Chapter 2

Manufacturing Technology of Ready-to-Eat Cereals

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Ready-to-eat (RTE) breakfast cereals are processed grain formulations suitable for human consumption without further cooking in the home. They are relatively shelf-stable, lightweight, and convenient to ship and store. They are made primarily from corn, wheat, oats, or rice, in about that order of the quantities produced, usually with added flavor and fortifying ingredients.

Hot breakfast cereals, on the other hand, are made primarily from oats or wheat; those made from corn or rice are of minor importance, being produced in relatively small quantities. The original hot cereals required cooking in the home before they were ready for consumption, but now some varieties are preprocessed so that they are ready for consumption with the addition of either hot water or milk to the cereal in the bowl.

RTE cereals originated in the United States in the latter part of the nineteenth century. At first developed and used as healthful vegetarian foods in a clinical context, they soon caught on with the general population, and an entire industry was thereby spawned (Fast, 1999). Their processing typically involves first cooking the grain with flavor materials and sweeteners. Sometimes the more heat-stable nutritional fortifying agents are added before cooking. Two general cooking methods are employed in the industry—direct steam injection into the grain mass in rotating batch vessels and continuous extrusion cooking. Both of these cooking operations and the equipment commonly used are discussed in detail in Chapter 3.

Most RTE cereals may be grouped into 12 general categories for discussion of their manufacturing processes: 1) flaked cereals (corn flakes, wheat flakes, and rice flakes), including extruded flakes, 2) gun-puffed whole grains, 3) extruded gun-puffed cereals, 4) shredded whole grains, 5) extruded and other shredded cereals, 6) oven-puffed cereals, 7) granola cereals, 8) extruded expanded cereals, 9) baked cereals, 10) compressed flake biscuits, 11) muesli-type products, and 12) filled bite-size shredded wheat. Also included in this chapter is a brief discussion of breakfast cereal types of products manufactured for use as ingredients in other foods.

Flaked Cereals

Flaked cereals include those made directly from whole grain kernels or parts of kernels of corn, wheat, or rice and also extruded formulated flakes. The basic objective in making a flaked cereal is to first process the grain in such a way as to obtain particles that form one flake each. We know of no process by which flaked cereals can be made from a large, thin sheet that is broken down to individual flakes after toasting.

Grain selection is therefore very important to the finished character of flaked cereals, and one or more intermediate size reductions and sizing or screening operations may be necessary to provide flakable-sized particles, known as *flaking grits.*

Corn flakes and wheat flakes are typically made from whole-grain kernels or parts of kernels. This practice developed in the early years of the industry, since these materials after processing can be made the correct size for flaking.

With the advent of cooking extruders, however, finer materials, such as flours, can be used, since the flakable grit size is attained by mechanical means. By cooking a dough and forming from it the grits for flaking, much of the equipment for preflaking size reduction and screening in the traditional process can be eliminated.

CORN FLAKES

The best example of a cereal made from parts of whole grain is traditional corn flakes. New varieties of corn flakes made by continuous extrusion cooking have been developed and improved since the 1980s. They have made inroads into the demand for traditional corn flakes, which have been on the market for about a century. We cover extruded corn flakes later in this chapter.

Formulation

The basic raw material for the traditional corn flake is derived from the dry milling of regular field corn. Dry milling removes the germ and the bran from the kernel, and essentially what is left is chunks of endosperm. The size needed for corn flakes is one half to one third that of the whole kernel. These pieces are raw, unflavored, and totally unsuitable for flaking until they have been processed. They never lose their identity while being converted into flakes. Each finished flake typically represents one grit, although sometimes two small grits stick together and wind up as one flake.

A typical formula for corn flakes is as follows: corn grits, 100 lb (45 kg); granulated sugar, 6 lb (3.7 kg); malt syrup, 2 lb (1 kg); salt, 2 lb (1 kg); and water sufficient to yield cooked grits with a moisture content of not more than 32% after allowing for steam condensate. Liquid sucrose at 67°Brix can be substituted for the sugar, with a decrease in the amount of water. Likewise, 26% saturated brine can be used rather than dry salt; however, this solution is very corrosive on pumps and meters. Malt syrup is a very viscous material, and some manufacturers prefer malt flour. The traditional malt syrup is one that does not have any diastatic enzyme activity. Both diastatic and nondiastatic malt flours have also been used.

Mixing

The first step in converting raw corn grits into corn flakes is to mix them with a flavor solution. Master batches of the flavor materials (sugar, malt, salt, and water) may be made up for multiple cooking batches. When this is done, it has been found better to weigh out the correct proportion of flavor syrup to be added to each cooker batch rather than draw it off volumetrically. Temperature and viscosity variations in master batches can result in inconsistent addition of the flavor solution. Every effort should be made to weigh each and every ingredient accurately. Inaccurate and haphazard proportioning of ingredients results in differences in the handling and the quality of grits in subsequent processing steps and ultimately in the quality of the finished product.

