Chapter 4
Mixing and Dough Processing

An integral part of all breadmaking is the formation of a smooth and homogeneous dough with a developed gluten structure. As discussed in an earlier chapter, in some breadmaking processes dough development continues during resting after mixing while in others full development is achieved during the mixing process itself. Whatever the method by which dough development is achieved the next stage in bread manufacture is the subdivision of the bulk dough (dividing) and the shaping of the individual dough pieces (moulding) to conform to the requirements of the bread variety being made. Shaping may be a multi-stage operation and may involve a further resting period between moulding stages (intermediate or first proof). Once finally formed the dough pieces commonly pass on to be proved before baking.

Before the introduction of machinery, dough the world over was made by hand mixing of the ingredients and then by kneading the mixture until a dough was created. The processes of mixing, dividing and moulding can be carried out by hand; indeed this is still the case in many bakeries, for example in India where the production of loaves in Bombay is still based on hand mixing. Increasingly the operations of mixing, dividing and moulding are becoming mechanized. The purpose of this chapter is to discuss the essential elements of dough mixing and processing, to consider how they are achieved and to consider how equipment design can impact on final product quality.

Functions of Mixing

All mixing machines available today are designed to incorporate both the mixing and the kneading characteristics of the manual process. In essence mixing is simply the homogenization of the ingredients, whereas kneading is the development of the dough (gluten) structure by 'work done' after the initial mixing. In mixing machines today this 'work' is carried out by a variety of methods, each suiting the output capacity required, the type of dough required for the final product specification and its use in subsequent processing.

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Some of the basic requirements for dough mixing have been introduced in previous chapters, but it is worthwhile to summarize them again before considering the different types of mixing machines which are available and how they may or may not meet the basic requirements of dough mixing.

We can summarize mixing requirements as the following:

- To disperse uniformly the recipe ingredients;
- To encourage the dissolution and hydration of those ingredients, in particular the flour proteins;
- To contribute energy to the development of a gluten (hydrated flour protein) structure in the dough;
- To incorporate air bubbles within the dough to provide gas nuclei for the carbon dioxide generated from yeast fermentation and oxygen for oxidation and yeast activity;
- To provide a dough with suitable rheological character for subsequent processing.

While not a requirement of mixing it should be noted that all types of mechanical mixing action will result in the transfer of heat to the dough, the amount of heat which is transferred is directly related to the mixing action and total energy imparted during the mixing time. Not all of the energy will be transferred to the dough as some will be lost to the metal of the mixer and a little to the surrounding atmosphere. Some of the heat absorbed by the metal of the mixing machine will subsequently be lost to the surrounding atmosphere but in many commercial bakeries where dough mixing machinery is running for long periods of time the amount of heat transferred to the dough quickly reaches what is in effect a ‘steady state’. This in turn means that most of the energy of mixing translates to heat input to the dough.

Types of Mixer

Mixing machines vary widely from those that virtually mimic a hand mixing action, to high-speed machines which are able to work the mix intensively to the required dough condition within a few minutes. Many mixing machines still work the dough as originally done by hand through a series of compressing and stretching operations (kneading), while others use higher speed folding coupled with intensive mechanical shear to impart the necessary work to the dough.

In many mixing processes the velocity of the dough being flung around within the mixing chamber is used to incorporate the full volume of ingredients into the mix and to impart energy to the dough from the mixing tool during kneading. Where mixing systems rely more heavily on this effect they tend to require a higher minimum mixing capacity for a given mixing chamber capacity in order to remain efficient because the mixing tool does not come into intimate contact with every ingredient molecule. This practical effect tends to limit the higher-speed mixers to the large-scale bakeries where bread plants are running at near maximum capacities and variations in batch mixing sizes are not common. In smaller-scale production greater versatility of batch size may be required from the mixers, and so lower mixing speeds and more intimate contact between the mixing tool and dough are an advantage.

In order to describe the most common variants of mixing machines and their applications, they may be divided into six common groupings (the first four being based on batch mixing) as follows:

- Chorleywood Bread Process (CBP) compatible, where the essential features are high mixing speeds and high-energy input, to develop the dough rapidly, and with control of the mixer atmosphere;
- High speed and twin spiral, where a high level of work can be input to the dough in a short time but atmospheric control is usually lacking;
- Spiral, in which a spiral-shaped mixing tool rotates on a vertical axis;
- Horizontal bar mixers in which the mixing tools rotate on a horizontal axis and sweep the developing dough against the sides of the mixer;
- Low speed, where mixing is carried out over an extended period of time;
- Continuous where the dough leaves the mixer in a continuous flow.

CBP-Compatible Mixers

The essential features of the CBP have been described in Chap. 2 and elsewhere (Cauvain and Young 2006a). For a mixer to be compatible with the CBP it must be capable of delivering a fixed amount of energy in a short space of time, usually 2–5 min. The required energy will vary according to the properties of the flour and the product being made. In the UK energy levels of about 11 Wh/kg (5 Wh/lb) of dough in the mixer are common, while in other parts of the world or with products such as breads in the USA, this may rise to as much as 20 Wh/kg (9 Wh/lb) of dough (Tweedy of Burnley 1982). Whatever the absolute energy level to be used, the short mixing time is very important in achieving the correct dough development and bubble structure formation in the dough.

Because of the CBP requirements, motor power levels will be large. The most common CBP-compatible mixers consist of a powerful vertically mounted motor drive, directly coupled through a belt system to a mixing blade (impeller) mounted vertically in a fixed bowl or tub (Fig. 4.1). The high velocity of dough being flung off the impeller sweeps the bowl walls clean during mixing and subsequent mechanical development. The mixing bowl is mounted on horizontal pivots and is capable of being tilted to receive ingredients and for dough discharge into a trough (Fig. 4.2). Other systems are available using a horizontal motor drive directly coupled to the mixing tool via a straight coupling or gearbox. Some versions have additional motor-driven bowl scrapers to encourage dough into the mixing area. In these mixers discharge is through an end door or through a bottom-mounted gate.

There are many variations to the design of the impeller blades used within CBP-compatible mixers. The primary function of the impeller is to aid dough development and it does this by interaction with a series of projections fitted on the inside of the bowl. As the dough impact on the bowl wall the projections turn it back

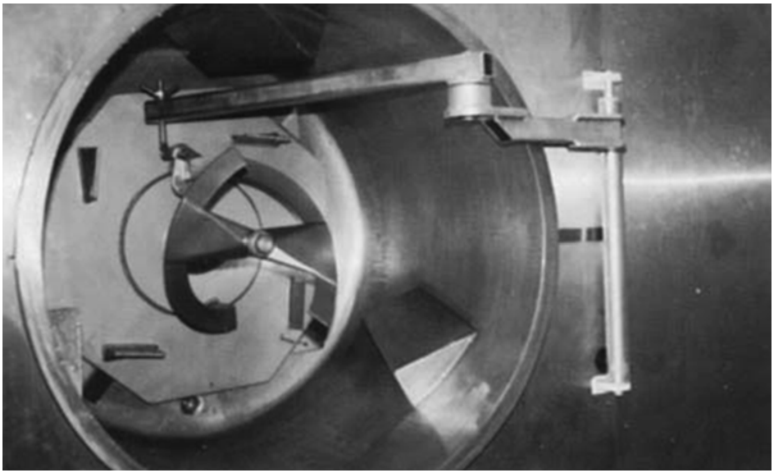

Fig. 4.1 Mixing chamber for CBP-compatible mixer shown with tool for removing mixing blade (courtesy Benier bv)

Fig. 4.2 Mixer and ingredient feed system for CBP doughs (courtesy Baker Perkins)

to towards the impeller blade and gravity pulls the dough downwards. In addition to this tumbling action the action of the impeller blades sweeping past the internal projections stretches the part of the dough which is momentarily trapped in the narrow space between projection and impeller plate. The number and positioning of the internal projections can have an effect on the rate of energy transfer during mixing, as can the design of the impeller or impact plate. However, measurements of gas bubble populations and bread crumb cell structure suggest that the design of the impeller has a limited effect on these dough and bread properties (Cauvain 1999).

In the production of US style-breads, where fine cell structures and higher energy inputs are required to achieve optimum dough development, CBP-compatible mixers may be fitted with a cooling jacket to maintain control of final dough temperatures (French and Fisher 1981). However, it should be remembered that as the result the mixing action in Tweedy-type mixers that the dough mass contact with the sides of the bowl is limited in the 2–5 min of mixing time and so the amount of heat that can be removed from the dough during mixing is relatively limited.

Additional features of CBP-compatible mixers include:

- Measurement of energy input to permit mixing to a defined dough energy input rather than time (though a time-out facility may be fitted to ensure that plant output is monitored);
- Automatic control of the mixing cycle and changes in mixer headspace pressure;
- Automatic ingredient feed systems;
- Programmable logic controls integrated with a preselectable recipe menu and fault diagnostic system;
- An integrated washing and cleaning system.

The most common applications of CBP-compatible mixers are the high-capacity production of bread and rolls with production lines rated for continuous 24 h output. Typical mixing plants are available as single or duplex mixers with outputs from 2000 (single mixer) to 10,000 (larger twin mixers) kg dough/h (900–4500 lb/h). More bread is produced from dough mixed with CBP-compatible mixers in the UK than from any other mixing system, and they can be found in use in many other countries around the world, including Australia, New Zealand, South Africa, India, the USA, Germany, Spain, France and Greece. A wide range of bread products are manufactured with CBP-compatible mixers and include pan breads, rolls and hamburger buns (Cauvain and Young 2006a).

Mixing Under Pressure and Vacuum with CBP-Compatible Mixers

In many CBP-compatible mixers control of the headspace atmosphere is incorporated into the mixing arrangements. In its ‘classic’ form this consisted of a vacuum pump capable of reducing the headspace pressure to 0.5 bar (15 in of mercury). This arrangement permitted the addition of extra water to the dough, provided a denser dough at the end of mixing (Cauvain and Young 2006a) and reduced variations in dough divider weights. It also yielded a finer, more uniform cell structure, a softer crumb and a brighter crumb appearance. The application of partial vacuum can continue throughout the mixing period or may be delayed to the latter part of the mixing cycle. The advantages in delaying the application of partial vacuum are that better oxidation via ascorbic acid can be achieved in the early part of the mixing cycle before oxygen levels are depleted by gas volume reduction and yeast activity.

The oxygen dependency of ascorbic acid and its contribution to dough development has been discussed above. With the loss of potassium bromate as a permitted oxidizing agent in UK breadmaking (and elsewhere), the relationship between mixer headspace atmosphere and ascorbic acid became more critical. If ascorbic acid was the sole oxidant and the whole of the (short) dough mixing cycle was carried out under a partial vacuum the resultant bread lacked volume and had a coarse crumb cell structure and a dark coloured crumb. Delaying the introduction of partial vacuum to the later stages of mixing brought about some improvements in final product quality. However, a key requirement of the successful application of partial vacuum was that the dough should be subjected to the reduced pressure setting for a reasonable period of time during mixing. In other words, it was not simply a case of achieving the final reduced pressure level at the end of the mixing cycle, the reduced pressure had to be achieved and held for some time before mixing was completed. Typically the length of time required for the reduced pressure to be effective in delivering the required cell structure in the final product was in the order of 30 s. Thus, in a 3 or 4 min mixing cycle the efficiency of the vacuum pump in lowering the mixer headspace pressure to the required level becomes critical. In practice these requirements tended to limit the introduction of pressure reduction to about half-way through the mixing cycle and deficiencies in bread quality could still arise.

