CHAPTER 28

BAKERY PRODUCTS

THIS chapter addresses refrigeration and air conditioning as applied to bakery products, including items distributed (1) at ambient temperature, (2) refrigerated but unfrozen, and (3) frozen. Refrigeration plays an important part in modern bakery production.

Some of the major uses of refrigeration in the baking industry are

- Ingredient cooling
- Dough and batter temperature control during mixing
- Refrigerating dough products
- Freezing dough for the food service industry and supermarkets
- Freezing bread for later holding, thawing, and sale
- Freezing fried and baked products for sale to consumers

Refrigeration methods and equipment needed to accomplish these uses include

- Normal air conditioning
- Dough mixers with jackets through which chilled water, low-temperature antifreeze, or direct-expansion refrigerant passes
- CO_2 chips or CO_2 fog placed directly into dough mixer bowls
- Cooling tunnels with refrigerated air flowing counterflow to the product
- Medium-temperature cool rooms for storage of refrigerated dough products
- Freezing tunnels for dough
- Kettles for fillings
- Spiral freezer chambers in which the product remains for about 20 min to 1 h and is subjected to air at about −34°C for freezing
- Holding freezers: –23 to –29°C

Total plant air conditioning is increasingly used in new plant construction, except in areas immediately surrounding ovens, in final proofers, and in areas where cooking vessels prepare fruit fillings and hot icings. Total plant cooling was first used in plants producing Danish pastry, croissants, puff pastry, and pies, and has expanded to new-construction facilities for frozen dough operations and general production. Flour dust in the air should be filtered out because it fouls air passages in air-conditioning equipment, seriously reduces heat transfer rates, and is a potential respiratory health hazard.

INGREDIENT STORAGE

Raw materials are generally purchased in bulk, except in small operations. Deliveries are made by truck or railcar and stored in bins or tanks with required temperature protection while in transit and storage.

Flour. Flour is stored in bins at ambient temperature. Some bakeries locate these bins outside their buildings; however, inside storage is recommended where outside temperatures vary greatly. This improves control of product temperature and decreases the risk of moisture condensation inside the storage bins. Pneumatic conveyance and subsequent sifting before use generally increase flour temperature a few degrees. Smaller quantities of other flours, such as clear, rye, and whole wheat, are usually received in bags and stored on pallets.

Sugars and Syrups. Sugar is handled in both dry and liquid bulk forms by many large production bakeries. Although most prefer liquid, many cake and sweet goods plants produce their own powdered sugar for icings by passing granulated sugar through a pulverizer. Refrigeration dehumidifiers are sometimes used to minimize caking or sticking of the powdered sugar for proper pneumatic handling. Liquid sucrose (cane or beet sugar), generally with a solids content of 66 to 67%, is stored at ambient temperature; however, it can be cooled to as low as 7°C without crystallizing out of solution. Corn syrups and various blends of sucrose and corn syrups should be stored at 32 to 38°C to improve fluidity and pumpability. Unlike sucrose, corn syrups become more viscous when cooled. High-fructose corn syrups are best handled at 27 to 32°C. Lower storage temperatures cause sugars to crystallize, and higher temperatures accelerate caramelizing. Dextrose (corn sugar) solutions containing 65 to 67% solids must be stored in heated tanks at 54°C to prevent crystallization. Many bakeries use high-fructose corn syrups. Because these syrups are stored at a lower temperature than conventional syrup, less thermal input is required during storage, and the refrigeration load during mixing is significantly reduced. Smaller-volume and specialized sugars are received in poly-lined bags and stored at ambient temperature.

Shortenings. Shortenings are stored in heated tanks or a "hot room," where the temperature is maintained at 6 K above the American Oil Chemists' Society (AOCS) capillary closed-tube melting point of the fat (AOCS 1999, 2004). Lard, for example, should be stored at 49°C to be totally liquid. Other shortenings need slightly higher temperatures. Fluid shortenings and oils are stored at room temperature, but fluid shortenings need constant slow-speed agitation to prevent hard fats from separating to the bottom of the tanks.

Yeast. Fresh yeast comes in 0.5 kg blocks packaged in cartons of various sizes, in crumbled form in 25 kg bags, and in liquid cream form handled in bulk tanks. Refrigerated storage temperatures ranging from 7°C to the freezing point of the product are required. For maximum storage life, 1 to 2°C is considered best. Active dry and instant dry forms of yeast are available that do not need refrigeration.

Egg Products. Liquid egg products (whole, whites, yolks, and fortified) are commonly used in small retail and large cake and sweet goods bakeries. They generally come frozen in 15 kg containers that must be thawed under refrigeration or cold-water baths. Where large quantities are needed, liquid bulk refrigerated handling can be an economic advantage. Storage temperatures for liquid egg products should be less than 4.5°C, with 2 to 3°C being the ideal storage temperature range. Dried egg solids, which need no refrigeration, are also used. A shelf-stable whole egg that requires no refrigeration has been introduced. This stability was achieved by

The preparation of this chapter is assigned to TC 10.9, Refrigeration Application for Foods and Beverages.

removing two-thirds of the water from the eggs and replacing it with sugar, thereby lowering the water activity to the point that most organisms cannot grow.