Cooking

The weighed amounts of raw corn grits and flavor syrup are charged into batch cookers, which are usually vessels about 4 ft in diameter and 8 ft long (about 1.2 × 2.4 m). They are capable of being rotated and are built to withstand direct steam injection under pressure. One brand that has been popular is the Johnson cooker, formerly manufactured by the Adolph Johnson Co., of Battle Creek, Michigan. In the United Kingdom, similar pieces of equipment are called Dalton cookers. The Lauhoff Corporation produces a redesigned version of the Johnson cooker, as do APV Baker, Inc., in the United States and United Kingdom and Buhler, Inc., in the United States and Switzerland. Batch cookers are discussed in more detail in Chapter 3.

The grits and flavor syrup may be loaded simultaneously, or the grits may be added first, the cooker lid closed (or *capped,* as it's called), the rotation started, and then the flavor syrup added. No hard-and-fast rules exist, except that the end result must be a uniform dispersion of flavor throughout the grain mass.

Normally the raw ingredients when fully loaded into the cooker occupy not more than one-half to two-thirds of its volume, to leave room for expansion during cooking. In cooking corn for corn flakes, it has been found best to increase the batch size so that at the end of the cooking time the cooker is filled to capacity. This batch size, which is slightly larger than that normally used for wheat or rice, produces cooks that are less sticky and easier to process further.

With the grits and flavor in the cooker and the cooker tightly capped, the steam is turned on. The steam quality should be that permitted for food contact. The mass of grits and flavor is normally cooked at 15–18 psi (1.0–1.25 bar) for 2 hr. Some batches take more time than others, as a result of variations in the cooking behavior of the corn grits.

The rotation speed of these batch cookers is usually 1–4 rpm, with the higher rate used for initial mixing only. Too high a speed can lead to attrition of the particles, resulting in slime or mushiness in the cooked product. On the other hand, too low a speed can lead to uneven cooking within a batch.

The moisture content of the cooked mass at the end of the cooking cycle should be not more than 32%. Some batches can be considered well cooked and in good processing condition with a moisture content as low as 28%.

The cooking is complete when each kernel or kernel part has been changed from a hard, chalky white to a light, golden brown and is soft and translucent. A batch is undercooked if large numbers of grain particles have chalky white centers, and it is overcooked if the particles are excessively soft, mushy, and sticky. Properly cooked particles are rubbery but firm and resilient under finger pressure, and they contain no raw starch. Raw starch present after cooking remains through further processing and shows up as white spots in the finished flakes.

When the cooking time cycle is completed, the steam is turned off, and the vent opened to help reduce the pressure inside the cooker back to the ambient pressure and cool its contents. The exhaust may be connected to a vacuum system for more rapid cooling. The cooker is carefully uncapped and the rotation restarted. Cooker operation, venting, and exhausting are covered in some detail in Chapter 3.

Dumping

The cooked food is dumped onto a moving conveyor belt under the cooker discharge. Dumping creates an interesting processing problem—that of placing a properly cooked batch of grain, which is optimum at time zero, into the slower continuous flow in the next steps of the process. A batch of cooked corn grits can be dumped from a cooker in about 7 min, but no dryers in the industry can dry them to flakable moisture in 7 min. Almost all processors therefore face the problem of how to get the cooker empty, cool the cooked material to stop the cooking action, and space that material out in a uniform flow to feed a dryer and cooler of reasonable size. While this is being done, the cooker may be needed for the next batch, with its own loading time, steam come-up time, 2-hr cooking time, steam exhaust time, and dump time.

The most common method of solving the dumping problem is to spread the cooked food out over a large area. Some spread it on wide, slow-speed conveyors under the cookers. Others spread it over large areas of perforated plates, with air blowing up through the perforations; these can be stacked to save space and are sometimes agitated.

Delumping

Once on a moving belt, before they are conveyed to a dryer, the cooked grits pass through delumping equipment to break the loosely held-together grits into mostly single grit particles. Delumping is essential to obtain particles or agglomerates of grits small enough for good circulation of heated air around each particle for uniform drying. It may be necessary to accomplish delumping and cooling in steps to get good separation of the grits so that they are the optimum size for drying. In most cases cooling takes place first, to stop the cooking action and remove stickiness from the grit surface. Cooling is kept to a minimum, because in subsequent drying the product is reheated to remove moisture. Most cooling-delumping systems include screening devices. The most common are flatbed gyrating sifters or rotating-wire or perforated-drum screeners.

Drying

From the cooling-sizing operation, the grits are metered in a uniform flow to the dryer. The most prevalent dryer configuration is that of wide, perforated conveyor units passing through a surrounding chamber in which the temperature, humidity, and airflow can be controlled. Dryers and drying in general are discussed in greater detail in Chapter 4.

Drying corn grits is best done at temperatures below 250°F (120°C) and under controlled humidity. It should result in a minimum of skinning over of the particle surface, as this impedes the removal of moisture from the center of the grit. Controlled humidity prevents such case-hardening of the grit surface and greatly decreases the time needed for drying to the desired end moisture, usually 10–14%.

Cooling and Tempering

After drying, the grits are put through a cooler to bring them back down to the ambient temperature. Such cooling is usually done in an unheated section of the dryer itself. In certain hot climates or under certain plant conditions some refrigerated air may be required. If the grits are not properly cooled, they darken and lose quality during the next step in the process.