In response to the deficiencies in product quality of some breads produced using the CBP with only ascorbic acid, an alternative new CBP-compatible mixer was developed in which mixer headspace pressures could be varied both above and below atmospheric (APV Corporation Ltd 1992). This mixer is most commonly referred to as a ‘pressure-vacuum’ mixer. It utilizes many of the basic principles of the CBP-compatible based on the original design of Tweedy mixer but has a mixer bowl which is capable of withstanding positive pressures as well as operating at negative pressures. An inlet device allows for the movement of air through the mixer which ensures improved ascorbic acid-assisted oxidation. In some versions of the mixer the running speed of the motor may be varied. The mixer headspace pressure may be changed during the mixing cycle and so it is possible to start at one mixer headspace pressure and move sequentially to another. This arrangement is similar to the delayed application of partial vacuum commonly used with CBP-compatible mixer but differs in that pressures greater than atmospheric may be applied.

The versatility of control of mixer headspace atmosphere pressures with the pressure-vacuum mixer provides a mixer capable of producing fine-structured sandwich breads or open-structured French baguette simply by varying the pressure combinations applied during the mixing cycle (Cauvain 1994, 1995). As discussed above, it is necessary for the dough to be subjected to the pre-set pressure for a short period of time before mixing is completed. This is true whether the required mixing pressure is above or below atmospheric pressure. The changes introduced in the pressure-vacuum mixers have a direct impact on the gas bubble populations which are formed in the dough during mixing and in doing so directly impact the final cell structure in the baked product. The control of mixing conditions is critical because of the strong link between crumb cell structure and the softness and eating qualities in bread and fermented products (Cauvain 2004). The versatility of the pressure-vacuum mixer with its ability to more closely control the final crumb structure provides unique opportunities for bakers.

Oxygen-Enrichment of the Mixer Headspace with CBP-Compatible Mixers

The critical relationship between oxygen and ascorbic acid in the development of a suitable gluten structure in modern bread dough has been discussed above. In the case of the pressure-vacuum mixer pressures greater than atmospheric can be used to deliver more oxygen to the dough via increased air flow. An earlier alternative to the use of pressure to deliver increased oxygen levels to the dough during mixing was developed for CBP-compatible mixers based on oxygen-enrichment of the gases in the mixer headspace. This method of mixing was based on the study of the role of gases in the CBP by Chamberlain and Collins (1979) who showed that a mixture of 60 % oxygen and 40 % nitrogen in the mixer headspace would yield bread with improved volume and finer cell structure than could be obtained from doughs mixed in air. The other advantage of using an oxygen-enriched gaseous mixture was that the application of partial vacuum was not required to yield fine and uniform cell structure in the product.

The concept of oxygen-enrichment of the mixer headspace was developed to a commercial-scale based on a mixture of oxygen and air rather than oxygen and nitrogen. All of the necessary safety features were developed and applied in the manufacturing environment. The quality of the bread was considered acceptable but the process was discontinued in the UK because of concerns about the ‘legality’ of the process. The concerns revolved around whether the use of oxygen in this way determined that it should be classed as an ‘additive’ and rather than be caught up in a protracted and potentially expensive investigation the commercial bakeries concerned stopped using the concept. An alternative to using an oxygen enriched atmosphere could be achieved by blowing air through the mixer but the cell structure of the final product was not as fine as that achieved with oxygen enrichment. With the development of the pressure-vacuum mixers interest in oxygen enriched atmospheres in mixers diminished.

High-Speed and Twin-Spiral Mixers

This category includes the widest variation in mixing design. It may be defined by the single ability of the mixer to impart a high level of mechanical work to the dough in a short period of time. Effectively, any mixer which can fully develop a dough within 5 min could be termed a high-speed mixer but the absence (mostly) of mixer headspace control separates this category of mixers from the CBP-compatible types.

Mixing criteria vary from one mixer design to another. Mixing to fixed time is the most common element, but some manufacturers offer alternative mixing controls based on dough temperature, energy consumption or even a combination of two different criteria (e.g. mix for y min unless dough temperature exceeds x°C). Not all high-speed mixers achieve mechanical dough development through an intense shearing and shearing action as experienced in most fixed-bowl machines with high-speed impellers. Manufacturers of twin-spiral and so-called ‘Wendal’ mixing systems (Fig. 4.3) claim that mechanical development is achieved through the stretching and folding action induced during the kneading stage (see Fig. 4.4). Whatever the mechanism of dough development, the absence of mixer headspace atmosphere control in this category of mixers does not permit as wide a range of cell structures in the final product as can be obtained in the CBP-compatible style. The absence, in some cases, of mixing to a fixed energy may lead to variations in the final bread qualities.

Fig. 4.3 Wendal kneader (courtesy Dierkes and Sohne Gmbh)

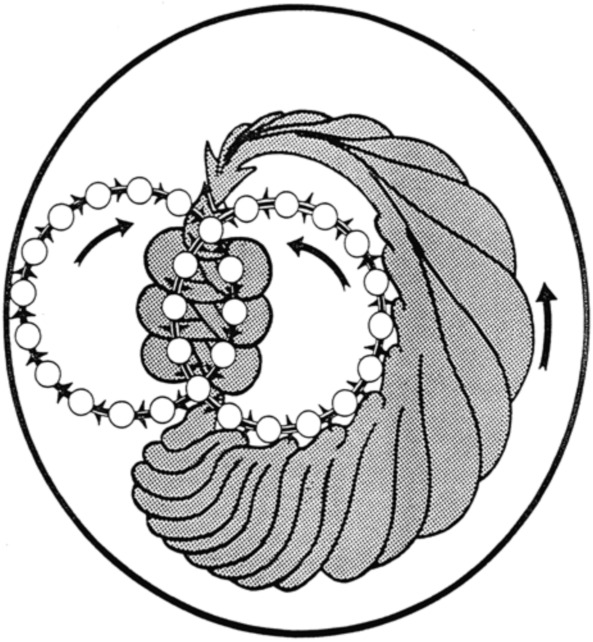

Fig. 4.4 Wendal kneading action (courtesy Dierkes and Sohne Gmbh)

High-speed mixers come in a multiplicity of designs, many of which were not originally born from the needs of bread manufacture. Usually the bowl or mixing tub is static during mixing. In some versions the mixing bowl is removable to enable dough to be handled across the bakery, reducing the time for the dough to be transferred from one container to another. Twin spiral mixers are a development of the single spiral mixer where the dough is brought by the rotation of the driven bowl through two mixing tools, instead of one as seen on conventional single spiral mixers. A variation of this form, which is able to generate a very high intensity of mixing action, is where the dough is drawn by the action and design of the mixing tool between two high-speed integrated tools (e.g. Wendal). Most twin-spiral mixers have removable bowls, with the bowl driven during the mixing cycle and offer two speeds for mixing (slow) and kneading (fast). High-speed mixer capacities vary from 50 to 300 kg dough/h (22–140 lb/h) but most commonly dough outputs from such mixing arrangements are 1500–3000 kg dough/h (680–1350 lb/h).

Spiral Mixers

The spiral mixer in its many variations has become the most common batch mixer throughout the baking industry with mix sizes ranging from 10 to 300 kg (4–140 lb). Production capacities may rise to 2300 kg/h (1000 lb/h), or higher when spiral

Fig. 4.5 Spiral mixer (courtesy Dierkes and Sohne Gmbh)

mixers are combined into integrated mixing systems. A basic definition for this ubiquitous type is that the mixing machine is equipped with a spiral-shaped mixing tool (Fig. 4.5) rotating on a vertical axis against the inner circumference of a bowl which is also rotating about its vertical axis. The mixing criteria are usually based on mixing time with most mixers having two speeds, slow for mixing and fast for kneading. Some mixers are available with control criteria based on dough temperature or energy consumption, and one example is available with a form of dough viscosity measurement.

The speed of the fast mixing setting on spiral mixers in this category is typically slower than that typically produced by high-speed or CBP-compatible mixers, and energy input into the dough is much less, typically half that required for CBP in 5 min of mixing. As a result of lower energy inputs, the temperature rises experienced during spiral mixing are lower than with high-speed and CBP-compatible types.

The rotation of the mixing tool with respect to bowl rotation and the ratio of spiral blade diameter to bowl diameter vary from one manufacturer to another. Mixing tool designs and speeds also vary, although the basic mixing action is for the mixing blade to generate a downward force on the dough. Ingredients are mixed and later the dough is kneaded by the action of the spiral blade stretching the dough against the bowl wall and base and by folding the dough on itself repeatedly. The intensity of the mixing action varies with the different velocities and surface areas of different spiral mixers. In each case the rotation of the bowl is used to re-circulate the mix/dough back to the mixing tool for more work. Many claims are made with respect to the advantages of different designs to ensure that all of the dough is mixed in the most beneficial way. Some manufacturers provide a large, high-powered mixing tool which sweeps an area the diameter of which is greater than the bowl radius in order to eliminate ‘dead spots’ in the centre of the bowl. Others engineer central posts to guide the dough into a smaller mixing tool. These central posts are also engineered to achieve different effects on dough development; some are large central spigots which increase the effective kneading surface, while others are blade-like to generate a shearing action between them and the mixing tool. All such designs may have advantages of one type or another. The test of the complete mixing system, however, depends on how well the dough is homogenized, its structure, the time taken to accomplish mixing and the energy lost as heat during mixing. The variety of dough structures required from various ingredients for various bread products also means that there is no perfect design for all doughs. In reality, since most spiral mixers come equipped with two speeds, the ratio of the slow to fast periods is varied to accommodate the different kneading intensities required. Typically the slow period is extended for ‘weaker’ doughs with a corresponding reduction in the length of the fast period.

Reference has already been made to the lower energy input from spiral mixers compared with CBP-compatible types, and the effect that this will have on dough development has been discussed in an earlier chapter. There are two other important differences which require comment, and both are related to gas occlusion in the dough during spiral mixing. Compared with CBP-compatible mixers, spiral mixers are more effective in occluding air into the dough during the mixing cycle. A comparison of typical gas occlusion values is given in Table 4.1. The occlusion of a greater volume of air during spiral mixing increases the quantity of oxygen available for ascorbic acid conversion, so that the potential oxidizing effects are greater. However, the mixing action involved in a typical spiral mixer generates a gas bubble size range which is considerably greater, and with a larger ‘average’ size than would occur with CBP-compatible mixers (see below). These two factors, perhaps more than any others, explain why spiral mixers have become so commonly used in the production of breads with an open cell structure, such as French baguette.

