</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Can it be cleaned by brushing</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>cleaned by washing</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cleaned by sterilisation</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>heated or cooled</td>
<td>✖</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>adapted easily to pressure or vacuum operation</td>
<td>✖</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Does it produce light out-of-balance loading</td>
<td>✖</td>
<td>✖</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>produce heavy out-of-balance loading</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>require external guards</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>have low starting torque</td>
<td>✖</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>have high starting torque</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Power requirement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 5hp/tonne</td>
<td>✖</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5–10 hp/tonne</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;10 hp/tonne</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

✔ = yes, ✖ = no, ✖/✔ = dependent on detailed design.
Mixers are classified into types that are suitable for:

1. dry powders or particulate solids
2. low- or medium-viscosity liquids
3. high-viscosity liquids and pastes
4. dispersion of powders in liquids.

Pownall (1986) has surveyed mixing equipment available for each category and some factors used to select mixing equipment are described in Table 5.1. In general, mixing efficiency can be improved in both batch and continuous mixers by mixing in several stages (Fig. 5.3). For example, if 1 kg of an ingredient is to be mixed into 500 kg of water, it is mixed more efficiently if it is first mixed with about 25 kg of water and this is then mixed with the remainder of the water (Campbell, 1995).

**Mixers for dry powders and particulate solids**

These mixers have two basic designs: the tumbling action of rotating vessels and the positive movement of materials in screw types. They are used for blending grains, flours
and the preparation of powdered mixes (for example cake mixes and dried soups). Tumbling mixers include drum, double-cone (Fig. 5.4), Y-cone and V-cone mixers. They are filled approximately half full and rotate at speeds of 20–100 rev min$^{-1}$. Optimum mixing for a particular blend of ingredients depends on the shape and speed of the vessel, but speeds should be lower than the 'critical speed', when centrifugal force exceeds gravity. The efficiency of mixing is improved by internal baffles or counter-rotating arms. These mixers are also used for coating applications (Chapter 23).

Ribbon mixers have two or more thin narrow metal blades (Fig. 5.5) formed into helices which counter-rotate in a closed hemispherical trough. The pitch of the ribbons is different so that one moves the material rapidly forwards through the trough, and the second moves the material slowly backwards, to produce a net forward movement of material. This type of mixer is used for dry ingredients and small-particulate foods.

Fig. 5.4 Double-cone mixer.
(Courtesy of Winkworth Engineering Ltd.)

Fig. 5.5 Ribbon mixer.
(Courtesy of Winkworth Engineering Ltd.)
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*Vertical-screw mixers* have a rotating vertical screw, contained within a conical vessel which orbits around a central axis to mix the contents. This type of equipment is particularly useful for the incorporation of small quantities of ingredients into a bulk of material.

**Mixers for low- or medium-viscosity liquids**
A large number of designs of agitator are used to mix liquids in unbaffled or baffled vessels. The advantages and limitations of each vary according to the particular application but are summarised in Table 5.2.

The simplest *paddle agitators* are wide flat blades (Fig. 5.6(a)) which measure 50–75% of the vessel diameter and rotate at 20–150 rev min⁻¹. The blades are often pitched to promote longitudinal flow in unbaffled tanks. *Impeller agitators* consist of two or more blades attached to a rotating shaft. The blades may be flat, angled (pitched) or curved. Turbine agitators are impeller agitators which have more than four blades mounted together. The size is 30–50% of the diameter of the vessel and they operate at 30–500 rev min⁻¹. The blades are flat, pitched or curved to increase radial and longitudinal flow. In addition blades may be mounted on a flat disc (the *vaned disc impeller* (Fig. 5.6(b))), mounted vertically in baffled tanks. High shearing forces are developed at the edges of the impeller blades and they are therefore used for pre-mixing emulsions (Chapter 4).