Tempering is merely holding the grits in large accumulating bins or another section of the dryer but under ambient conditions. This allows the moisture content to equilibrate among grit particles as well as from the center to the surface of individual particles. Other physical and chemical changes also take place within the grit components that affect the degree of blister development in the toasting operation. These are discussed in some detail in Chapter 5.

In earlier days of processing grits for corn flakes, before controlled-humidity dryers were available, tempering times were long—as long as 24 hr—to allow complete equilibration of moisture. Now, with controlled-humidity drying, tempering times have been reduced to a matter of hours. The moisture content at the end of tempering should be 10–14%.

Flaking

After tempering, the grits are rolled into thin flakes by passing between pairs of very large metal rolls. Flaking rolls are made of a variety of materials, including chilled iron, steel, and special alloys. They are fitted with a means of injecting cooling water and removing it once it has served its purpose of taking up heat generated by flaking. Usually, chilled water at a controlled temperature is injected into the shaft at one end of the roll, and the used, heated water is removed from the shaft at the other end. In some rolls, the flow of water through the roll is accomplished by a continuous spiral groove channeled in the interior surface of the roll from one end to the other. Flaking rolls and flaking are discussed in detail in Chapter 5.

Tremendous pressures are necessary to flatten the grits into flakes. For normal-sized rolls, 20 in. in diameter and 30 in. long (50 × 75 cm), these pressures are on the order of 40 tons (36 tonnes metric) (Matz, 1959).

For normal flaking of corn grits, a good temperature at the roll surface is 110–115°F (43–46°C), as measured after the rolls have been used for about 1 hr and are evenly warmed up. Temperatures much over 120°F (50°C) cause excessive roll wear and sticking of the product to the roll surface. Cooling the rolls to temperatures much below 110°F (43°C) is not necessary, as it does not prolong roll life to any great extent and requires excessive amounts of chilled water. Colder roll surfaces also lack the "grabbing" ability needed to draw the grits into the roll nip, or area where the rolls are closest together.

The moisture content at the time of flaking is most important and has a great bearing on the blister formation, or *development,* of the finished flake. The moisture and the matching oven temperature profile are the two main determining factors in good development, which is generally best in the 10–14% moisture range. To flake cooked corn grits at this low moisture content, it is necessary to steam them or otherwise heat them just sufficiently to make their surfaces sticky enough to allow the rolls to grab them and draw them in.

Roll knives are used to scrape the flakes off the rolls. They must be kept sharp and properly mounted. Roll knives are described more fully in Chapter 5, which also explains roll-feeding devices. These are necessary to maintain a uniform feed of grits, evenly spaced across the whole width of the rolls.

Older-style rolls with babbitt bearings roll on the order of 150 lb (68 kg) of flakes per hour. This tonnage was well matched to the capacity of old-style, direct-fired rotary toasting ovens. Modern rolls, with roller bearings in place of babbitt bearings, can roll between 400 and 1,200 lb (180–550 kg) of flakes per hour; the flakes are then toasted in indirect-fired ovens within which the temperatures are closely controlled.

Flaking rolls are mounted in close proximity to the feed end of the oven, usually on the floor or a mezzanine above. It is not unusual to have two pairs of rolls (two-roll stands) feeding one oven.

Toasting

Flakes are usually toasted by keeping them suspended in a hot airstream rather than by laying them out on a flat baking surface like those used for cookies and crackers. The classical flake-toasting oven is a rotating perforated drum, 3–4 ft (1.0–1.25 m) in diameter and 14–20 ft (4–6 m) long, mounted in an insulated housing. Once matched to the product type and the production rate, the speed of rotation of the drum is rarely varied.

The oven slopes from the feed end to the discharge end. It is important for the slope and the speed of rotation of the drum to be adjusted so that the flakes remain suspended in the air as much as possible and are not thrown out so that they stick to the inside of the drum. The perforations should be as large as possible for good airflow but small enough that flakes do not catch in them and remain there until they burn.

Properly toasted flakes have the correct and desired color and moisture content. Color can be checked visually by the oven operator, and excellent color-measuring systems run by programmable logic controllers (PLC) or computer networks are also available. A standard acceptable range from too light to too dark can easily be established with these instruments. They may be read and the readings manually recorded on quality control charts on a regular basis, and closed-loop automatic recording and control are also possible with state-of-the-art instrumentation.

The moisture content of flakes is usually in the range of 1.5–3%. Checking is done both by feel and by moisture meter. Like color-measuring meters, moisture meters can be read and the readings recorded on quality control charts, or they can be linked to PLC and computer controls. Properly trained oven operators can become very expert at judging product quality, but the use of meters is strongly recommended for constant quality. For properly toasted corn flakes, oven temperatures in the range of 525–625°F (275–330°C) are usually employed, and the residence time is about 90 sec.

Another style of toasting oven also suspends the flakes in heated air, but they are carried through the oven by a vibratory trough from the feed end to the discharge. These ovens can be zoned or coupled together to provide varying oven temperature profiles for varying toasting effects. Oven styles are covered in greater detail in Chapter 5. Various aspects of nutritional fortification are discussed in Chapters 7, 10, and 11.