Table 4.1 Examples of gas occlusion in different mixers

Mixer type	Proportion of gas by volume (%)
Spiral	12–15
CBP-compatible	8
CBP + partial vacuum	4
CBP + pressure	20+
Low speed	3–5

Dough handling for spiral mixers is typically either by hand from machines where the bowl is fixed, or by a bowl discharge system, usually tipping the bowl above a hopper for subsequent handling. In the latter case the bowl is usually removable from the machine. The rotating bowl is particularly suited to automated scraping of sticky doughs from its walls during discharge by means of tipping. There are variations on this theme with examples where the whole mixer is tipped up for discharging, where the bowl discharges through an orifice in its base to the elevating systems and where the bowl and its drive are attached to a high tip which is an integral part of the machine. The flexibility provided by the removable but interchangeable mixing bowl equips this style of mixer for use in automated mixing systems incorporating many ingredient stations, mixing stations, emptying stations and resting/fermentation stations. Earlier designs for such operations were based on the so-called ‘carousel’ arrangement where several bowls rotate in a frame around a central axis, moving from one station to another. More recent systems incorporating large numbers of resting/fermentation stations are based on linear arrangements where the bowl is handled from rails (mounted above or below) between stations positioned either side of the rail system.

Horizontal Mixers

The largest high-speed mixers can be found in the USA and Japan with batch capacities up to 1000 kg (450 lb). Such machines are used on high-output production lines where very highly developed doughs are produced on horizontal or ‘Z-blade’ mixers. This type of mixer usually consists of twin horizontally turning mixing tools contra-rotating in a drum-shaped mixing tub which can be tilted about its horizontal axis for discharging. Dough development is considered to be delivered by sweeping dough against the side of the bowl and the stretching and folding actions imparted by the contra-rotating blades. The energy imparted to the dough during mixing is so great that pre-cooling of the ingredients or additional cooling from a refrigerated mixer jacket are required to maintain the required final dough temperatures. The efficiency of the cooing jacket is aided by the long periods of contact of the dough with the sides of the mixing chamber. Typical mixing times are in the order of 10–15 min though they may be extended to 20 min in some cases.

Low-Speed Mixers

The first development of mixing machines for bread doughs were what we would now describe as slow-mixing systems. This was due to the requirement to mimic the hand-mixing process, rather than to a limitation of engineering capability. Low-speed mixers are still used today as they are still the most appropriate mixing system for some types of dough and products, e.g. baguette and ciabatta. The most common slow-mixing systems are the twin reciprocating arm mixer and the oblique axis fork mixer or ‘wishbone’, and less commonly the single-arm reciprocating mixer. All feature a gentle mixing action and consequently a low rate of work input. The low level of mechanical development and comparatively low rate of air occlusion are the main reasons why today these mixers are most commonly linked with bulk fermentation processes, as they were before the advent of mechanically and chemically developed doughs.

Twin-Arm Mixers

In a direct mimic of hand mixing, two linked arms are driven in a symmetrical reciprocating action such that the mixing tools mounted on the end of the arms fold ingredients from the centre to the outside of the mixing bowl during mixing (Fig. 4.6). The arms also lift, stretch and fold the dough during kneading. Ingredients are returned to the mixing tools by rotation of the mixing bowl, which also aids stretching during kneading. Unlike other mixing systems very little kneading takes place

Fig. 4.6 Twin-arm mixer (courtesy Artofex)

against the bowl wall and the mixer usually has only one speed. Typical mixing times are between 15 and 25 min and the mixing time is dependent on machine capacity, ingredient specification and the dough character required. Capacities for this type of mixer typically range from 50 to 350 kg (22–160 lb) dough weight. This style of mixer is particularly effective for the incorporation of delicate fruits without damage or the mixing of doughs with a weak or delicate gluten structure.

Oblique-Axis Fork Mixers

This type of mixer has a single mixing tool shaped like a wishbone, with profiled ends, mounted obliquely to the axis of the bowl (Fig. 4.7). The mixing bowl typically has a centre boss such that the tool action takes place between the boss and the bowl wall. Most mixers of this type have no bowl drive but allow the bowl to rotate against a friction clutch, the drive force being provided by the action of the tool against the outer bowl wall as the tool rotates. Adjustment of the clutch therefore

Fig. 4.7 Oblique-axis or fork-type mixer (courtesy VMI)

has a direct influence on the kneading characteristics of the mixer. If a mixer of this type has a driven bowl it will have a fixed kneading characteristic. Initial mixing is a function of folding the ingredients into each other as the mixing tool rotates. Later kneading is with respect to the squeezing action between the mixing tool and the bowl. The profiled ends of the tool act as plough shares to incorporate dough from between the forks into the kneading zone. Typical mixing times are between 15 and 20 min. Capacities for this type of mixer typically range from 50 to 350 kg (22–160 lb) dough weight. Larger mixers are available with removable bowls.

Continuous Mixers

These have been developed to meet the needs of dough make-up processes that are particularly sensitive to changes in dough consistency and density arising from variations in processing time between mixer and divider which occur with some batch mixing processes. Where bakers produce large quantities of dough to a narrow specification the continuous mixer also offers advantages in terms of operator requirements because some versions can run continuously without operator supervision. The most common form of continuous mixer in use for bread production today is the two-stage mixing system. As with all such systems it is the integration of an ingredient feed system with a flow-through mixing system. Dry ingredients are stored locally to the mixer, in bins which can be discharged at a controlled rate. The reader will understand that proper control over the discharge rate is essential, and so some systems continuously check this by placing the storage bins on weighing load cells so that the 'loss in weight rate' can be checked against the required recipe. Discharge is typically achieved by properly sized spiral or screw conveyors which have variable-speed drives to enable the rate of loss in weight to be adjusted by the control system. Some systems feed directly from the dry ingredient bins to the primary mixing chamber, while others feed into a transport auger which conveys and blends the different dry ingredients. At the primary mixing chamber, water is added along with other liquid ingredients such as cream yeast or pumpable (fluid) fats. If fresh yeast is used it is often added after the primary mixing chamber. Various designs of primary mixing chambers are offered by manufacturers. Important aspects of this part of the system are that the ingredients are uniformly distributed and the mix achieves homogeneity. The primary mixing chamber design is such that the mix is 'pumped' from this chamber into the secondary mixing or kneading chamber.

The common kneading action at this stage is similar to that of a horizontal mixer described earlier. However, the mixing tool is placed in a tightly configured trough with an opening at the discharge end, so that the mix and dough fed into one end of the kneading trough displace fully developed dough at the discharge end by virtue of the fact that the total dough quantity is greater and the level of dough in the trough is higher. The work done during kneading is a function of the flow rate and tool speed. Some manufacturers include variable-speed tool drives in order to adjust the dough development with respect to recipe, throughput and product requirements. While variations in mixing speeds in order to match changes in plant speeds can be readily accomplished, this may lead to variations in dough development unless a compensatory change can be made. Such a change could be a variation in the speed of the mixing tool, such that more or less work is imparted to the dough as the throughput rate changes. An adjustment in ingredient temperatures or the effectiveness of the cooling system might also be required. Such considerations explain why continuous mixers are best suited to production lines running dedicated or very limited product ranges. The kneading trough is commonly provided with a refrigerated cooling jacket to maintain and control dough temperature during the mixing process. The use of an integrated control system is essential with this type of mixing plant, and so a computer or PLC-based system is used to enable the operator to choose different recipes and mixing parameters without having to set up complex machine functions.

It is necessary for the system to be full of ingredients and product for it to work effectively and efficiently. Hence, some product is lost at the beginning and end of production shifts, if the mixer is stopped, during product changes and during cleaning periods. Some of the potential drawbacks of continuous mix systems have been the difficulties associated with reconciling raw material in and dough product out, i.e. yield, and potential losses from plant interruptions. The creation of bubble structure and dough development during mixing follow similar lines to those discussed previously for batch mixers and no-time doughs. In general bubble distributions from continuous mixers are uniform. Some opportunities exist for modifying mixer atmospheres, but the relatively ‘open’ nature of the mixer limits the potential for oxygen enrichment. Because of these practical considerations the range of bread structures which may be created during continuous mixing are mostly limited. There have been attempts to adapt continuous mixing to permit the control of pressure in the mixing chamber. In the COVAD project (Alava et al. 2005) a prototype continuous mixer was developed to provide sections capable of operating at both above and below atmospheric pressure and thus was able to achieve some of the advantages of the batch pressure-vacuum mixer, namely to increase ascorbic-acid assisted oxidation and to provide a range of cell structures in the final product.

Control of Dough Temperature and Energy Transfer

Control of Dough Temperature

During mixing the temperature of the mixture of ingredients which constitute the developing dough begins to rise as a direct consequence of energy being transferred to the dough. It is important for bakers to produce dough with a consistent final dough temperature in order to ensure uniform processing after mixing and to optimise final product quality. The heat rise which typically occurs during mixing is compensated for through the adjustment of ingredient temperatures, most notably the temperature of the water. The principles which can be used for calculating the required water temperature for a given final dough temperature and a given mixer are discussed in Chap. 2.

The availability of sufficient chilled water is critical to the delivery of a dough at a consistent temperature at the end of mixing. This means that there must be a sufficient capacity of chilled water and the refrigeration equipment must have the capability of delivering the chilled water at the required rate. The calculation of the required capacity of the refrigeration plant is a relatively straightforward but should be based on realistic conditions which take into account flour and water temperatures in the warmest conditions likely to be experienced in the bakery. In some cases the mixing environment will dictate that the temperature of the dough water required will be 0 °C or even lower. Clearly this is not realistic for water which at such temperatures will form as ice. It is possible to use ice to aid the control of dough temperature, not least because of the high latent heat required to convert ice to water. The addition of ice may have an inhibitory effect on hydration of the gluten-forming proteins, never the less the cooling advantages to be gained cannot be overlooked in those situations where temperature control could not otherwise be achieved. In practice, the use of and ice slush, a mixture of finely divided ice and water is possible. An alternative to the ice slush is the use of a chilled salt solution which has the advantage that the solution will remain liquid a few degrees below zero (32 °F) because the salt depresses the freezing point of the water. A disadvantage of using a salt solution in this way is that variations in the level of liquid addition to compensate for any variations in the water absorption capacity of the flour or the dough handling requirement of the plant result in small variations in the level of salt in the dough which, in turn, leads to potential variations in yeast activity. A common practice is to deliver both chilled salt solution and chilled water to the mixer so that the salt level remains consistent. Such an approach requires sufficient refrigeration capacity to ensure that the requirement for chilled water can be met.

Other proposed means of combating the heat rise during mixing have been the chilling of the flour and the use of carbon dioxide snow. The problems and expenses associated with the chilling of flour are considerable and are not really practicable. The delivery of carbon dioxide snow directly to the mixer does have significant potential for compensating for the heat rise of mixing. However, the use of carbon dioxide in this way will impact on the gas composition in the mixer headspace. In particular it will increase the carbon dioxide concentration and most critically reduce the oxygen (from the air) concentration with the potential for limiting the effectiveness of ascorbic acid additions.