Other. Dried milk products, cocoa, spices, and other raw ingredients in baking are usually put into dry storage, ideally at 21°C. Ideal storage is rarely achieved under normal bakery conditions. Refrigerated storage is sometimes used where longer shelf lives are desired or high storage temperatures are the norm. This decreases flavor loss and change, microbial growth, and insect infestation.

MIXING

Bread, buns, sweet rolls/Danish, yeast-raised doughnuts, and honey buns are the most important yeast-leavened baked products in terms of production volume. After scaling the ingredients, mixing is the next active step in production. Proper development of the flour's gluten proteins is what gives doughs their gas-retaining properties, which affect the volume and texture of the baked products. Temperature control during mixing is essential. Refrigeration is generally required because of the heat generation and the necessity of controlling dough temperature at the end of mixing. However, ingredient temperatures combined with room temperature may require addition of warm water to produce the desired finished dough temperature.

Yeast metabolism is materially affected by the temperatures to which the yeast is exposed. During dough mixing, the following heat factors are encountered: (1) **heat of friction**, by which the electrical energy input of the mixer motor is converted to heat; (2) **specific heat** of each ingredient; and (3) **heat of hydration**, generated when a dry material absorbs water. If ice is used for temperature control, **heat of fusion** is involved. Finally, the temperature of the dough ingredients must be considered. Yeast acts very slowly below 7.2°C. It is extremely active in the presence of water and fermentable sugars at 27 to 38°C, but all yeast cells are killed at 60°C and at a lower but sustained pace below its freezing point of –3.3°C. Precise temperature control is essential at all stages of storage and production, especially during mixing, because of its effect on downline processing.

Mixers

The three most common styles of mixers are the horizontal, vertical or planetary, and spiral. **Horizontal mixers** are primarily used by wholesale bakeries and are designed with horizontal agitator bars. They range in capacity from 90 to 1350 kg. Because of the large dough sizes, these mixers are generally jacketed with some form of cooling. **Vertical mixers** are more common in retail bakeries and are categorized by their largest bowl capacity. Bowls range in size from 11 to 19 L for tabletop models to as high as 320 L in some large wholesale plants. The bowls have no refrigeration jacket and can be removed from the mixers. The hook or agitator revolves as it travels around the inside of the bowl. **Spiral mixers** are somewhat newer and are gaining in popularity with retail and specialty bread bakers. Here the bowl revolves, bringing the ingredients to the off-center spiral agitator. Bowls for smaller models (23 to 180 kg) are not removable, but those for the larger models (up to 450 kg) can be removed. Like vertical mixers, spiral mixers are not jacketed.

Where flour is pneumatically transferred to the mixer, liquid CO_2 can be injected directly into the flour stream. This technique has been used for mixers, such as vertical and spiral mixers, that are not jacketed for temperature control. Dry ice (CO_2) chips have also been used in frozen dough production, where dough temperatures below 21°C are required. Dry ice is used as an aid to other forms of refrigeration. Because of expansion of CO_2 gas, horizontal mixers should be left open slightly.

Dough Systems

The four principal types of batch dough mixes are straight, no-time, sponge, and liquid ferment. These methods are called **dough systems** or **dough process** in the baking industry. The type of dough system determines the stages in the process, the equipment needed, and the general processing parameters (times and temperatures). **Straight dough** and **no-time dough** systems are the two most common in retail bakeries. All of the ingredients are mixed at one time. Straight doughs require fermentation, whereas no-time doughs do not. The no-time system is also used in wholesale or large plant bakeries that produce hearth and specialty breads, in which fermentation flavor is not as important as compared to white pan bread and buns.

The more common systems used in wholesale bakeries are the sponge dough and liquid ferment or liquid sponge. The **sponge dough** process requires more equipment and longer fermentation times than the straight and no-time dough systems. Here, only a part of the total amount of flour and water required are mixed with all of the yeast and yeast food. The resulting mixture, or sponge, is then fermented before it is given the final mix or remix with the remaining ingredients. This is done just before makeup, improving both tolerance of schedule disruptions and dough machinability.

The principal heat generated during mixing comes from hydration, as the flour absorbs water, and from the friction of the mixer. To absorb this excess heat and maintain the dough at 25.6 to 27.8°C, the dough-side water is usually supplied to the mix at 2 to 4°C, and horizontal mixers are generally jacketed to circulate a cooling medium around the bowl.

The **liquid ferment** or **liquid sponge** process has gained popularity with wholesale bakeries because of its excellent temperature control and acceptable product quality. Liquid sponge ingredients can be incorporated and fermented in special equipment either in batches or on an uninterrupted basis. To render the mixture pumpable, more water is incorporated than the actual amount used in a sponge to be fermented in a trough. After fermentation, the liquid sponge (at required pH and titratable acid levels) is chilled through heat exchange equipment from about 26 to 31°C to about 7 to 13°C. The cold liquid sponge is then maintained at the required temperature in a storage or feed tank until it is weighed or metered and pumped to the mixer, where it is combined with the remaining ingredients before being remixed into a dough. Regular sponges come back for remixing at about 29°C. Often, it is necessary to use the refrigerated surface on the mixer jacket in conjunction with ice water or ice to achieve the required dough temperature after mixing.