WHEAT FLAKES

The processing of wheat flakes is different from that of corn flakes because of differences between the grains. For corn flakes, the starting material is broken chunks of corn kernel endosperm from which the bran and germ have been removed, but for wheat flakes, the starting material is whole wheat kernels with all seed parts intact (germ, bran, and endosperm).

Preprocessing

The object of the cooking process is the same for wheat flakes as for corn flakes: complete gelatinization of all the starch present and even distribution of the flavors (sugar, salt, and malt) throughout the individual kernels. This requires a preprocessing step before cooking, since the bran coat is a barrier that keeps the water and flavor materials from penetrating to the interior of the kernel.

The kernels are broken open by a process referred to as *bumping*; the grain is lightly steamed and then run through a pair of rolls to crush the kernels slightly. If the crushing and flattening are too severe, the resulting flour and fine material cause the cook to be excessively soft and gluey and difficult to process further.

Formulation

Wheat used for the production of wheat flakes is usually soft red or white winter wheat. Rarely is it necessary to pay premium prices for hard wheat for wheat flake production.

A typical formula for wheat flakes is as follows: bumped wheat, 100 lb (45 kg); fine-granulated sugar, 8–12 lb (3.6–5.5 kg); malt syrup, 2 lb (1 kg); salt, 2 lb (1 kg); and water sufficient to yield a cooked product with a moisture content of 28–30%, including steam condensate. The flavor materials and water can be made up in a master batch sufficient for multiple cooks, and aliquots then are weighed for each cook.

Cooking

The cooking and processing of the grain for wheat flakes is similar in many respects to the processing of corn grits for corn flakes. Yet there are significant differences, one of the first of which is in loading the cooker with grain and flavor syrup. For wheat flakes, this is typically done by metering the grain from a weigh scale and pumping the flavor syrup through a delivery hose located at the cooker opening, in such a way that the two streams commingle as they fall into the cooker. Once the cooker is loaded and capped, it is common practice to rotate it through four to six revolutions to mix the syrup more thoroughly over the grain before turning on the steam.

It is not necessary to fill the cooker as full as a cooker used for corn grits. If it is too full at the end of cooking, the wheat mass may pack in the cooker and not dump unless the operator digs at it manually to loosen it.

A steam pressure of 15 psi (1.0 bar) is sufficient for cooking wheat. At this pressure, batches can be thoroughly cooked in 30–35 min rather than the 2 hr necessary for corn grits. At the end of the cooking period, the cook appears different from a corn cook. Corn rolls from the cooker as individual particles, which can be broken apart very easily. Wheat rolls from the cooker in rather tightly stuck-together balls ranging in size from that of golf balls to that of soccer balls. The pulling and tearing action required to pull these balls apart calls for a delumping system different from that for corn flakes.

Lump Breaking

Lump breakers for wheat flakes are commercially made units usually consisting of a rectangular steel frame in which one or two horizontally rotating shafts or drums are located. In a one-shafted machine, a matching and intermeshing comb is mounted on the interior wall of the frame. The rotation of the drum forces the material through the comb, crushing it into smaller pieces as it goes. In a two-shafted machine, the shafts usually rotate toward each other at differential speed, with projections on each intermeshing, thus tearing and crushing the material. Details on lump breakers are outlined in Chapter 3.

More than one lump breaker is usually necessary in a wheat flake line, with those closest to the cookers performing the coarse breaking and those farther downstream performing the finer crushing. Screening operations between lump breakers separate properly sized material from the stream and return oversized material for further size reduction.

Large volumes of air are drawn over the product and through the lump-breaking equipment. This is needed to cool the cooked wheat back down to near ambient temperature and to skin over the individual pieces, so that they have a nonsticky surface. Wheat overcooked or too high in moisture becomes very sticky and difficult to process down to the size of dryable and flakable grits.

The desired grit size for flaking is about 0.375 in. (1 cm) in diameter, with some grits as small as 0.125 in. (0.3 cm) and some up to 0.50 in. (1.25 cm). The grit size range determines the bulk density of the finished, toasted flakes and is the biggest factor determining the carton weight of the packed product.

Drying

Drying cooked wheat grits is not unlike drying corn grits. Wheat grits are somewhat more fragile, and care should be taken not to beat them around mechanically to the point of generating fines that must be removed before flaking in order to maintain a correct bulk density of the finished product. Moisture is more easily removed from wheat than from corn. Excessive dryer temperatures have a darkening effect, which carries right through to the finished product. This is true of all grains processed for breakfast cereals.

The moisture content of wheat grits from the dryer should be in the range of 16–18%. This is noticeably higher than that of corn flakes, one reason being that wheat flakes, unlike corn flakes, do not blister appreciably during toasting and therefore are not dependent on moisture content. Wheat grits are agglomerated particles made up of smaller particles stuck together. If they are too dry (12–13% moisture) they shatter into smaller pieces when flaked, resulting in a finished product with higher bulk density. If the grits are too high in moisture content (19–20%), they are too sticky and gummy for flaking. The flakes stick to the roll surfaces and are very difficult to scrape off.