Energy Transfer

Mixer design and operating speed have significant impacts on the transfer of energy to the dough during mixing. A key element is the interaction between the mixing tool and the dough as it moves around the mixing bowl. In most mixing actions the dough is squeezed through a relatively narrow space which stretches the dough in a manner similar to that achieved with hand mixing. If the mixing speed is low then the heat which is transferred to the dough may quickly dissipate and there may be no sign of a rise in dough temperature. As the speed of mixing increases then there is less opportunity for the energy to be dissipated and it is stored as heat in the dough. This is commonly the case with all mechanical mixers. In some cases the rate of transfer of energy to the dough is increased through the use of internal projections in the mixing bowl while in others the mixing tools are designed to 'screw' the dough more vigorously. A number of such variations have been discussed above. In all cases it appears that the basic principle illustrated in Fig. 2.5 applies, namely that an increase in the rate at which energy is transferred to the dough will give increased dough gas retention for a given work input. In other words, the faster that the dough is mixed (the lower limit seems to be around 90 to 120 s) and therefore the more rapid the development of the dough the greater will be the bread volume for the optimum work input of the flour being used.

Dough Transfer Systems

As discussed above, mixing systems can discharge dough in a variety of ways to the next dough processing stage. The most common is batch handling the full mixing capacity of the mixer using either a mobile bowl or receiving dough tub (trough) from the mixer to a receiving hopper feeding the dough divider or extruder. Alternative mixing systems provide for a continuous flow of dough either directly to the divider or via a conveyor system. Some equipment combinations require the dough to be pre-divided prior to the divider to allow a divider hopper of smaller capacity than that of the batch mixer.

Ideally all such transfer equipment should be minimized by choosing compatible mixing and dough processing batch equipment and arranging the equipment such that transfer distances are as short as possible. When dough transfer equipment is required, the following points should be borne in mind:

- Whenever we work the dough we change (usually detrimentally) the dough structure.
- Dough transfer equipment usually has to handle several varieties of dough through one plant. The potential for cross-contamination should therefore be minimized by making the equipment as resistant as possible to 'dough pickup'. There are also obvious hygiene considerations.
- When handling doughs which are particularly difficult, care should be taken to avoid modifying the dough to suit the handling system. Usually the most difficult doughs are those which are wet and sticky, and the temptation is to use excessive dusting flour, oiling of the conveyors and hoppers, or to skin the dough excessively by warm air circulation systems used to 'dry' conveyor belts.

- Many doughs are sensitive to transfer times between mixer and divider or the time between mixer and moulder.
- Hoppers should be designed so that dough flow is even across their section without the risk of dough 'eddy' causing some dough to age excessively in the hopper.

A common reaction to problems with dough handling properties during processing is to reduce the level of water used in dough making; often this is with the intention of reducing dough stickiness. Many of the problems associated with dough during processing are induced by the interaction of the dough with the processing equipment and often arise from the effects of shear on the dough rheology. Often it is this shear which creates dough stickiness and not the recipe water level and indeed reducing the water level will not eliminate problems of dough stickiness. A fully developed dough is more capable of withstanding the impact of dough processing.

The other common reaction to handling properties during dough processing is to lower the temperature of the dough ex-mixer, in part to limit gas production by the yeast. Changes in dough density which can arise from long processing times or process delays increase the risk of dough damage during subsequent processing. However, lowering dough temperatures ex-mixer may lead to compromises in bread quality by reducing dough development as a consequence of slowing down the chemical processes which underpin development and require a compensatory increase in recipe yeast level in order to maintain a given proof time.

Dough Make-Up Plant

As described earlier, dough is delivered to the divider with most of its structural properties and rheological character already determined by the ingredients and formulation, and the bubble structure created during mixing. In these respects, further mechanical handling after mixing can only alter the outward size and shape of dough; it cannot improve the dough's structural properties but it can 'damage' them. The Dutch 'green dough' process (Chap. 2) is an exception in that it incorporates a fermentation stage after dividing and initial rounding, which changes dough rheology in such a way as to permit advantageous modification of bread cell structure. The critical issues for the dough as it is processed revolve around the degree to which the gas bubble structure created in the mixer is modified during the collective and individual processing stages before it reaches the prover. In most no-time doughmaking the ultimate bread cell structure is largely created in the mixer and during subsequent processing the bubble structure in the dough undergoes little beneficial modification. The absolute gas volume in the dough as it reaches the divider depends on the type of mixer and the breadmaking process being used, as discussed above. Generally, gas volumes in no-time doughmaking processes are much lower than in sponge and dough and bulk fermentation processes. Such differences will affect both divider weight control and subsequent moulding operations.

Dividing

In order to generate the shape and size of product we require we must first divide the bulk dough from the mixer into individual portions and then shape them to form the basis of the final product we wish to achieve after proving and baking. Dough is generally divided volumetrically, that is to say, it is cut into portions of a given size either by filling a chamber with dough and cutting off the excess (piston dividing) or by pushing the dough through an orifice at a fixed rate and cutting billets from the end at regular intervals (extrusion dividing). In either case the accuracy of the system depends on the homogeneity of the dough. This is largely decided by the distribution of gas bubbles within the dough. Where the gas structure is comprised of bubbles of uniform size and even distribution, the density of the dough remains constant throughout its volume and dividing is more accurate (for example in CBP-type doughs). Where the bubble structure is comprised of uneven sizes and distribution then dividing is accordingly less accurate (for example in bulk-fermented and some sponge and dough systems).

Dough Damage During Dividing

Compression of the dough during dividing will reduce the effect of weight irregularity due to variations in gas volumes in the dough. Any ‘degassing’ at this stage will contribute to damage of the dough structure, and so a compromise has to be found between efficiency of dividing and the level of dough damage. This means that different dividers will need to be matched to different dough types in order to give optimum dividing accuracy with minimal compression damage in each instance. For example, typically ‘strong’ North American bread doughs can withstand high compression loads whereas more delicate French baguette doughs are more readily damaged. To minimize damage to the dough bubble structure, some dividers are available with pressure compensators which permit adjustment for different types of doughs. Some dividers incorporate servo drives and control systems to limit the pressures exerted upon the dough throughout the process of dividing.

Suction damage can be much more serious than compression damage, especially if the rate of suction is not compatible with the rheology of the dough or the size and shape of the hopper and chamber. Once again, some doughs are more sensitive than others to damage. The effects of over-suction on final volume can be considerable, with evidence of individual larger bubbles in the dough structure bursting during dividing with subsequent loss of structure in products like baguette and ciabatta.

Mechanical damage occurs if dough is subject to aggressive tearing between machine parts during dividing. It can also occur when dough is pumped or transferred to the divider by a screw drive. This should not be compared with mechanical development, the difference being that the mechanical work done during mixing is uniformly distributed throughout the dough structure, whereas mechanical work during such dough transfer systems is not uniformly distributed and confers different changes in dough properties in different areas of the dough mass, which may be manifested as changes in the final product.

Two-Stage Oil Suction Divider

The two-stage oil suction divider is probably the most common bread dough divider in use. Its principles of operation are shown in Fig. 4.8. These dividers commonly have a central drive whereby the three different motions of ram, knife and slide are controlled. An essential feature of the divider is an airtight oil seal formed around the main ram and knife. Should this seal leak air back into the primary chamber, then divider weight accuracy is prejudiced and it is wear in this area that most influences long-term operational accuracy. Materials chosen for this important part of the mechanism are generally hard-wearing nickel–iron alloys designed to withstand the wear loads inherent in the system. The main knives are sometimes made from a similar, or slightly softer, alloy to encourage wear in the knife rather than the more expensive ram and main body casting. Some systems use main rams made from hard modern plastics which have self-lubricating properties and so reduce oil consumption in the system. In this case the ram becomes the main wear part. Die materials vary with manufacturer; some using the more dimensionally stable plastics and others opting for food-grade bronze alloys.

In suction dividers the dough is pushed into the division box dies under some force, and so upon ejection the release of pressure allows an increase in dough volume. This has no effect on individual weight accuracy at this point, but can cause individual dough pieces to ‘balloon’ into each other during transfer between division box and belt. These groups of dough pieces should be parted as soon as possible to avoid cross-flow of dough between pieces (this is particularly important with soft or low viscosity doughs). This separation is usually achieved by using a second conveyor running faster than the first to ‘snatch’ the dough pieces apart. It is important to note that, for the efficient running of down-line equipment, the speed of these conveyors should be linked to the output speed of the divider to provide a continuous flow of evenly separated dough pieces both across and between the batch quantities delivered by the divider.

Typical cycle speeds range up to 1800 cycles/h (although purpose-designed single-die dividers for some French doughs have been rated up to 3000 cycles/h). Where higher outputs are required multiple dies or pockets (Figs. 4.9 and 4.10) are used to achieve outputs of up to 9000 pieces/h at 1000 g (2.2 lb) with five pockets and up to 14,400 pieces/h at 120 g (4 oz) with eight pockets.

Extrusion Dividers

This type of divider relies upon the ability to pump dough, usually by means of a helical screw, through an orifice at a constant rate and density. As dough emerges from the orifice it is cut by a blade or wire at a constant rate to achieve billets of

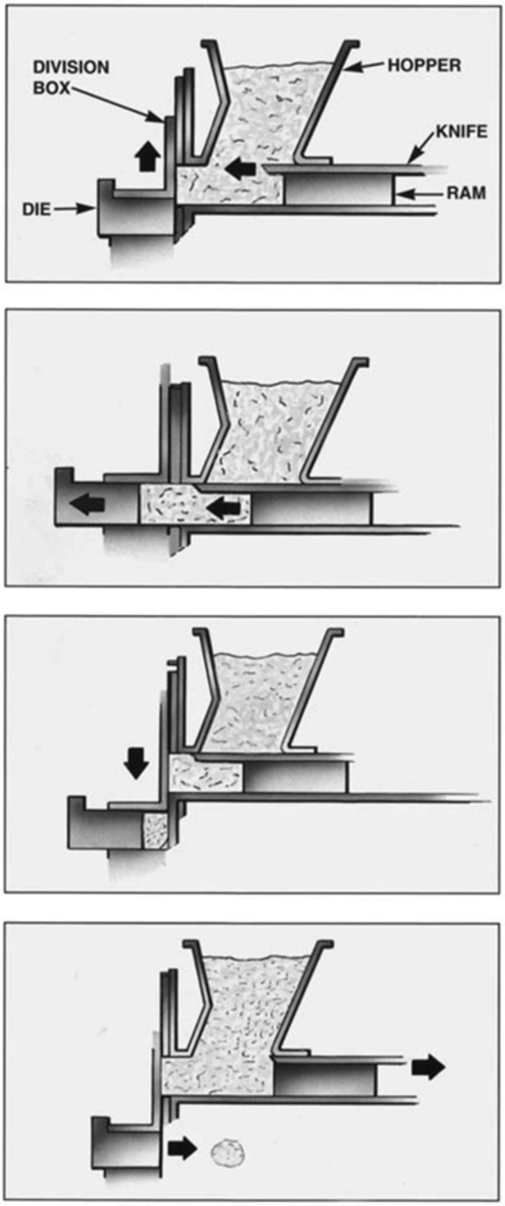

Fig. 4.8 Two-stage oil suction divider (courtesy Baker Perkins bv)

Fig. 4.9 Multi-pocket bread dough divider (courtesy Benier bv)

dough of uniform shape and size. The dough is worked considerably during this process and such dividers are best suited to strong doughs which are already highly developed. Typically such dividers are used with doughs formed using a North American bread process, such as sponge and dough. Manufacturers of these divider systems are able to claim high levels of accuracy at high outputs.