Positive dough temperature control is achieved using a cold liquid sponge at 7 to 13°C, which limits the need for the refrigeration jacket and eliminates using ice in the doughs. In cold weather, remaining dough water temperatures of 38°C or higher are often required.

A fifth dough system, the **continuous mix** method, was developed in the 1950s and requires specially designed continuous mix equipment for making bread and buns. Originally, a liquid ferment, then called a brew or broth, was formed, using 0 to 10% of the flour, 10 to 15% of the sugar, 25 to 50% of the salt, all of the yeast, and yeast food in about 85% of the total water. Through the years, the amount of flour has increased to as high as 50% and the needed sugar decreased. Using mass flow meters, the liquid ferment is metered into an incorporator or premixer, where the remaining ingredients are added. The resultant thicker batter finally passes through a developer head/mixer, from which the finished dough is extruded and deposited directly into a greased baking pan. Properly formulated dough can also be deposited onto floured belts that then pass through conventional makeup equipment. Final dough temperatures could reach as high as 48°C, though today, with higher levels of flour in the ferment, they could be as low as 32°C. It is estimated that less than 5% of the U.S. bread and bun market uses this system.

Table 1 Size of Condensing Units for Various Mixers

Dough Capacity, kg	Condensing Unit Size, kW
300	3
450	7
600	10
750	13
900	15

Hot dog and hamburger rolls are also produced in quantity by pumping bun dough from the continuous mix developer directly to the hopper of the makeup equipment. A coating of flour on outside dough surfaces affects gas development and retention, which in turn leads to a grain/texture more closely resembling that of sponge dough products. External symmetry and crust characteristics are similarly changed.

Dough Cooling

Some dough mixers are cooled by direct-expansion refrigerant, but the most common means of cooling is with chilled water or an antifreeze such as propylene glycol. The temperature of the evaporating refrigerant or antifreeze supplied may often be as low as –1°C to maintain the dough at the desired temperature. When the dough mixers are cooled by evaporating refrigerant, the condensing unit is usually located close to the mixers. Table 1 lists the sizes of condensing units commonly selected for mixers. The ingredient water is cooled in separate liquid chillers, and when the mixer bowl is cooled by antifreeze, the liquid chiller may be remotely located.

When large batches of dough are handled in the mixers, the required cooling is sometimes greater than the available heat transfer surface can produce at –1°C, and the refrigerant temperature must be lowered. Refrigerant temperatures below –1°C can, however, cause a thin film of frozen dough to form on the jacketed surface of the mixer, which effectively insulates the surface and impairs heat transfer from the dough to the refrigerant.

Formulas, batch sizes, mixing times, and almost every other part of the mixing process vary considerably from bakery to bakery and must be determined for each application. These variations usually fall within the following limits:

Final batch dough mass	Up to 1500 kg
Ratio of sponge to final dough mass	50 to 75%
Ratio of flour to final dough mass	50 to 65%
Ratio of water to flour	50 to 65%
Sponge mixing time	240 to 360 s
Final dough mixing time	480 to 720 s
Number of mixes per hour	2 to 5
Continuous mix production rates	Up to 1 kg/s

The total cooling load is the sum of the heat that must be removed from each ingredient to bring the homogeneous mass to the desired final temperature plus the generated heat of hydration and friction. In large batch operations, the sponge and final dough are mixed in different mixers, and refrigeration requirements must be determined separately for each process. In small operations, a single mixer is used for both sponge and final dough. The cooling load for final dough mix is greater than that for sponge mix and is used to establish refrigeration requirements.

Some bakery manufacturers inject CO_2 into a mixer to chill ingredients before mixing; this helps obtain lower dough temperatures when mechanical refrigeration is not adequate for desired mixing times. This technique is principally applied to laminated and frozen doughs.

FERMENTATION

After completion of the sponge mix, the sponge is placed in large troughs that are rolled into an enclosed conditioned space for a fermentation period of 3 to 5 h, depending on the dough formula. The sponge comes out of the mixer at 22 to 24.5°C. During fermentation, the sponge temperature rises 3 to 6 K as a result of the heat produced by the yeast and fermentation, or about 1 K per hour.

To equalize the temperature substantially throughout the dough mass, room temperature is maintained at the approximate mean sponge temperature of 27°C. Even temperature throughout the batch produces even fermentation action and a uniform product.

Water makes up a large part of the sponge, and uncontrolled evaporation causes significant variations in the quality and mass of the bread. The rate of evaporation from the sponge surface varies with the ambient air's relative humidity and airflow rate over the surface. The rate of moisture movement from the inside of the sponge to the surface does not react similarly to external conditions, and surface drying and crust formation can result. Crusted dough is inactive and does not develop. When folded into the dough mass later, undeveloped portions produce hard, dark streaks in the finished bread.

To control the evaporation rate from the sponge surface, air is maintained at 75% rh, and the conditioned air is moved into, through, and out of the process room without producing crust-forming drafts.