Cooling and Tempering

After drying, it is important to cool the grits well below 110°F (43°C) before binning them to temper. If they are too warm going into a temper bin, the result is continued darkening, which carries over to the finished product. Tempering can also take place in a section of the conveyor at the end of the dryer if good humidity control can be maintained there.

The temper time for wheat grits is generally shorter than that for corn and does not exert as great an influence on the texture and appearance of the finished product, since wheat flakes do not blister during toasting.

Temper bins come in various sizes and shapes. Most consist of sides mounted over a slowly driven conveyor belt. They are loaded from an overhead conveying system in such a way that they can be unloaded on a first-in, first-out basis. This is most important. Usually some kind of raking device is needed to loosen the grits into individual pieces again.

After tempering, it is necessary once again to sift to remove fines and oversized grits. The latter are processed by a lump-breaking device and then resifted. The fines from this operation, plus those from other parts of the process and from packaging, are collected in a sanitary manner and added to subsequent cooks with new raw materials. If the amount of fines reworked in a cook is larger than about 100 lb (45 kg) in a 1,000- to 1,500-lb (450- to 700-kg) cook, a decrease in the consistency and the color quality of cooks and flakes is noted, to say nothing of the inefficiency involved.

Flaking

Good-quality wheat flakes can be made without any further pretreatment of the grits before rolling and toasting. Since the physical composition of the bran particles in the grits is so different from that of the endosperm, there are many points in the flake for uneven heating and drying during toasting. This characteristic improves the texture of the finished flakes, since it causes them to curl during toasting. A slight to moderate amount of curling is desirable, making the flakes appear more appetizing and interesting. If the flakes are perfectly flat, they lack interest, and they tend to lie flat in the carton, resulting in an excessively high net weight.

The curling points in wheat flakes are at interfaces of materials of different composition (bran and endosperm), slightly different moisture levels, or different rates of heat transfer. The moisture content of finished toasted wheat flakes should be 1–3%. Essentially everything already said about the toasting of corn flakes also applies to wheat flakes.

RICE FLAKES

The processing of rice flakes differs in only minor ways from that of corn flakes and wheat flakes.

Formulation

Rice flakes can be made from head rice (whole grain) or second heads (broken pieces of whole kernels). From an economic standpoint, the latter are preferred. Whole grains are preferred for oven-puffed rice cereals, in which each kernel forms an individual piece of finished, toasted cereal, as described later in this chapter.

The broken grain size used is referred to in the U.S. standards for milled rice as second-head milled rice. The smaller sizes of broken kernels, referred to as brewers' rice, can also be used, but they may not be available, because of demand by the brewing industry.

A typical formula for rice flakes is as follows: second-head rice, 100 lb (45 kg); fine-granulated sugar, 8–12 lb (3.6–5.5 kg); malt syrup, 2 lb (1 kg); salt, 2 lb (1 kg); and water sufficient to yield a cooked product with a moisture content of about 28%. The flavor materials and water can be made up in a master batch sufficient for multiple cooks, and aliquots can then be weighed for each cook.

Cooking

Cooking of rice grits is similar to that described for wheat flakes, except that the cooking time is 60 min at a steam pressure of 15–18 psi (1.0–1.5 bar). Moisture control and the sugar content are more critical in rice cooks than in corn or wheat cooks. Moisture contents much over 28% at the end of cooking render the cooked rice extremely sticky and difficult to handle through the cooling, lump-breaking, and initial drying phases. Likewise, sugar amounts much over 20 lb/100 lb (9 kg/45 kg) of rice cause excessive stickiness.

Lump Breaking and Drying

Lump breaking and drying in the processing of rice flakes are similar to these steps in the processing of wheat flakes. The properly sized grit for drying, tempering, and flaking is an agglomeration of many individual pieces of broken rice that have been stuck together by the cooking action. The identity of the individual pieces of broken rice is not lost, and it is maintained throughout cooking and subsequent steps.

Because of this grit construction, cooked rice grits must be handled more gently than corn grits. If handling is too rough, excessive amounts of broken grain pieces are abraded into useless fines, which have to be reworked or used in other products.

The drying time of rice grits is longer than that of wheat and more like that of corn. At the end of drying, a desirable moisture for flaking is 17%. If the moisture content is too low, the grit shatters during flaking, and small flakes are produced as a result. If the moisture content is too high, the flaking rolls gum up.

Cooling and Tempering

Cooling and tempering in the processing of rice flakes are similar to these steps in the processing of wheat flakes and corn flakes.

Toasting

Toasting rice flakes requires more heat than toasting wheat flakes. The moisture content of the entering flakes and the heat of the oven must be such that the flakes blister or puff during toasting. If they do not, they become excessively hard and flinty. Blistering is usually accomplished by having the feed end of the oven hotter than the discharge end. As with wheat and corn, the moisture content of the finished rice flakes should be in the range of 1–3%.

EXTRUDED FLAKES

Extruded flakes differ from those made by the traditional process in that the grit for flaking is formed by extruding the mixed ingredients through a die hole and cutting off pellets of the dough in the desired size. A typical process using wheat as the basic grain is described here.