Single-Stage Vacuum Dividers

Single-stage dividers extract the dough directly from the hopper into the measuring chamber where the dough volume is set and cut via the action of a rotary chamber or mobile hopper base. The measuring piston ejects the dough piece directly onto a discharge conveyor. As there is no intermediate chamber to pre-pressure the dough, the dough hopper should be maintained at a near constant volume or the dough used should exhibit good fluidity to aid flow into the division chamber. Some manufacturers have assisted dough flow by the use of a semi-porous base to the division chamber to draw excess air from the chamber and provide some compression by suction. Single-stage dividers are commonly used where the final bread product requires a dough which has a low viscosity.

Fig. 4.10 Accurist divider (courtesy Baker Perkins)

Rounding and Pre-moulding

After dividing, the individual dough pieces are almost universally worked in some way before first or intermediate proof. If we look at traditional hand moulding methods we will see the baker kneading the dough with a rotary motion on the make-up table to produce a ball-shaped piece with smooth skin, except one spot on the base (Fig. 4.11), when two pieces are moulded (one in each hand) there is the opportunity to use the circular motion of one piece against the other and this often aids the formation of the round or ball shape. The moulding action has forced dough to move from within the body of the piece across the surface of the dough towards the base spot. This is essentially achieved by stretching the surface of the dough piece. The degree to which this can be done without permanent structural damage is a function of the rheology of the initial dough which in turn depends on the ingredients and formulation, and the characteristics of the mixing processes and divider. Further, one should note that for many hand-moulded products this process would be the one and only time the product is worked after dividing, and so it replaces both rounding and final moulding in more automated bread production systems.

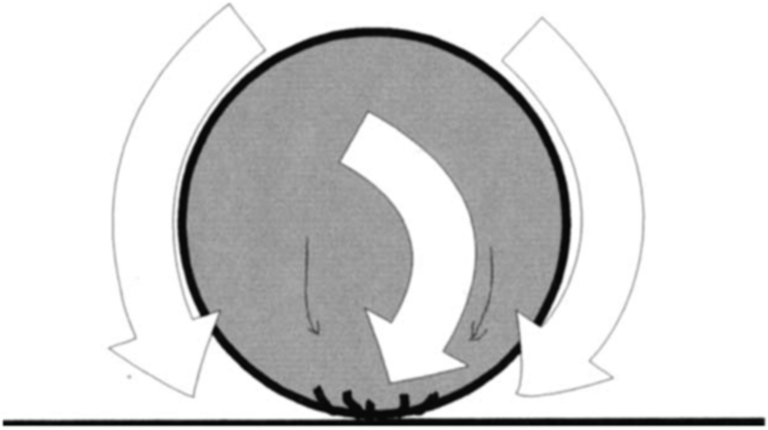

Fig. 4.11 Movement of dough around the ball during hand rounding

The action of rounding or pre-moulding adds stresses and strains which may lead to damage to the existing dough structure. However, it is clear that some breadmaking processes benefit from limited structural modification at this stage, particularly if followed by a relatively long first proof (e.g. 15 min or more) before final moulding takes place. This is seen in some forms of French baguette manufacture and is still the preferred method with many traditional British, Dutch and German bread varieties.

Some breadmaking processes require the rounder to have a degassing effect; however, if the dough has been accurately machine divided, or comes from a breadmaking process which leaves little gas in the dough then this requirement is unnecessary. In doughmaking processes where the first proof time is short, the rounder adds little or nothing to the structural properties of the final product and for a given first proof time limits the extensibility of the dough piece during final moulding and increases dough elasticity. It does, however, generate a uniform, largely spherical dough piece which makes it suitable for handling in pocket-type provers, rolling down chutes and conveying without concern for orientation. It also plays an important role in delivering a uniform dough piece to the final moulder. In some processes this may be the sole function of the rounder, but in others the dough piece may be moulded into a cylindrical shape prior to first proof. Ideally, the orientation of this shape is retained throughout the initial first proof, so that it is always presented to the final moulding system with the same side 'leading' though this is affected by the degree of tumbling experienced by the dough piece in the first prover.

The action of rounding machines is similar to that of hand rounding described above. Basically the dough piece is rotated on its axis between the two inner surfaces of a 'V', where one side is driven and the other fixed or moving at a lower speed. The dough piece quickly forms the shape of the V (hence many rounders have profiled rounding tracks to encourage a more spherical shape) and moves under the force of the driven side. The difference in speed between the two surfaces is the same but the angular diameter of the dough piece reduces as the two surfaces converge, so that the top of the dough piece is rotated faster than the bottom, effectively attempting to twist it about its axis. However, because the dough piece slips on one of the surfaces (at least one low friction surface is required for most dough types), the action is changed to one of spiralling or rolling. This is deliberately enhanced on moulding systems where the fixed surface pushes the dough piece up or across the driven one. The reader will note that the V-angle, the differential speed, the length of moulding track and the shape of the track all contribute to the moulding effect and the final shape of the dough piece.

Types of Rounder and First Shaping

There is a wide variety of rounders available where rotational speed, angle of cone, angle and shape of track, inclination of track and different surface finishes all modify rounder action on the dough.

Conical Rounders

The most common type of rounder is the so-called 'standard' (Fig. 4.12) or 'inverted' forms. They consist of a cone which is rotated about a vertical axis, with the track of the fixed moulding surface located in a spiral pattern about the outside of it. An interesting aspect of this design is that the differential speeds are lower at the top, where the axial diameter of the cone is less, hence the rounding effect changes as the dough ball travels up the cone and the forward velocity of the dough piece is reduced, causing the initial gap between dough pieces to become smaller. In inverted forms the cone is inverted and hollow with the rounding track on the inside. Versions can be found where the cone is fixed and the track rotates within it, although these are less common. With both these types the dough pieces are charged centrally into the bottom of the rounder and driven up the inner wall of the cone. Here the effects described above are reversed.

Cylindrical Rounders

A variation on the conical rounder uses a track around a cylindrical drum (Fig. 4.13). The track profile and angle of inclination are important for the final dough shape and consistency of drive on this type of moulder.

Rounding Belts

These can be classified as 'V'-type, vertical and horizontal types. V-types are simply two belts orientated in a V, at least one of which is driven. This system provides the simplest moulding concept with a conical-shaped dough piece coming from it

Fig. 4.12 Typical conical rounder, note this model has operator adjustable tracks (courtesy Benier bv)

because of the lack of a cross-drive across the moulding surface. Vertical belt rounders work in a similar manner to cylindrical moulders, with a track wrapped around a conveyor belt with the end-roller axis in a vertical orientation. With horizontal belt rounders a track is placed upon or across a conveyor with its axis in the horizontal plane. The track must be shaped to ‘trap’ the dough piece and cause it to be driven across the belt at an angle to that of the conveyor direction. Such rounders are generally found to be ideal for low-viscosity doughs and can be used with lower speeds and less sharp track angles for light forming applications.

Reciprocating Rounders

Here neither of the two faces of the rounder may be driven but at least one will reciprocate to present a ‘tucking’ action to the dough piece and give an action similar to that found with hand moulding. The reciprocating action also pushes the dough piece along the one face and imparts a forward motion to the piece. Such rounders can be either linear or ‘drum-like’ in operation.

Fig. 4.13 Typical vertical drum rounder (courtesy Benier bv)

Non-spherical Pre-moulding

This is basically the pre-moulding of a cylindrical shape in which shaping is carried out between horizontal belts or a belt and a board. Given that the dough piece from a divider can often be quite cuboid in shape such pre-moulding can be performed with minimal working of the dough.

Intermediate or First Proving

In most modern dough make-up processes the intermediate or first proof stage is used as a period of rest between the work carried out by dividing and pre-moulding, and final sheeting and moulding. The length of time chosen for intermediate proof period should be related to the dough rheology after pre-moulding compared with the dough rheology required at final moulding. During first proof the yeast activity begins to generate carbon dioxide gas. The extent of the activity depends on the length of time involved and (mostly) the dough temperature. There is a small effect from the temperature of the intermediate prover but more important is the requirement to prevent skinning. Because of the yeast activity the gas bubbles in the dough begin to increase in size and first proof time can be used to influence the final bread cell structure. The longer the first proof time, the more open the bread cell structure will be, provided that no degassing occurs in final moulding. A long first proof time is therefore critical in the development of products with an open cell structure, such as French baguette, and even high-speed mixing dough processes (e.g. the CBP) can be used to produce suitable baguette cell structures by lengthening the first proof (Collins 1993).

The changes which occur in dough properties as it rests are influenced by many factors other than time, and the reader must not assume that the first proof time may be simply extended until the dough has reached a ‘suitable’ condition for the next-stage moulding process. This is particularly the case where reducing agents (Chap. 3) or proteolytic enzymes are used to improve dough extensibility, since extending the first proof time may eventually adversely affect dough rheology and final bread quality rather than improve it. In some breadmaking processes the changes in dough rheology which may occur in first proof can have a considerable effect on final bread quality. This is the case in no-time doughmaking processes, such as the CBP, where the elimination of first proof can lead to a reduction of loaf volume and an increase in damage to the bubble structure in the dough when ascorbic acid is the only oxidant in the recipe. Enzymic action may also be enhanced during first proof, the total effect depending on the time and temperature conditions used.

In some dough processes the first proof period is used to enhance the fermentation process, in particular the traditional Dutch green dough process (Chap. 2), where the first proof time may be as long as 50–75 min (sometimes with a second rounding midway through proving). Here it is claimed that the resting time, as well as temperature and humidity within the prover, allow ‘natural’ dough conditioning to take place, thus requiring lower levels of reducing agents and other dough improvers to be used.

Where first proving times are long and the water content of the dough is high, care should be taken to ensure that the prover air is conditioned to prevent skinning (in cool, low-humidity environments the temperature and humidity should be increased) or sticking (in warm, high-humidity environments the temperature and humidity should be reduced). Care should also be taken when trying to enhance the ‘resting’ process by raising the humidity and temperature in the cabinet of a pocket prover, since condensation occurring on the dough pieces will encourage sticking of the pieces to prover pockets with subsequent transfer problems. Ideally, the first proof time is a function of recipe and bread type and as such should remain constant. However, within limits first proof times can often vary with actual plant speed in order to ensure that some plant in-feed systems and subsequent moulding machines receive a balanced supply of dough pieces regardless of plant speed.