In calculating the room cooling load, the product is not considered because the air temperature is maintained at approximately the mean of the various dough temperatures in the room. Transmission heat loss through walls, ceiling, and floor is the principal load source. Infiltration is estimated as 1.5 times the room volume per hour. The lighting requirement for a fermentation room is usually about 2 W per square metre of floor area. The conditioning units are often placed within the conditioned space, and the full motor heat load must be considered.

The only source of latent heat is the approximate 0.5% loss of mass in the sponge. Under full operating load, this could account for a 1 K increase in dew-point temperature. For conditions of 27°C db and 75% rh, the dew-point temperature would be 21.9°C, and the supply air would be introduced into the conditioned space at 22.2°C db and 21°C dew point.

In large rooms, sufficient air volume can be introduced to pick up the sensible heat load with a 4.5 K rise in air temperature. In smaller rooms, a latent heat load may need to be added by spraying water directly in the room through compressed-air atomizing nozzles. Water sprays have been most successful when a relatively large number of nozzles is spaced around the periphery of the room.

Because a high removal ratio of sensible to latent heat is desirable, the condensing unit is usually specified for operation as close to 15°C evaporator temperature as is practicable with the temperature and quantity of condensing water available.

BREAD MAKEUP

After the dough is mixed using conventional mixers, and perhaps given floor time to become more elastic and less tacky, it is placed into the hopper of the divider. There are two types of dividers used in wholesale bakeries. With the **ram and piston divider**, the dough is forced into cylinders; the pistons adjust the cylinder opening, which controls the unit mass. The **rotary (extrusion) divider** extrudes the dough through an opening using a metering pump; a rotating knife then cuts off the dough. The unit mass is adjusted by the speed of the metering pump and/or the speed of the knife. Because dough density changes with time and the dividers work on the principle of volume, the baker must routinely check scaling mass and adjust the dividers.

Next, the irregularly shaped units are rounded into dough balls for easier handling in subsequent processing. This **rounding** is done on drum, cone, or bar/belt rounders. The dough pieces are well floured, and a smooth skin is established on the outer surface to reduce sticking.

A short resting or relaxation period on an intermediate proofer follows rounding. Flour-dusted trays or belts hold the dough pieces and carry them to the next pieces of equipment via a transfer shoot. Residency time is 1 to 8 min.

The dough is next formed into a loaf by the **sheeter** and the **moulder**. The relaxed dough ball is sheeted (e.g., to about 3 mm thick for white pan bread) by passing through sets of rollers. This reduces the size of gas cells and multiplies them, producing a finer grain in the baked bread. Next the dough goes to the moulder, where it receives its final length and shape before it is placed into the greased baking pan. There are three styles of moulders: (1) straight grain, (2) cross grain, and (3) tender-curl.

FINAL PROOF

After the loaves are formed, they are placed in baking pans, and set in the **proofer** for 50 to 75 min. The proofer is an insulated enclosure with a controlled atmosphere in which the dough receives its final fermentation or proof before it is baked. To stimulate the yeast's fermentative ability, the temperature is maintained at 35 to 43°C, depending on the exact formula, prior intensity of dough handling, and desired character of the baked loaf.

For proper crust development during baking, the exposed surface of the dough must be kept pliable by maintaining the relative humidity of the air in the range of 75 to 95%. Some bakeries find it necessary to compromise on a lower humidity range because of the effect on dough flow.

With dew points inside the proofer at about 33 to 41°C and ambient conditions as low as 18°C at times, the proofer must be adequately insulated to keep the inside surface warm enough to prevent condensation from forming because mold growth can be a serious problem on warm, moist surfaces. A thermal conductance of $C = 0.68$ W/(m^2·K) is adequate for most conditions.

In small and midsized bakeries, one of the more commonly used proofers for this process consists of a series of aisles with doors at both ends. Frequent opening of the doors to move racks of panned dough in and out makes control of the conditioned air circulation an unusually important engineering consideration. The air is recirculated at 90 to 120 changes per hour and is introduced into the room to temper the infiltration air and cause a rolling turbulence throughout the enclosure. This brings the newly arrived racks and pans up to room temperature as soon as possible.

The problem of air circulation is somewhat simpler when large automatically loaded and unloaded tray and conveyer or spiral proofers are used. These proofers have only minimal openings for the entrance and exit of the pans, and the thermal load is reduced by elimination of the racks moving in and out.

BAKING

Most 454 to 680 g bread loaves are baked in ovens at around 200 to 230°C for 18 to 30 min. High temperatures are used for hearth breads, and lower temperatures for denser styles of breads. Buns and rolls are baked at 216 to 232°C for 10 to 12 min. Because of their small size, a quick bake is desired so as not to dry out the product during the bake.

Deck ovens are found in some smaller retail establishments, specialty cookie and hearth bread bakeries, pizzerias, and restaurants. The baking surfaces are stationary, requiring manual loading and unloading. Uneven heat distribution, little air movement, and low clearance between decks make the deck oven unsuitable for some products. Newer designs have made this oven the choice for retail baking of the denser, heavy, European-type hearth breads.