Formulation

A typical formula might be as follows: whole wheat kernels or whole wheat flour, 100 lb (45 kg); sugar, 8–12 lb (3.6–5.5 kg); salt, 2 lb (1 kg); malt syrup, 2 lb (1 kg); natural or artificial color as desired; and water sufficient for pellet formation and cooking.

Color is added to the formula for a definite reason. In the traditional process for corn flakes and wheat flakes as described in previous sections, mechanical working or shearing of the ingredients is kept to a minimum by the very nature of the processing steps. The resulting flakes have a brightness of color, called *bloom,* which makes them attractive and appetizing. When the ingredients are processed in extrusion systems, more mechanical working takes place, and the resulting flakes can appear dull in color, even slightly gray. This effect is increased if the formulation is low in sugars or does not contain malt syrup as a source of reducing sugars to participate in the Maillard browning reaction. A small amount of natural or artificial yellow color can partially overcome this effect.

Mixing and Extruding

If whole wheat kernels are used, soft red or white winter wheat is preferable. The extruder elements are set up in such a way as to knead or crush the wheat early in its path through the unit. Also early in the extrusion process, the flavor solution is added directly to the barrel of the unit by means of a metering pump. Sometimes it is preferable to hold out some of the water from the flavor solution and add it by means of a separate metering pump system. In this way, the moisture content and consistency of the extruded pellet can be controlled without altering the flavor and color elements in the dough. Heat input to the barrel of the extruder near the feed point is kept low to allow the mixing of the ingredients before too much cooking and gelatinization start. Heat is applied to the barrel to accomplish the cooking. Very close control of temperatures is necessary. Chapter 6 and a section of Chapter 3 deal in greater detail with the extrusion process.

The last section of the barrel, directly behind the die, is usually cooler than the center sections. The dough, as it extrudes from the die, therefore remains in a compact form rather than expanding due to moisture flash-off. A knife rotating against the die severs the extrudate into pellets about 0.25 in. (0.6 cm) in diameter and 0.375 in. (1 cm) long. The moisture content of these pellets is usually 22–24%. If it is much higher than this, they are too gummy for good cutting. The moisture content can also be lower, depending on the equipment used. If it is possible to achieve complete cooking and flavor development at moisture contents in the range of 17–18%, so much the better, since this eliminates a drying step otherwise necessary before tempering, flaking, and toasting.

Flaking and Toasting

Tempering the extruded dried pellets is necessary only if there is a great difference between their surface moisture and their internal moisture. In some cases it may be desirable for the outside to be drier or slightly skinned over, because the dry skin forms interfaces with the more moist portions, and the flakes twist and curl at the interfaces during toasting. This skimming-over step is sometimes referred to as "conditioning." If the moisture is very uniform throughout the pellet, flat, poker-chip-like flakes result.

Flaking and toasting the pellets is accomplished as explained in the traditional manufacture of corn flakes and wheat flakes.

Gun-Puffed Whole Grains

Gun puffing of whole grains is a very interesting process. Two things are necessary for grain to puff—the grain must be cooked, and a large, sudden pressure drop must occur in the atmosphere surrounding the grain. As steam under pressure in the interior of the grain seeks to equilibrate with the surrounding, lower-pressure atmosphere, it is released.

Grains Used

Rice and wheat are puffed as whole-kernel grains and marketed as puffed rice and puffed wheat cereals. Other cereal grain materials, such as corn and oats, also are used for puffing, but not as whole grains. These are discussed later as extruded gun-puffed cereals.

The rice used for puffing is either long-grain white rice or parboiled medium-grain rice. Other than normal milling to produce head rice, pretreatment of the grain before puffing is not needed. Milling should be such that the fat content of the rice is reduced to 0.5–1.5%. In batch guns, as manufactured by the Puritan Manufacturing Company, in Omaha, Nebraska, a small amount of water is added to the grain to generate steam for puffing.

The wheat used for puffing is generally hard wheat, preferably durum. In the trade, such wheat is known as *puffing durum,* implying that the wheat has been specially sized and cleaned so that the range of individual kernel sizes is as small as good economics allows. Puffing durum carries a premium price because of this extra cleaning and sizing.

Pretreatment

Unlike rice, wheat requires a pretreatment step to avoid loosening the bran from the grain in a very ragged, haphazard manner, with some of it adhering and other parts being blown partially off the kernels.

One form of pretreatment is to apply about 4% saturated brine solution (26% salt). The water is used to generate steam for puffing. The salt toughens the bran during the preheating time and makes it adhere to itself better and become less fragile. The puffing action then blows the bran from the grain, resulting in a much cleaner-appearing and more appetizing puffed product.

Another form of pretreatment involves removing part of the bran from the grain altogether before puffing. This is accomplished by pearling, just as is done for the removal of rice bran in the manufacture of white rice. The grain is passed through a machine in which revolving, high-speed silicon carbide or Carborundum stones are mounted. These vary in grit size, depending on their position in the unit—the coarser being closer to the grain inlet, and the finer closer to the grain outlet. The bran coat is abraded off the kernels, and the bran particles are removed by air suction and deposited in a dust collector. About 4% of the kernel weight must be removed by pearling to make a good-quality puffed wheat.