Impellers which have short blades (less than a quarter of the diameter of the vessel) are known as propeller agitators (Fig. 5.6(c)). In each type the agitator is located in one of the positions shown in Fig. 5.1(b) to promote longitudinal and radial movement of the liquids and to prevent vortex formation. Alternatively, baffles are fitted to the vessel wall to increase shearing of the liquids and to interrupt rotational flow, but care is necessary in the design to ensure that the vessel may be adequately cleaned (Chapter 26). Propeller agitators operate at 400–1500 rev min⁻¹ and are used for blending miscible liquids, diluting concentrated solutions, preparing syrups or brines and dissolving other ingredients.

*Powder-liquid contacting devices* are short-residence-time mixers which are used to incorporate powders into liquids. They operate by mixing a uniform stream of powder into sprays of liquid and may also involve subsequent mixing by blades or rotors. Typical examples are shown in Fig. 5.7. Powders may also be mixed with liquids by pumping them through pipes that are fitted internally with stationary mixing blades. *Pumps* mix ingredients by creating turbulent flow both in the pump itself and in the pipework (Chapter 1). There are a large variety of pumps available for handling different fluids and suspensions: the different designs and applications are discussed by Leniger and Beverloo (1975) and in Chapter 26 (Section 26.1.2).

**Table 5.2**  Advantages and limitations of selected liquid mixers

<table>
<thead>
<tr>
<th>Type of mixer</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paddle agitator</td>
<td>Good radial and rotational flow, cheap</td>
<td>Poor perpendicular flow, high vortex risk at higher speeds</td>
</tr>
<tr>
<td>Multiple-paddle agitator</td>
<td>Good flow in all three directions</td>
<td>More expensive, higher energy requirements</td>
</tr>
<tr>
<td>Propeller impeller</td>
<td>Good flow in all three directions</td>
<td>More expensive than paddle agitator</td>
</tr>
<tr>
<td>Turbine agitator</td>
<td>Very good mixing</td>
<td>Expensive and risk of blockage</td>
</tr>
</tbody>
</table>
Fig. 5.6  Agitators: (a) flat blade agitator; (b) vaned disc impeller; (c) propeller agitator. 
(After Smith (1985).)

Fig. 5.7  Powder–liquid contacting devices: (a) Neptune Chemix (part); (b) Schugi mixer; 
(c) Buss mixer. 
(After McDonagh (1987).)
Mixers for high-viscosity liquids and pastes

More viscous liquids are mixed using slow-speed vertical-shaft impellers such as multiple-paddle (gate) agitators or, more commonly, counter-rotating agitators to develop high shearing forces. The basic design in this group is the anchor and gate agitator (Fig. 5.8). It is often used with heated mixing vessels, when the anchor is fitted with scraper blades to prevent food from burning onto the hot surface. Some complex designs have arms on the gate which intermesh with stationary arms on the anchor to increase the shearing action, whereas others have inclined vertical blades to promote radial movement in the food.

The most common design of twin-shaft horizontal blade mixers is the Z-blade (or sigma-blade) mixer (Fig. 5.9). This consists of two heavy-duty blades which are mounted horizontally in a metal trough. The blades intermesh and rotate towards each other at either similar or different speeds (14–60 rev min\(^{-1}\)) to produce shearing forces between
the two blades and between the blades and the specially designed trough base. These mixers use a substantial amount of power which is dissipated in the product as heat. Mixing efficiency should therefore be high to reduce the mixing time. If necessary the walls of the trough are jacketed for temperature control. Special designs for shredding and mixing have serrated blades, and other blade configurations including the gridlap, double naben and double claw are available (McDonagh, 1987).

Planetary mixers are commonly found in both industrial and domestic applications, and take their name from the path followed by rotating blades (at 40–370 rev min$^{-1}$), which include all parts of the vessel in the mixing action. An alternative design employs fixed rotating blades which are offset from the centre of a co-currently or counter-currently revolving vessel. In both types there is a small clearance between the blades and the vessel wall. Gate blades are used for mixing pastes, blending ingredients and preparation of spreads; hooks are used for dough mixing and whisks are used for batter preparation.