Rack ovens are very popular in in-store supermarket bakeries, freestanding retail bakeries, and some wholesale bakeries. These ovens have a small chamber into which one or two racks of panned product can be rolled at one time. Using forced-air convection, baking can be accomplished at lower temperatures for shorter baking times. These ovens are highly efficient in heat transfer and easy to operate. They generate their own steam without boilers and are well suited for crusty breads.

There are two popular styles of tray ovens, which are loaded and unloaded at the same end. The **reel-type tray oven**, which looks like a Ferris wheel inside a heated baking chamber, is one of the most popular ovens in retail bakeries and is used by some large wholesalers. This design, with its manual loading and unloading, allows different products to be baked simultaneously. Because of the revolving action, hot spots and uneven baking are less likely than in deck ovens.

The **single-lap traveling tray oven** is used principally in large production bakeries and is usually equipped with pan loaders and unloaders for efficient product handling and continuous baking. There is also a double-lap design, which travels back and forth twice, but it is not currently popular.

Wholesale bakeries are equipped with either tunnel (traveling hearth) ovens or conveyor-style ovens. **Tunnel ovens**, as the name suggests, have the product loaded in at one end and unloaded at the other. This permits ideal temperature control for the entire baking time. **Conveyor-style ovens** have a continuous spiral climbing to the top of a heated chamber and then back down again, with each pan carried on its own section of the conveyor and every product passing through the same spot within the baking chamber. Another style of tunnel oven is the **impingement oven**. Its directional flow of heated air to the top and bottom of the product provides excellent baking speed and efficiency for pizza and other low-profile products.

Ovens are usually gas fired, but electric or oil firing may be more economical in some areas. Where gas interruption is a problem, combination oil and gas burners are an alternative. Gas firing can be direct or indirect, but indirect firing is generally more popular because of its greater flexibility. Ribbon burners running across the width of the oven are operated as an atmospheric system at pressures of 1.5 to 2.0 kPa.

Burners are located directly beneath the path of the hearth or trays, and the flames may be adjusted along the length of the burner to equalize heat distribution across the oven. The oven is divided into zones, with the burners zone-controlled so that heat can be varied for different periods of the bake.

Controlled air circulation inside the oven ensures uniform heat distribution around the product, which produces desired crust color and thickness. When baking hearth breads, ovens are equipped with steam ejection. Low-pressure (14 to 35 kPa), high-volume wet steam is used for the first few minutes of baking to control loaf expansion and crust crispness and shine. This is accomplished with a series of perforated steam tubes located in the first zone of baking in place of the air-recirculating tubes. Heating calculations are based on 1050 kJ per kilogram of bread baked. Steam requirements run approximately 620 kJ per kilogram of bread baked.

Many wholesale and plant bakeries use the internal temperature of product exiting the oven as a guide to judge the proper bake. A judgment to minimize baking time is based on establishing product structure and, at the same time, minimizing bake loss. Desired crust color is essential; however, a target internal finished product temperature of 91 to 96°C can help control product characteristics and maximize oven throughput by minimizing baking time.

BREAD COOLING

Baked loaves come out of the oven with an internal temperature of 91 to 96°C because of the evaporative cooling effect of moisture that is driven off during baking. The crust temperature is closer to the oven baking temperature, 230°C.

Loaves are then removed from the pans and allowed to cool to an internal temperature of 35 to 41°C. A hygroscopic material cools in two phases, which are not distinct periods. When the bread first

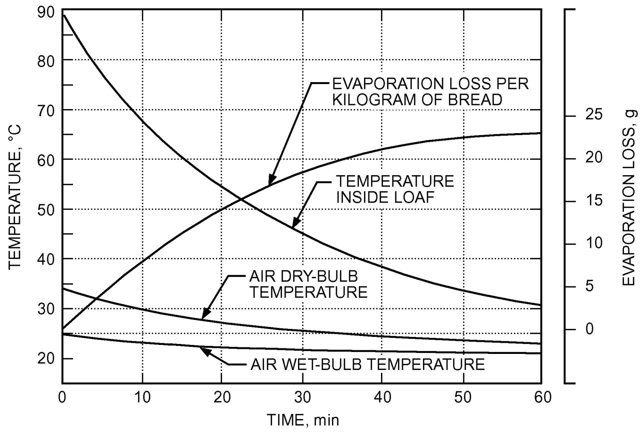

Fig. 1 Moisture Loss and Air Temperature Rise in Counterflow Bread-Cooling Tunnel

comes out of the oven, the vapor pressure of moisture in the loaf is high compared to that of moisture in the surrounding air. Moisture is rapidly evaporated, with a resultant cooling effect. This **evaporative cooling**, combined with **heat transmission** from bread to air caused by a relatively high temperature differential, causes rapid cooling in the early cooling stage, as indicated by the steepness of the temperature versus time curve (Figure 1). As vapor pressure approaches equilibrium, heat transfer is mainly by transmission, and the cooling curve flattens rapidly.