Pocket-Type Prover

Where first proof times of longer than 1–2 min are required the most common method of achieving this is by means of pocket-type provers where dough balls are transferred into ‘pockets’ or ‘troughs’ for the whole of the resting period (Fig. 4.14). The pockets are held in ‘frames’ which are in turn fixed between two chains carrying the ‘swings’ around the proving cabinet from charging to discharging stations. Either due to condensation or capillary action between the dough piece and the pocket surface, the dough piece can stick to the pocket if left in contact with it for too long. Hence, pocket-type first provers with times longer than 5 min often incorporate turnover devices which roll the dough piece from one pocket to another allowing the temporarily empty pocket to dry in some cases and allowing the simple rolling action of the dough ball to alleviate the problem in others. Where the charging method does not fill all of the pockets in a swing, these turnover devices are also used to transfer dough balls across the swings to the discharge side of the prover.

Fig. 4.14 Pocket type first prover (courtesy Benier)

First Prover Charging Methods

Dough balls from rounders and pre-moulding devices on bread production lines are transferred in a single stream of pieces into the pocket prover, such that at fully rated capacity every pocket of the prover is filled. Because of the slippage in the rounder, the pitch of dough pieces coming from it is not always constant and they must be synchronized to fall properly into the prover pocket. This task becomes more critical at higher throughputs, and so a variety of loading methods are adopted to cater for different dough types, sizes and throughputs.

Single-piece in-feed with intermittent prover drives (sometimes referred to as 'park and ride') receives one dough ball at a time at one charging point. As each dough ball is charged into a pocket, the swing chain is driven until the next swing is at the charging point and waits for the next dough ball. Note that the actual first proof time achieved is a function of the dough ball supply rate and not preset by the prover drive system. Also, the prover will only discharge whilst dough pieces are arriving, so a discharge switch is required for the end of a production run. This method is very common with throughputs below 1200 pieces/h.

Indexing Conveyors

These are used when feeding a continuously running prover at up to 2000 pieces/h (more commonly 1500 pieces/h) for single-pocket filling or 3000 pieces/h for twin-pocket filling. Basically the conveyor stops and starts to synchronize the dough ball to the prover operation. Twin-pocket systems feed a valve or 'gate' which diverts the dough piece to side-by-side pockets, while in some systems the conveyor itself swings from one position to another. Note that two pieces fed at a time means two pieces discharged at a time.

Pusher In-Feed Systems

For throughputs of up to 7000–8000 pieces/h this is the most common form of prover loading system and the type usually found in industrial bakeries with pocket-type first provers. Simply the dough balls are placed on a conveyor travelling across the front of a pocket prover. The pitch between the pieces must be the same as the pocket pitch. When a batch of dough balls are aligned before a swing, a pusher bar rolls them all into the pockets of the swing. Different manufacturers have variations about this theme with different swing widths (six, eight, ten or 12 pockets per swing) and differences in pusher bar design and action. The most critical aspect is the timing of dough balls onto the transfer belt. Some systems use re-pitching conveyors to correct errors occurring in the rounder and transfer conveyors, while others gear the divider and rounder speed to the prover speed to maintain constant dough ball pitching.

Pallet In-Feed Systems

Pallet loading systems are used at higher speeds but have some limitations with respect to dough type and size at higher outputs. They are commonly used with firm doughs and smaller dough weights at throughputs greater than 7000 pieces/h. The principle of operation is that of a series of shallow troughs ('pallets') travelling across the front of the prover as the conveyor for the pusher in-feed system. Each of these pallets is filled with a dough ball, and when the pallets are aligned above individual chutes, each feeding a prover pocket, they swing open, dropping the dough balls down chutes into the pockets of the waiting swing. The actions of both pallet conveyor and swings have to be synchronized, and again a critical aspect of the system is the placement of dough balls into the pallet.

Discharging

Where more than one dough piece leaves the first prover at the same time they are often synchronized with valves to the subsequent discharge conveyor. On higher capacity lines, two swings are sometimes discharged simultaneously to feed separate final moulders.

Conveyorized First Provers

In order to eliminate the need for complex pocket prover in-feed systems, some industrial bread producers modify their recipe and process in order to eliminate or considerably reduce the need for first proof times greater than 1–2 min. This then makes simple conveyor transfer of dough pieces from rounder to moulder a practical consideration. If a slightly longer rest time of up to 3 min is required then spiral conveying systems can be used to provide the residence time required. Some producers eliminate the rounder, so that a simply moulded cylinder of dough is conveyed (appropriately orientated) directly to the final moulder.

Final Moulding

Throughout this chapter the reader will have noted how dough make-up machinery has been developed to copy or simulate the original manual process and later superseded by subsequent alternative processes. Modern moulding machines still sheet, curl (or roll) and mould the dough in simulation of the traditional manual process, with four-piecing and turning of the dough pieces prior to panning for some bread types.

When moulding dough for single-piece sandwich pan bread the objective is to achieve a cylindrical dough piece with roughly squared ends and a dough piece with a length and diameter equal to those of the bottom of the pan. For single-piece 'farmhouse' bread the objective is to achieve a cylindrical dough piece with hemispherical ends where the length and diameter of the dough piece are equal to those of the farmhouse pan. In the production of four-piece sandwich pan bread the objective of moulding is to achieve a cylindrical dough piece before four-piecing with flat ends where the length is four times the pan width and the diameter is one-quarter of the pan length. For baguette and bloomer the moulding requirements are such that the dimensions of the moulded dough pieces are close to the size ultimately required when fully proved. Other bread types may require hand finishing to achieve their traditional shapes, with the exception of large cobs or coburgs (round shapes) which may be finished in rounders properly designed for that purpose. All of the dough shapes described above (with the exception of cobs and coburgs) undergo extensive sheeting and curling prior to passing under the final moulding board.

The reader will note from previous sections that the majority of dough make-up processes utilize a rounder for initial handing-up of the dough piece prior to the first proof so that it is usually presented to the moulder as a sphere or more correctly a slightly flattened sphere. By studying Fig. 4.15 we can see that when such dough pieces are sheeted they become elliptical in shape which on curling gives an ellipsoid-shaped dough piece. Final moulding of this piece requires additional work to generate the ultimate cylindrical shape with the following effects.

- Because the dough piece is ellipsoidal, the drive between the moulding belt and board is only effective in the centre of the dough piece, where a greater frictional force is exerted. This causes a twisting action between the centre and ends of the dough piece. The reader may test this by drawing a line along the outside of an

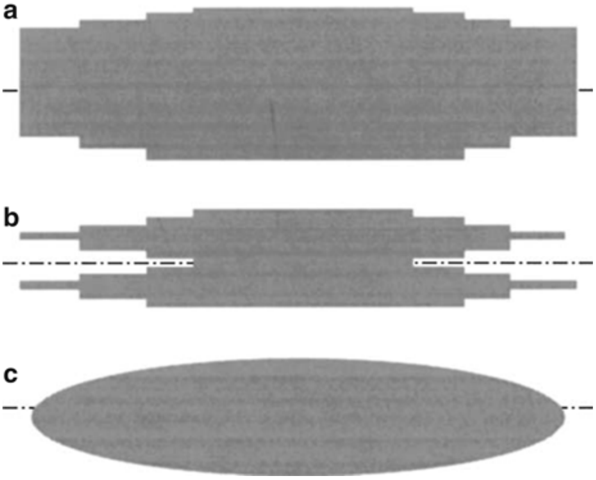

Fig. 4.15 (**a**, **b**) show the theoretical lamination structure of dough in a sheeted and curled piece ((**b**) being a cross-section of (**a**)), and (**c**) showing the final ellipsoid shape achieved

ellipsoid dough piece and passing it under a flat moulding board. The resultant moulded piece will demonstrate the conversion of this line into two opposite-handed spirals emanating from the centre of the dough piece.

- Because the dough piece reaches its required length before its desired shape the ends begin to press into the side guides of the moulder, which causes additional drag and twisting as the centre pulls the ends of the dough piece along the side guides. When this is done, the internal structure at the centre collapses and dough quickly migrates to the outer edges, forming an 'hour-glass'-type shape. On conventional baguette moulders with no side guides the external surface at the centre is damaged by over-moulding, causing immediate shrinkage of the centre of the dough piece as it exits the final moulder, and a bulge appears in the centre of the piece.
- Since the initial ellipsoid has concave ends, in some systems large air bubbles can be entrained into each end of the final dough piece.

If we now compare the above with a moulding system presented in which a dough piece is already cylindrical in shape (Fig. 4.16), we will see a sheeted dough piece of roughly rectangular shape, curled to a cylindrical shape and (particularly if already the correct length) moulded lightly to eliminate the moulding seam and finished at the ends.

Given the above, we can observe that in order to achieve the quality of product seen from bread producers today the dough must be fully relaxed (i.e. have a low resistance to deformation) and suitably plastic when entering the final moulding stage. This is particularly true when starting from a rounded dough ball. As discussed above the removal (or significant shortening) of the first proving stage is greatly assisted by the removal of the rounder and the proper presentation of the dough piece to the final moulder, though there can be other adverse effects. It is essential that the dough piece is presented centrally to the rollers and is maintained centrally throughout the moulding process (Cauvain and Collins 1995). A typical mechanism for achieving such centralization is shown in Fig. 4.17.

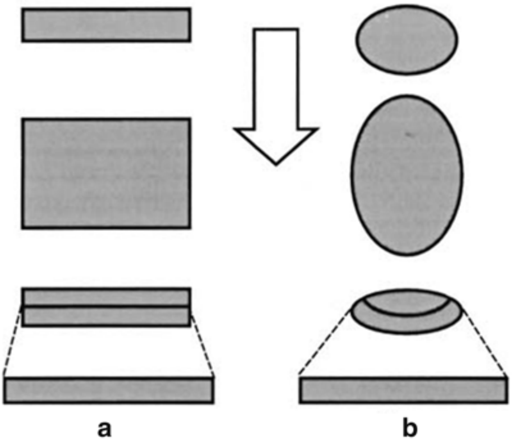

Fig. 4.16 Sheeting, curling and moulding from (**a**) a dough cylinder and (**b**) a dough ball

Fig. 4.17 Dough piece being centred before sheeting

Sheeting Action

Sheeting requires the dough piece to be positioned between pairs of rollers in order to reduce its thickness, either a single set of rollers or consecutive pairs of rollers. During this process the thickness of the dough piece can be reduced by up to one-tenth and the surface area increased by a factor of more than three. We should note that this represents a considerable reworking of the dough structure. The prime objective is to stretch the cell structure and to close the relaxed open cells delivered by the first prover. The sheeting action cannot degas the dough piece unless the latter has some particularly large gas bubbles (as distinct from bubbles which will become large cells) caused by lengthy first proving, poor distribution of ingredients during mixing or inadequate degassing of fermented doughs during dividing and rounding. Similarly there is little evidence that any gas cells are created during sheeting. However, given the extent of the reworking some inter-cell walls must be broken whilst others must be stretched and thinned to a considerable extent.