Screw conveyor mixers are typical of the type known as continuous rotor-stator mixers. A horizontal rotor fits closely into a slotted stationary casing (or ‘barrel’). Single or twin screws are used to convey viscous foods and pastes through the barrel and to force it through perforated plates or grids. The small clearance between the screw and the barrel wall causes a shearing and kneading action. This is supplemented by shearing and mixing as the food emerges from the end plate or grid. The screw may be interposed with pins to increase the shearing action. This type of equipment is also used for extrusion (Chapter 14) and butter or margarine manufacture (Chapter 4). Recent developments include automatic microprocessor control with recipe storage for rapid change of products, process monitoring and control and logging of process and product data (Chapter 2). These continuous mixers are used to produce doughs for crackers, biscuits, breads, crispbreads, rusk, cakes and confectionery products.

A number of other designs, including butter churns, bowl choppers and rollers are each used in specific applications to mix foods, often with simultaneous homogenisation or size reduction. Roller mills and colloid mills are suitable for mixing high-viscosity materials in addition to their function as size reduction equipment (Chapter 4). More recently, static or ‘motionless’ mixers have been developed for viscous materials and fluids. These mixers comprise a series of precisely aligned static mixing elements contained within a housing that is installed in the processing line. The elements split, rotate and integrate the food material in a precisely defined pattern, according to the type of food to be mixed and the degree of mixing required. They operate using three mixing actions: radial mixing, flow division and transient mixing. In radial mixing, the fluid is deflected by the elements through a series of 180° rotations which forces the fluid from the centre to the wall of the pipe and back again. In flow division, the material is split into two components by the first mixing element and then rotated through 180° before being split into four streams by the second element and so on past succeeding elements until the required degree of mixing has been achieved (Fig. 5.10). Transient mixing employs spaces between the elements to allow relaxation of viscous material after successive radial mixings. It has been used in chocolate manufacture for the processing of cocoa mass (Richards, 1997). Static mixers eliminate the need for tanks, agitators and moving parts, thus reducing capital costs and maintenance requirements.

5.1.4 Effect on foods
The action of a mixer has no direct effect on either the nutritional quality or the shelf life of a food but may have an indirect effect by allowing components of the mixture to react
together. The nature and extent of the reaction depend on the components involved but may be accelerated if significant heat is generated in the mixer. In general, mixing has a substantial effect on sensory qualities and functional properties of foods. For example, gluten development is promoted during dough making by the stretching and folding action which aligns, uncoils and extends protein molecules and develops the strength of the gluten structure to produce the desired texture in the bread. The main effects are to increase the uniformity of products by evenly distributing ingredients throughout the bulk.

5.2 Forming

There are many designs of moulding and forming equipment made specifically for individual products. In this section the equipment used for bread, biscuits, pies, snackfoods and confectionery is described.
5.2.1 Bread moulders

This equipment (Fig. 5.11) shapes the dough into cylinders that will expand to the required loaf shape when proofed. The three stages are

1. sheeting
2. curling
3. rolling-sealing.

The first three sets of rollers have successively smaller gaps (or ‘nips’) to roll the dough gently into sheets without tearing. The sheet is loosely curled, rolled into a cylinder and then sealed by a revolving drum, which presses the dough against a pressure plate. The pressure is gradually increased to expel trapped air. Compression of the dough structure causes the moisture content of the sheet to increase at the trailing end. It is preferable to have the moist part of the dough at the centre of the cylinder, and a variety of designs are used to change the direction of the sheet to roll the trailing edge first (for example cross-grain moulders and reverse sheeting moulders) (Matz, 1972).

Equipment for forming and encasing balls of dough with other materials is described by Hayashi (1989). In this process, the inner material and outer material are co-extruded and then divided and shaped by two 'encrusting discs' (Fig. 5.12(a)). In contrast to conventional forming techniques, where the size of the product is determined by the size of the feed material, the relative thickness of the outer layer and the diameter of the inner sphere are determined by the flow rate of each material. It is therefore possible to alter the relative thickness of inner and outer layers (Fig. 5.12(b)) simply by adjusting the flowrates, giving a high degree of flexibility for the production of different products. This equipment was developed in Japan for production of cakes having an outer layer of rice dough and filled with bean paste, but they have found wide application and are used to produce sweetbreads filled with jam, doughnuts, meat pies, hamburgers filled with cheese and fish filled with vegetables.