Small bakeries still cool bread on racks standing on the open floor for 1 to 3 h, depending on air conditions, spacing, and size of product. Many large operations cool bread while it is moving continuously on belt, spiral, or tray conveyors. Cooling is mostly atmospheric, even on these conveyors. However, to ensure a uniform final product, cooling is often handled in air-conditioned enclosures with a conventional counterflow movement of air in relation to the product.

An internal temperature of 35 to 41°C stabilizes moisture in the bread enough to accomplish proper slicing and reduce excessive condensation inside the wrapper, thus discouraging mold development. Approximately 50 to 75 min of cooling is required to bring the internal loaf temperature to 35°C, as shown in Figure 1.

In counterflow cooling, the optimum temperature for air introduced into the cooling tunnel is about 24°C. Air at 80 to 85% rh controls moisture loss from the bread during the latter stage of cooling and improves the bread's keeping quality.

Attempting to shorten cooling time by forced-air cooling with air temperatures below 24°C is not satisfactory. The rate of heat and moisture loss from the surface becomes much greater than that from the interior to the surface, causing the crust to shrivel and crack.

Product heat load is calculated assuming sensible heat transfer based on a specific heat of 2.93 kJ/(kg·K) for bread and a temperature reduction from 82°C to 35°C. For calculating purposes, moisture evaporation from the bread may be considered responsible for reducing the bread temperature to 35°C.

Under normal conditions, air conditioning can best be accomplished by evaporative cooling in an air washer. When the outdoor wet-bulb temperature exceeds 22°C, which is the maximum allowable based on 24°C db and 85% saturation, refrigeration is required.

The amount of air required is rather high because the maximum temperature rise of air passing over the bread is usually about 11 K; consequently, the refrigeration load is comparatively high. Where wet-bulb temperatures above 22°C are rare or of short duration, the expense of refrigeration is not considered justified, and the bread is sliced at a higher than normal temperature.

SLICING AND WRAPPING

Bread from the cooler goes through the slicer. The slicer's high-speed cutting blades (similar to band saw blades) cut cleanly through properly cooled bread. If the moisture evaporation rate from the surface and replacement rate of surface moisture from the interior are not kept in balance, the bread develops a soggy undercrust that fouls the blades, causing the loaf to crush during slicing. A brittle crust may also develop, which leads to excessive crumbing during slicing. From the slicer, the bread moves automatically into the bagger.

BREAD FREEZING

Bagged bread normally moves into the shipping area for delivery to various markets by local route trucks or by long-distance haulers. Part of the production may go into a quick-freezing room and then into cold storage.

Bakers face two important problems in freezing bread and other bakery products. The first is connected with the short work week. Most bread and roll production bakeries are inoperative on Saturday; thus, production near the end of the week is much larger than for the earlier part of the week. The problem increases for bakeries on a 5 day week, with Tuesday usually being the second day off. Freezing a portion of each day's production for distribution on the days off can enable a more even daily production schedule.

A second problem is increased demand for variety breads and other products. The daily production run of each variety is comparatively small, so the constant setup change is expensive and time-consuming. Running a week's supply of each variety at one time and freezing it to fill daily requirements can reduce operating cost.

Both problems concern staleness, because bread is a perishable commodity. After baking, starch from the loaf progressively crystallizes and loses moisture until a critical point of moisture loss is reached. A tight wrap helps keep the moisture content high over a reasonable time. Starch crystallization, when complete, produces the crumbly texture of stale bread. The rate of this spontaneous action increases as either moisture or temperature decreases. Starch crystallization accelerates as the product passes through a critical temperature zone of 10°C to the freezing point of the product. The rate then decreases until the temperature reaches –18°C, where moisture loss seems to be somewhat arrested.

Bread freezes at –9 to –7°C (Figure 2). Bread should be cooled through the freezing or latent heat removal phase as fast as possible to preserve the cell structure. Because moisture loss rate increases with reduced temperature, bread should be cooled rapidly through the entire range from the initial temperature down to, and through, the freezing points. Successful freezing has been reported in room temperatures of –18, –23, –29, and –34°C.

In U.S. Department of Agriculture (USDA) laboratory tests, core temperatures of loaves of wrapped bread placed in 3.5 m/s cold air blasts were brought down from 21°C to –10°C in the times given:

Freezer Air Temperature, °C	Cooling Time, 21°C to –10°C, h	Bread Core Temperature at End of 2 h, °C
–40	2	–9.4
–34.4	2.25	–8.9
–28.9	3	–7.2
–23.3	3.75	–6.1
–17.8	5	–5.5

Changes in air velocity from 1.0 to 6.5 m/s had relatively little effect on cooling of wrapped bread.

Cooling from –18 to –29°C is 10 to 30 min faster for unwrapped bread than for wrapped bread. However, the wrapper's value in retaining moisture during freezing and thawing makes freezing wrapped product advisable.