Puffing

In batch puffing, single-shot guns (some of which may still be in use) are heavy-walled steel vessels capable of withstanding pressures in excess of 200 psi (14 bar), with an internal volume of 0.4–0.5 ft^3 (0.01–0.015 m^3) (Figure 1).

The opening through which the gun is loaded with grain, and through which the grain is fired at puffing time, is closed and sealed with a lid operated by a system of levers and cams. At firing time this cam system allows the lid to be opened instantly. Heat is applied by means of gas burners with very hot flames impinging on both sides of the gun. During the heating cycle, as the gun rotates on a shaft mounted on each side of the gun body, the moisture in the grain and any added before gun loading is converted to steam. When the lid is opened to fire the gun, the internal pressure is released, and the puffed grain is caught in a continuously vented bin (Figure 2). A typical cycle for a batch firing is given in the accompanying box.

The operation of puffing guns can be dangerous if strict safety precautions are not adhered to. Operators should wear full safety face shields at all times. The firing noise is very loud, and so suitable ear protectors should be worn at all times. Diligence must be shown by operators to be sure that pressure gauges and safety valves are in proper working condition and that guns in operation are not allowed to exceed the desired firing pressure of 200 psi (14 bar). Lid seals and locking cam devices must be kept in good working order at all times,

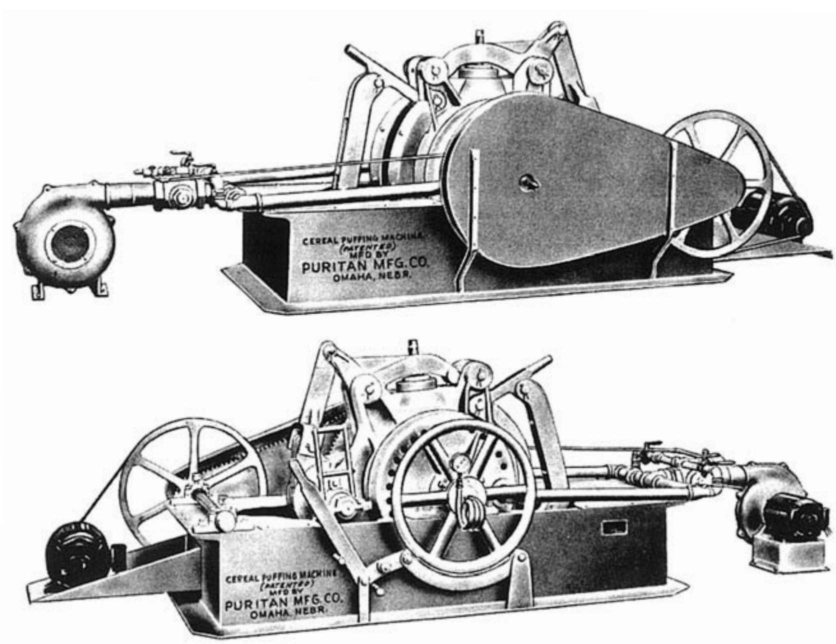

Figure 1. Single-shot cereal-puffing gun: drive side (top); operating side (bottom). (Courtesy Puritan Manufacturing Co.)

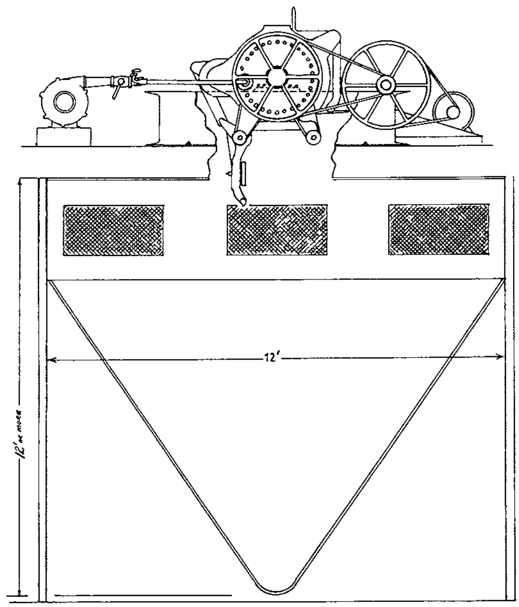

Figure 2. Vented bin for puffed grain, with a single-shot gun in shooting position. (Courtesy Puritan Manufacturing Co.)

Typical Cycle for Batch Puffing

Preheat the gun body to approximately 400–500°F (200–260°C).

Apply 0.8 lb (0.36 kg) water to 20 lb (9 kg) of rice or pearled wheat and distribute it uniformly over the grain.

Load the wetted grain into the gun.

Close and clamp the lid tightly with the cam and lever system.

Start the gun rotation.

Turn the gas flames on.

Monitor the gun until the internal pressure gauge reads 200 psi (14 bar).

Stop the gun with the lid pointed in the appropriate direction for catching the puffed grain.

Turn off the gas.

Fire the gun by releasing the firing lever on the lid cam system.

Catch the puffed grain in a continuously vented bin (Figure 2).

or misfires are apt to occur. Misfiring of guns at unexpected times can cause very serious injuries.