The design of sheeting rollers differs between manufacturers. Some systems favour consecutive sheeting rollers of fixed but progressively narrowing gaps, while others favour larger drum and roller sheeting systems where the dough piece is reduced once between a non-stick roller and a drum (Fig. 4.18). Some manufacturers of the latter provide adjustable sheeting pressure using springs or compressed air, claiming that they make the sheeting action more responsive to the rheology of the dough passing through the gap. Certainly the gap reduction and roller speed ratio reflect the rheology of the dough. If the gap is narrow and the roller speed too

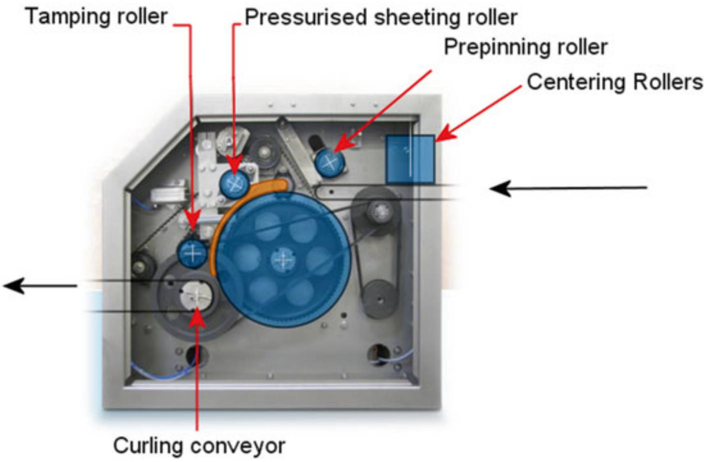

Fig. 4.18 Drum and roller sheeting action (courtesy Benier bv)

high for the dough rheology, then ‘scrubbing’ will take place either between the roller and the dough piece, or between the inner and outer structures within the dough piece. When this occurs there is excessive damage which will show as tear marks on the dough surface. Relative roller speeds may also be critical where multiple sheeting sets are combined. Subsequent sheeting sets can be set to run at speed such that the dough sheet may undergo some “stretching” as well as “squeezing”. Some manufacturers supply multiple roller sheeting systems with independent drives capable of being “tuned” to the rheology of the dough being processed.

Curling

Having achieved a sheet of dough it is then commonly ‘curled’ to form a ‘Swiss roll’ effect as illustrated in Fig. 4.19. Unlike a true Swiss roll, there should be no intermediate layers and in particular no air should be trapped between adjacent dough surfaces. Many systems achieve adequate curling by hanging a mesh belt along the moulding belt (Fig. 4.20) before the moulding board so that curling is achieved by the mesh dragging on the leading edge of the dough sheet and causing it to roll back over the following portion of the sheet. Some systems start curling in this manner and finish it under the moulding board. Other systems curl long sheets at high throughputs and incorporate a driven mesh belt (Fig. 4.21) acting against the direction of the moulding belt and so shorten the length of the moulder in this area. Whatever the curling method employed it is essential to minimize trapped air pockets during curling as these will directly contribute to the formation of unwanted holes in the baked loaf.

Fig. 4.19 Dough piece after curling

Fig. 4.20 Hanging curling chain

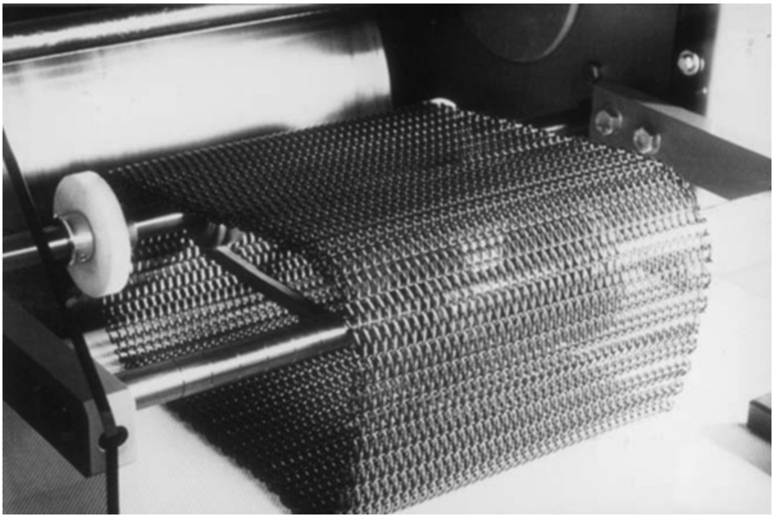

Fig. 4.21 A driven curling chain

The Final Moulding Board

As discussed above, considerable reworking of the dough can occur during final moulding for only a small dimensional change. It is important that the dough retains a degree of extensibility as it leaves the curling section prior to final moulding. Damage is minimized if the moulding pressure is minimized to encourage ‘dough flow’ rather than forcing it. It is therefore considered that a long moulding board with gradually reducing moulding gap is more ‘dough friendly’ than a short board with a narrow gap. Side guides should not be set in order to reduce the dough piece. This will cause extensive rubbing of the dough piece on the side guide incurring surface damage. In extreme cases the drag offered by the side guide will cause the dough piece to assume an “ox bow” shape. Under these conditions the dough centre undergoes a wringing action which can cause a break down in dough structure at the centre of the dough piece and may adversely affect final product shape with free-standing breads (Cauvain and Young 2009). The materials of the belt, board and side guides are chosen to allow some slippage as the dough piece is extended, and will reduce surface damage particularly when moulding doughs for baguettes, sticks or batons.

Four-Piecing

The objectives of four piecing are to cut the dough cylinder into four equal lengths (each equal to just less than the tin width), sometimes each piece is joined by a tail of dough to one or more others and turned through 90° to lie side by side across

Fig. 4.22 Typical bread dough moulder for four-piece bread (courtesy Benier bv)

the tin when panned (Cauvain and Young 2001). In other cases the pieces are completely separated from one another. To maintain control, the dough pieces are cut under or immediately after leaving the moulding board. Dough drag on the side guides should be minimized or accounted for when setting the gap between cutting blades. Further, the depth and length of the blades should be appropriate if dough tails are required during turning and panning. Side guides should finish before the end of the moulding board if not during mid-cut, especially if side guide drag is present. Typical bread moulders for four-piece bread are shown in Figs. 4.22 and 4.23. After the moulding board the pieces are 'knocked' into a 'W' (when viewed from the discharge end) as they fall over the end of the moulding belt onto a panning conveyor. The pieces are then pushed parallel between converging belts, rollers or plates and panned into the tin. It is important for subsequent processing that the panned dough pieces lie flat and parallel to one another in the tin in order to deliver the required effect on crumb cell structure, see below.

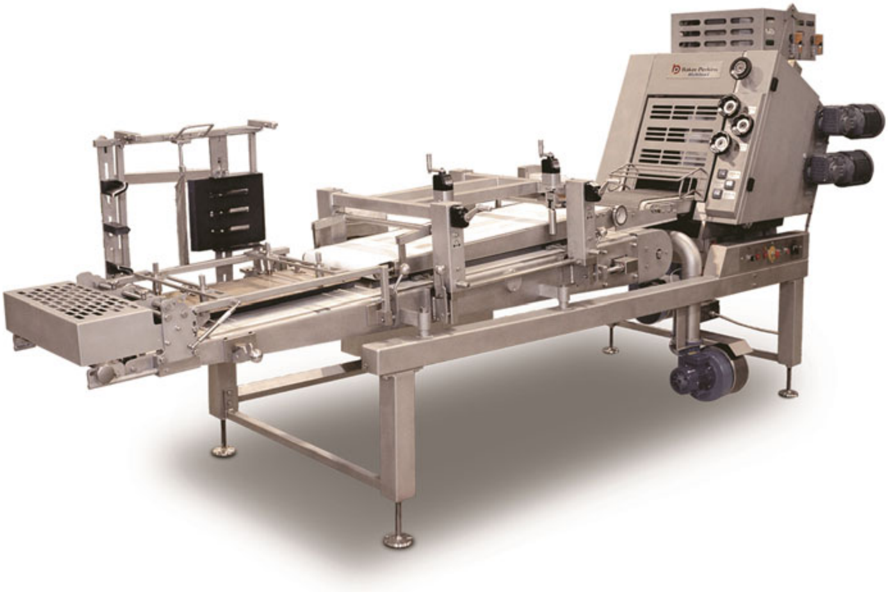

Fig. 4.23 Multiplex final moulder (courtesy Baker Perkins)

Cross-Grain Moulding

One method of achieving a wide sheeted dough piece prior to curling and moulding is to turn the sheet through a right angle so that the wider plane of the elliptical sheet is presented to the curling chain and moulding board. Besides the obvious advantage of reducing the work required during moulding, this method presents the elongated cells achieved during sheeting across the dough piece rather than around it, hence the term 'cross-grain'. Although in practice there are fewer dough layers after curling, equipment manufacturers claim that this presents a cell structure in the finished single-piece loaf which is similar to that found in four-pieced bread.

Other Sheeting and Moulding Systems

Where shapes of particularly long or narrow cross-section are required, special equipment is available to enhance the principles of dough moulding previously discussed. Many examples of these are used on automated baguette plants, where different designs of contoured moulding boards are used to encourage dough piece elongation. Similarly, some manufacturers use diverging 'polycord' conveyors above and below the dough piece to pull it out to a greater length. One manufacturer has patented a reciprocating upper moulding belt which reduces the twisting effect seen during final moulding.

Modification of Gas Bubble Structures During Processing

In the dough processing steps which follow mixing and precede the entry of the dough pieces to the final prover there are significant changes in the rheological properties of the dough pieces and the gas bubble structures contained within them. In modern no-time doughs the gas bubble structure created in the mixer is essentially the one which will be expanded in the prover and set in the oven. There will be some expansion of gas bubbles during dough processing but it will be relatively small by comparison with that which will be achieved in the prover and the oven. The interactions between dough rheology and moulding operations have to be optimized if damage to gas bubble structures in the dough is to be avoided. The most common manifestations of damage to the dough bubble structure are the formation of large holes and streaks of dull or dark coloured crumb (Cauvain and Young 2001).

Modern no-time doughs have considerably less gas within them when they reach the divider by comparison with those prepared by bulk fermentation. The upper limit of gas volume with no-time doughs is in the region of 20 % depending on how the dough has been prepared while in the case of bulk fermented doughs then a figure of 70 % would be more appropriate. By the time that both doughs reach the final moulder the figures for no-time doughs are 17–18% and for bulk fermented doughs around 25 % (see Table 4.2). It is clear from these data that considerable degassing of the bulk fermented doughs occurs but the no-time doughs remain essentially unchanged.