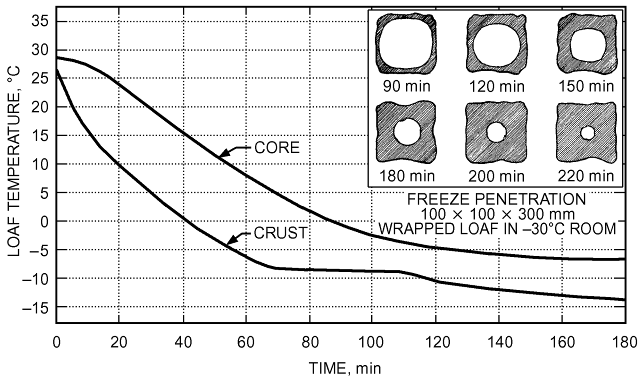

Fig. 2 Core and Crust Temperatures in Freezing Bread

Table 2 Important Heat Data for Baking Applications

Specific heat		
Baked bread (above freezing)	2.93	kJ/(kg·K)
Baked bread (below freezing)	1.42	kJ/(kg·K)
Butter	2.39	kJ/(kg·K)
Dough	2.51	kJ/(kg·K)
Flour	1.76	kJ/(kg·K)
Ingredient mixture	1.68	kJ/(kg·K)
Lard	1.88	kJ/(kg·K)
Milk (liquid whole)	3.98	kJ/(kg·K)
Liquid sponge (50% flour)	2.93	kJ/(kg·K)
Heat of friction per kilowatt of motive power of mixer motor	1	kW
Heat of hydration of dough or sponge	15.1	kJ/kg
Latent heat of baked bread	109.3	kJ/kg
Specific heat of steel	0.50	kJ/(kg·K)

Some commercial installations freeze wrapped bread in corrugated shipping cartons. The additional insulation provided by the carton increases freezing time considerably and causes a wide variation in freezing time between variously located loaves. One test found that a corner loaf reached –9°C in 5.5 h, whereas the center loaf required 9 h.

Most freezers are batch-loaded rooms in which bread is placed on wire shelves of steel racks. One of the principal disadvantages of this arrangement is that the racks must be moved in and out of the room manually. Continuous freezers with wire belt or tray conveyors allow steady flow and do not expose personnel to the freezer temperature. See Chapter 16 for freezer descriptions.

For air freezing temperatures of –29°C or below, consider using two-stage compression systems for overall economical operation.

In addition to primary air blowers designed for about 10 L/s per kilogram of bread frozen per hour, a series of fans is used to ensure good air turbulence in all parts of the room. Heat load calculations are based on the specific and latent heat values in Table 2.

After the quick freeze, bread is moved into a –23°C holding room where the temperature throughout the loaf equalizes. Bread is often placed in shipping cartons after freezing and stacked tightly on pallets.

Defrosting. Frozen bread must be thawed or defrosted for final use. Slow, uncontrolled defrosting requires only that the frozen item be left to stand, usually in normal atmospheric conditions. For quality control, the defrosting rate is just as critical as the freezing rate. Passing the product rapidly through the critical temperature range of 10°C to the product's freezing point yields maximum crumb softness. Too high a relative humidity causes excessive condensation on the wrapper, with some resultant susceptibility to handling damage. The product defrosts in about 1.75 h when placed in air at 49°C and 50% rh or less. Good air movement over the entire product surface at 1.0 m/s or higher helps minimize condensation and make the defrosting rate more uniform.

FREEZING OTHER BAKERY PRODUCTS

Retail bakeries freeze many products to meet fluctuating demand. Cakes, pies, sweet yeast dough products, soft rolls, and doughnuts are all successfully frozen. A summary of tests and commercial practice shows that these products are less sensitive to the freezing rate than are bread and rolls. Freezing at –18 to –12°C apparently produces just as satisfactory results as freezing at –23 to –29°C.

Storage at –23 to –29°C or below keeps packaged dinner rolls and yeast-raised and cake doughnuts satisfactorily fresh for 8 weeks. Cinnamon rolls keep for only about 3 weeks, apparently because of the raisins, which absorb moisture from the crumb of the roll.

Pound, yellow layer, and chocolate layer cakes can be frozen and held at –12°C for 3 weeks without significantly affecting their quality. Sponge and angel food cakes tend to be much softer as the freezing temperature is reduced to –18°C. Layer cakes with icing freeze well, but condensation on exposed icing during thawing ruins the gloss; therefore, these cakes are wrapped before freezing.

Unlike cakes, which can be satisfactorily frozen after baking, pies frozen after baking have an unsatisfactory crust color, and the bottom crust of fruit pies becomes soggy when the pie is thawed. Freezing unbaked fruit pies is highly successful. Freezing time has little, if any, effect on product quality, but storage temperature does have an effect. Frozen pies stored at temperatures above –18°C develop badly soaked bottom crusts after 2 weeks, and fillings tend to boil out during baking, possibly because of moisture migration from starch-based syrups. Freezing baked or fried products is generally a high-production operation carried out in freezing tunnels or spiral freezers.

One of the fastest growing applications of refrigeration is freezing dough for in-store bakeries. A few frozen dough products are sold in supermarkets directly to consumers, but most is destined either for food service or for supermarket bakeries.

Danish and sweet dough products are frozen baked or unbaked, depending on how quickly they will be required for sale after they are removed from the freezer. Custard and chiffon pie fillings have not had uniformly good results, but some retail bakeries have achieved satisfactory results by carefully selecting starch ingredients. Meringue toppings made with proper stabilizers stand up very well, and whipped cream seems to improve with freezing. Cheesecake, pizza, and cookies also freeze well.