5.2.2 Pie and biscuit formers

Pie casings are formed by depositing a piece of dough into aluminium foil containers or re-usable pie moulds and pressing it with a die. A filling is then deposited into the casing
Finally the lids are cut by reciprocating blades (Fig. 5.13).

Biscuits are formed by one of four methods:

1. the dough is pressed into shaped cavities in a metal moulding roller (die forming) (Fig. 5.14(a))
2. shapes are cut from a sheet of dough using a cutting roller. Raised characters on a printing roller simultaneously imprint a design on the upper surface of the biscuit (Fig. 5.14(b))
3. soft dough is extruded through a series of dies in a wire-cut machine (Fig. 5.14(c))

Fig. 5.12 (a) Two revolving encrusting discs continuously divide food and shape it into balls; (b) differences in thickness of outer layer (A) and inner layer (B) result from different material flowrates.

(Courtesy of Hayashi (1989).)
Fig. 5.13  Pie manufacture: 1, foil dishes; 2, dough divider; 3, blocking unit; 4, filling depositor; 5, pastry lid sheeting machine; 6, rotary lattice cutter; 7, crimping/lidding unit; 8, scrap return conveyor; 9, pie cross section.
(Courtesy of Machinefabriek C Rijkkaart BV.)
Fig. 5.14 Biscuit formers: (a) rotary moulder; (b) moulding rollers; (c) wire-cut machine. (Courtesy of Baker Perkins Ltd.)
4. A continuous ribbon of dough is extruded from a rout press (similar to a wirecut machine but without the cutting wires), and the ribbon is then cut to the required length using a reciprocating blade.

There are also numerous designs of equipment for laminating sheets of dough with fat (for croissants and pastries), folding doughs (to form pasties and rolls) and filling doughs (to form sausage rolls, fruit bars such as ‘fig rolls’ and cakes), described by Levine and Drew (1994).

5.2.3 Confectionery moulders
Confectionery depositing-moulding equipment consists of individual moulds, which have the required size and shape for a specific product, attached to a continuous conveyor. They are carried below a depositor, which has a piston filler to deposit accurately the required volume of hot sugar mass into each mould. Depositors can place food of a single type, in layers, or centre filled (Fig. 5.15(a)) (for example liquid centres or chocolate paste around hard-boiled sweets). The food is then cooled in a cooling tunnel. When it has hardened sufficiently, individual sweets are ejected and the moulds restart the cycle (Fig. 5.15(b)) (Verity, 1991). Details of chocolate moulding are given by Perreau (1989).

The three main types of equipment differ in the method of ejection, and the material used for the mould:

1. Metal moulds fitted with ejector pins are used for hard confectionery (for example butterscotch)
2. Flexible polyvinyl chloride moulds, which eject the food by mechanical deformation, are used for soft confectionery (for example toffee, fudge, jellies, caramel, fondant and chocolate)
3. Polytetrafluoroethylene-coated aluminium moulds, with compressed-air ejection, are used for jellies, gums, fondant and crèmes.

Fig. 5.15 (a) Depositing centre-filled confectionery; (b) confectionery moulding: an air demoulding depositor. (Courtesy of Baker Perkins Ltd.)
Each type of equipment is automatically controlled. Other types of forming equipment extrude sugar confectionery (Chapter 14) and shape it using a series of rollers, to produce a sugar ‘rope’. Individual sweets are then cut from the rope and shaped by dies.

Microprocessor-controlled depositors are used to form cake mixes and high-viscosity liquids for confectionery products into a wide variety of shapes. The memory can hold the sizes, shapes and weights of up to 99 different products, which are called up by the operator using a two-digit product code.

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5.4 References