The formation of voids or holes in the bread is commonly associated with dough processing, especially moulding. Often the holes are attributed to pockets of gas trapped within the dough at various stages. There are a number of opportunities for the occlusion of large gas pockets during dough processing but they are mainly associated with curling and the change of dough shape in the final moulder. Cauvain (1996, 2002) used Computerized Tomography (CT) to show that while voids may be occluded in dough pieces leaving the divider they did not survive the sheeting rolls, or if they did they had to be smaller in size than the gap of the last pair of rolls. This showed that the origins of many of the larger holes were most likely to come during the curling process since they were mostly situated towards the ends of the dough piece.

Table 4.2 Effects of sheeting on gas volume in dough

	Proportion of gas by volume (%)		
Dough processing stage	Fermented	CBP	Spiral
End mixing	5	5	7
End fermentation	70	–	–
End first proof	27	16	18
End moulding	18	15	17

Other holes which may form in the dough are likely to do so later during proof and the early stages of baking. Such holes are most likely to arise because the delicate bubble structure in the dough has been damaged, often because of the application of high pressures when the dough piece passes underneath the final moulding board. The high pressures are often used to ‘mould out’ trapped pockets of gas but in many cases create the very problem concerned. The mechanical breakdown of the gluten network between gas bubbles allows them to expand more readily and coalesce when they touch. The increase in bubble size which occurs creates localities of relatively lower pressure and the carbon dioxide gas from yeast fermentation preferentially diffuses into them. Thus the larger gas bubbles expand while the smaller ones remain relatively unexpanded. If the expansion is sufficient then a hole may remain in the final product. The rheological properties of the dough during final moulding are very important in reducing dough damage and unwanted hole formation with 'stiff’ doughs being more susceptible to damage (Cauvain and Young 2008).

Cauvain and Young (2006b) illustrated how the structure of bread which had been processed by four piecing varied in a systematic manner along the length of the baked loaf (i.e. from piece to piece). They suggested that the areas within each of the four pieces was dominated by a rounded cells structure while the areas where the pieces met in such bread (3 in all) were dominated by elongated cells. The uniformity of such structures is a direct consequence of the efficiency of the moulding, cutting and panning operations associated with four-piecing.

Sheet and Cut Dough Processing Systems

It has long been recognized that the gluten network and the gas bubble populations in dough should be subjected to as little mechanical pressure as possible. This is especially true of doughs required for the manufacture of French and Italian breads (baguette and ciabatta) which also require high water additions to create the characteristic open and random cell structure. In recent years the concept of ‘stress-free’ dough processing equipment has developed in order to handle high water doughs and manufacture open cell structure products. In one sense the term ‘stress-free’ is misleading since any handling of the dough to change its shape subjects it to stress. A more appropriate term would be ‘reduced-stress’ (Cauvain 2001). In reduced-stress dough processing systems the bulk dough is fed as a sheet onto a conveyor. The width of the dough sheet is adjusted to be constant before it is split into narrow strips. A guillotine knife arrangement divides the narrow strip into a series of units of the required weight and individual dough pieces move on for moulding into the appropriate shape. The avoidance of sheeting rolls ensures that the dough is not significantly de-gassed and the bubble structure within is largely preserved. Such sheet and cut systems are suited to the manufacture of artisan-type products which do not require the regularity of shape associated with products such as sandwich breads though they can be used to manufacture the latter.

More recently there has been interest in adapting lamination employed in the manufacture of puff pastry but without the incorporation of a fat layer. Essentially it is the process of folding the dough sheet which is being exploited in order to manage the stresses concerned with shaping.

Panning and Traying Methods

As bakery plant speeds and moulder speeds have increased so panning processes have to cope with faster throughput capacities. Most manufactures offer simple drop systems whereby the tin or tray is indexed under the discharge point of the final moulder as each dough piece exits the machine. Faster systems use retraction belts in order to fill a complete stationary strap or tray of sufficient dimension to allow it to be indexed between fillings. Other systems will synchronise the flow of tin strap/tray and dough product such that dough pieces are panned “on the move”. In plants where the dough piece has been cut in order to make several products from one dough piece (e.g. baguettes strings cut form to petit pains) the panning unit may be combined with a separating unit in order to space products on the receiving tray or fillet.

Equipment for Small Bread and Rolls

Previous sections have referred to dough handling equipment after the mixing process as separate dividing, rounding, proving and moulding machines. In the production of small breads and rolls it is common for these functions to be brought together in one piece of equipment or plant. A roll plant, however, still contains within it the various stages of dough make-up used for bread processing and the same dough-handling constraints will be relevant.

Small bun Divider Moulders

The divider principle used here is the same as that found with hydraulic dividers previously mentioned. Manual versions are available where pressure (to distribute the dough evenly under the knives) is applied by a lever. The dough is cut by the downward movement of the knives from the head mechanism. After dividing the cut dough pieces moves in a rotary motion to round the pieces between the plate, the knife walls and the top platen. Dough may be manually loaded into the machine on the plate, which is later removed with the rounded dough balls on it. Typical small bun divider moulders will produce between 15 and 36 dough balls per cycle with

Fig. 4.24 An automatic bun divider–moulder (courtesy Daub Verhoeven)

weights from 18 to 160 g depending on the model and manufacturer. Automatic versions which pressurize, cut and mould the dough are available (Fig. 4.24). Some have adjustable timers so that the length of the moulding period can be adjusted. Typical production rates are operator dependent, but capacities of up to 5000 pieces/h are possible.

Integrated, Multi-lane Roll Plants

Such plants are the most common type of equipment used for roll production. Output capacities vary from 4000 to 36,000 pieces/h depending on the number of 'rows' of product being processed and the speed of the plant per row. Depending on the type of product to be made, processing modules are added to the basic specification in order to achieve the different moulding, cutting, seeding or stamping effects. All such lines usually incorporate a divider–moulder which can use a combination of dividing and rounding, as already discussed. Two-stage dividing is still the most common, but without the use of oil or a knife, as found in the oil suction divider. Extrusion dividing is more commonly found, particularly in the production of burger buns and hot dog rolls, where the dough consistency is usually based on highly developed North American doughs with low viscosity and good flow characteristics (Chap. 9).

Rounding is largely based on the oscillating system described previously for the bun divider–moulder and the linear rounder. This is applied differently by different manufacturers, some moulding the dough piece between an oscillating cup and a processing belt, some incorporating the oscillating motion into a honeycomb frame mounted around a drum and others combining the dividing chamber with the moulding system to mould against an oscillating plate. Extrusion dividers commonly round by means of a linear rounding track mounted over a processing belt. Spreading belts are usually incorporated into the divider–rounder to alter the pitch dimension between rows before the next processing module or unit. This allows the individual rolls to be pinned out later to longer finger or hot dog rolls whilst maintaining clearance for later expansion during proving. Swing-type first proving modules are incorporated when higher levels of dough reworking are required to develop the final product shape and always when the dividing and rounding action is aggressive or the rheology of the initial dough is particularly poor. Moulding can be achieved with a board or contra-rotating belt as described earlier. Some products may be simply rolled to shape while others may be sheeted and rolled. Dough pieces for burger buns can be pinned simply to flatten the rounded dough piece to a disc.

The seeding and topping of fermented products is more commonly found prior to the final proof on roll lines than on bread plants. Hence it is common to find seeding systems incorporated into roll plants in which the roll dough piece is first wetted and then sprinkled with seed. Excess seed is returned to a collection bin for later use. Panning is usually onto flat or indented trays. Panning methods can consist of row-by-row panning similar to that seen with bread lines where the tray indexes under the panning point are in line with the flow of product or more commonly by a retracting belt which rapidly withdraws under the dough pieces to drop up to a tray full of dough pieces every cycle.

Combination Bread and Roll Plants

Some smaller plants combine the requirements of bread and role production into one largely automatic operation. The equipment is aimed at the smaller and in-store bakeries. The dough is mixed in the spiral mixer and after mixing is completed the dough is automatically extracted from the bowl and fed directly into the divider. The divided dough pieces are rested and transported to the appropriate final moulders and afterwards panned or trayed up by the one operator needed to run the plant. The settings required for the various product types are stored in a computer. The program chosen by the operator automatically controls the various process stages and choice of equipment so that the skill and manual input required of the operator are limited.

References

Alava, J. M., Navarro, E., Nieto, A., & Scauble, O. W. (2005). COVAD—the continuous vacuum dough process. In S. P. Cauvain, S. E. Salmon, & L. S. Young (Eds.), *Using cereal science and technology for the benefit of consumers* (pp. 169–173). Cambridge: Woodead Publishing Ltd.

APV Corporation Ltd. (1992). *Dough mixing*. UK Patent GB 2 264 623A, HMSO, London, UK.

Cauvain, S. P. (1994). *New mixer for variety bread production*. European Food and Drink Review, Autumn, 51–3.

Cauvain, S. P. (1995). Controlling the structure is the key to quality. *South African Food Review, 21*, 33, 35, 37.

Cauvain, S. P. (1996). *Controlling the structure is the key to bread quality* (pp. 6–11). Sydney: Proceedings of the Fiftieth Anniversary Meeting of the Australian Society of Baking.

Cauvain, S. P. (1999). The evolution of bubble structure in bread doughs and its effect on bread structure. In G. M. Campbell, C. Webb, S. S. Pandiella, & K. Niranjan (Eds.), *Bubbles in food* (pp. 85–88). St. Paul, MN: Eagan Press.

Cauvain, S. P. (2001) Time for a change? *Plant Baking* 15–16

Cauvain, S. P. (2002). Filling in the holes. *British Baker, 5*, 12–13.

Cauvain, S. P. (2004). Improving the texture of bread. In D. Kilcast (Ed.), *Texture in Food, volume 2: solid foods*. Cambridge: Woodhead Publishing Ltd.

Cauvain, S. P., & Collins, T. H. (1995). *Mixing, moulding and processing bread dough* (pp. 41–43). London: Baking Industry Europe.

Cauvain, S. P., & Young, L. S. (2001). *Baking problems solved.* Cambridge: Woodhead Publishing Ltd.

Cauvain, S. P., & Young, L. S. (2006a). *The Chorleywood bread process*. Cambridge: Woodhead Publishing Ltd.

Cauvain, S. P., & Young, L. S. (2006b). *Baked products: Science, technology and practice*. Oxford: Blackwell Publishing.

Cauvain, S. P., & Young, L. S. (2008). *Bakery food manufacture and control: Water control and effects* (2nd ed.). Oxford: Wiley-Blackwell.

Cauvain, S. P., & Young, L. S. (2009). *More baking problems solved.* Cambridge: Woodhead Publishing Ltd.

Chamberlain, N., & Collins, T. H. (1979). The Chorleywood Bread Process—the roles of oxygen and nitrogen. *Bakers Digest, 53*, 18–24.

Collins, T. H. (1993). Mixing, moulding and processing doughs in the UK. In *Proceedings on an International conference on 'bread—breeding to baking'*. Chipping Campden: FMBRA, Chorleywood, CCFRA.

French, F. D., & Fisher, A. R. (1981). High speed mechanical dough development. *Bakers' Digest, 55*, 80–82.

Tweedy of Burnley Ltd. (1982). *Dough mixing for farinaceous foodstuffs*. UK Patent GB 2 030 883B, HMSO, London, UK.