Although some products are of better quality if frozen at –23°C and others at –29°C, variety shops must compromise on a single freezer temperature so that all products can be placed in one freezer. The freezer is usually maintained between –23 and –29°C. Freezing time is not a factor because the products are kept in storage in the freezer. Freezers range from large reach-in refrigerators in retail shops to walk-in boxes in wholesale shops.

FROZEN PRE-PROOFED BAKERY PRODUCTS

Unlike yeast-leavened frozen dough products in today's market, which require thawing, proofing, and baking, frozen "pre-proofed" dough products are partially proofed (≈80% of full proof) before freezing at –20 to –30°C and do not need to be thawed and proofed before baking. Pre-proofed products eliminate the need for expert thawing and proofing, while still providing optimum quality for the end user. The products can go directly from the freezer onto baking trays and into the oven. Baking temperatures for various products are very important: sweet rolls and Danish pastries require 150 to 160°C, whereas croissants require 160 to 170°C. The product thaws and expands some during the first part of baking. Advantages include the following: (1) no proof box is needed, (2) no thawing or proofing time is required, and (3) there is no chance of over- or underproofing the product. This allows the freshest baked product delivered on demand in the shortest possible time. Some breads, bread rolls, sweet rolls, croissants, and Danish pastry are produced by this method.

Some companies use normal yeast levels, as for fresh products; others use higher levels (≈2% based on flour weight), as for frozen doughs. Other adjustments to formulation are a combination of gums to improve moisture retention and the use of oxidants for increased dough strength. Processing changes seem to be of great importance. Laminating dough adds strength to the gluten structure for optimum gas retention and product height, and partially proofing moulded dough pieces at lower temperatures than normal (≤27°C) reduces weakness produced by yeast. Some operations temper/refrigerate proofed product to an internal temperature of 16°C before freezing and packaging. Depending on the type and amount of product to be baked, a baking temperature 15 to 22 K lower than for conventional products is used, with a steam injection during the first one-third to one-half of the bake. Using lower temperatures and steam keeps the crust from setting too quickly, allowing proper product expansion. This new method of production ensures top-quality product for restaurant, food commissary, and in-store bakery markets. Product shelf life is said to be 9 months to 1 year. The primary disadvantages are that (1) frozen product is easily thawed during transport, and (2) more freezer space is required.

RETARDING DOUGHS AND BATTERS

Freezing is usually used if the products are to be held for 3 days to 3 weeks. For shorter holding periods, such as might be required to have freshly baked products all day from one batch mix, a temperature just cold enough to retard fermentation action in the dough is applied. Retarder temperatures of 0 to 4.5°C slow the yeast action sufficiently to allow holding for 3 h to 3 days.

Doughs to be retarded are sometimes made up into final shaped units ready for proofing and baking. Cold slabs of dough can also be stored, with baking units made up after thawing. This method is especially satisfactory for Danish pastry dough and other doughs with rolled-in shortening, such as croissants and puff pastries. Chilling to retarded temperatures improves flakiness of these products. Refrigeration load calculations should be made following the recommendations included in Chapter 13.

In the retarding refrigerator, about 85% rh is required to prevent the product from drying out. Condensation on the product is undesirable. Complete batch loading is usually used, so refrigeration calculations must be based on introduction of the batch over a short period of time. Refrigeration equipment be able to absorb product and carrier heat loads in 0.75 to 3 h, depending on cabinet size and handling technique. Products most commonly handled in this manner are Danish pastry, dough for sweet rolls and coffee cake, cookies, layer cake mixes, pie crust mixes, and bun doughs.

Temperatures required for retarding are very similar to those required for storing ingredients, and refrigerators are usually designed to handle both ingredient storage and dough retarding.

CHOICE OF REFRIGERANTS

The most popular refrigerants in the baking industry have been R-12, R-22, R-502, and ammonia (R-717). R-12 is a chlorofluorocarbon (CFC) and can no longer be used; its most successful replacement has been R-134a. In general, any R-12 system can be refitted with R-134a along with the substitution of the proper lubricant. R-22 is a hydrochlorofluorocarbon (HCFC), so it is destined for phaseout over several decades. R-502 is an azeotrope containing the CFC R-115, so no new R-502 systems are being installed. Hydrofluorocarbon (HFC) substitutes for R-502 and R-22 are available, but they cost much more. Therefore, the preferred configuration of the system may be different than for traditional refrigerants.

For water chillers, R-134a is becoming popular. For chilling antifreeze to lower temperatures, the HFC replacements for R-22 and R-502 are possibilities. For large freezing facilities (e.g., spiral freezers), ammonia dominates because of its excellent low-temperature performance. Some producers also choose expendable refrigerants, such as carbon dioxide (CO_2) or nitrogen (N_2), which many believe provides a superior frozen product because of the freezing medium's low temperature. Hybrid systems can be used in which CO_2 and N_2 rapidly freeze a crust on the product surface; vapor compression, with its lower operating cost, completes the freezing process.

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