Automation

Another type of single-shot gun is automatic in operation. In these guns, the grain is preheated before being loaded into the gun. Steam is then injected into the gun body at 200 psi (14 bar), and the time then necessary to transfer heat to the grain and condition it for puffing is drastically reduced, from 9–12 min to as low as 90 sec. In most cases it is desirable to have about 100°F (55°C) of superheat on the 200-psi (14-bar) steam, to avoid producing excessively wet and soggy grain. Automatic puffing has been described by Maehl (1964).

Two other types of automatic gun are available that operate on the principle of preheating the grain before loading it into the gun barrel. One gun is made in Belgium and the other in Italy (Figures 3 and 4). The preheating devices are heat-jacketed screw conveyors. Following continuous preheating, the grain is delivered in measured amounts to the gun barrel and the valves are closed. The grain is then subjected to superheated steam, with or without agitation, for a short prescribed period of time, after which the discharge valve is rapidly opened, causing the grain to shoot from the gun barrel and expand many times, as explained earlier.

The grain is fired into a vented collection tunnel from which a bottom conveyor removes the puffed kernels continuously. All sequences of preheating time and temperature as well as residence time, pressure, and temperature are under PLC control. Guns and vented tunnel are enclosed in safety and sound suppression enclosures to reduce operator occupational hazards.

Multiple-Shot and Continuous Guns

In multiple-shot guns, multiple barrels are used on the same loading center and firing point. For any one barrel, the load, steam, and fire cycle is similar to that for the single-shot automatics, including the use of preheated grain, but several barrels are mounted on a slowly rotating wheel so that each passes the load and fire positions at the correct time, with steaming taking place in between. Such automatic batch guns also lend themselves to modern-day electronic process controls, which help remove the danger to operators through human carelessness.

Several methods of puffing grain continuously have been developed and patented (Haughey and Erickson, 1952; Perttula, 1966; Tsuchiya et al, 1966; Paugh, 1975; Dahl, 1976). These generally involve admit-

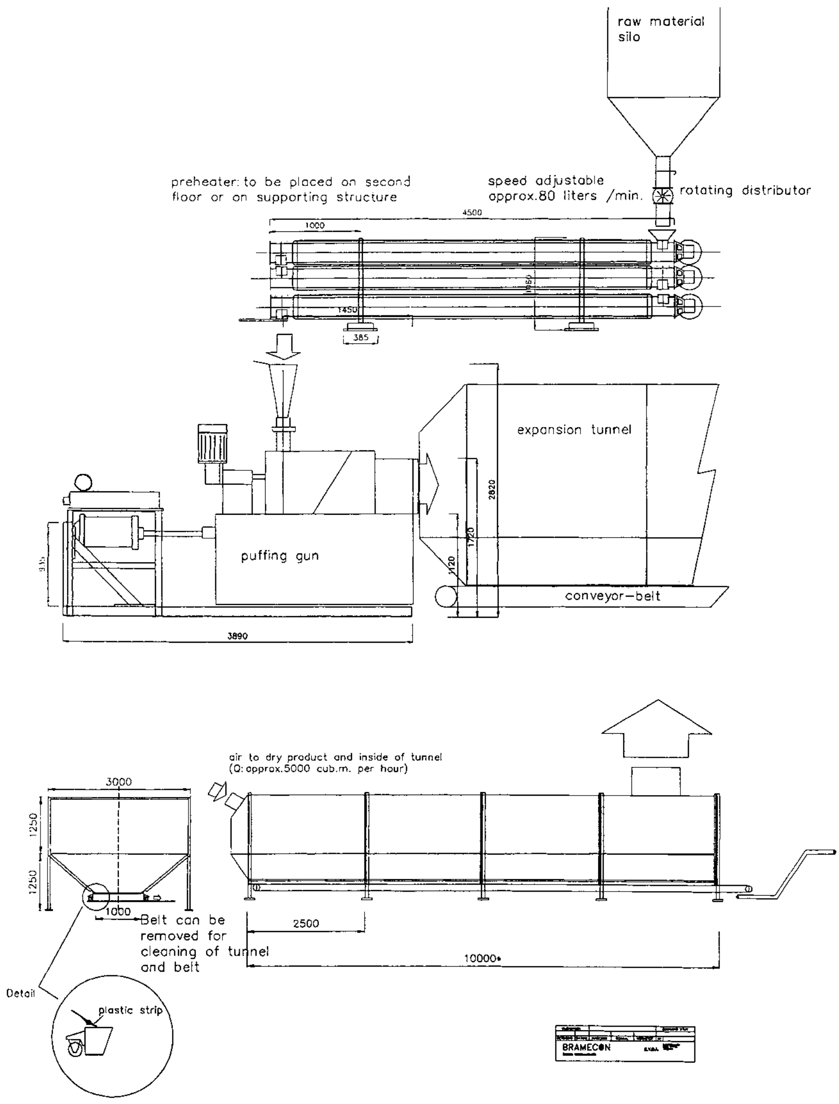

Figure 3. Schematic drawings of automatic preheater, puffing gun and expansion tunnel (top) and detail of the expansion tunnel (bottom). (Courtesy Incomec-Cerex)

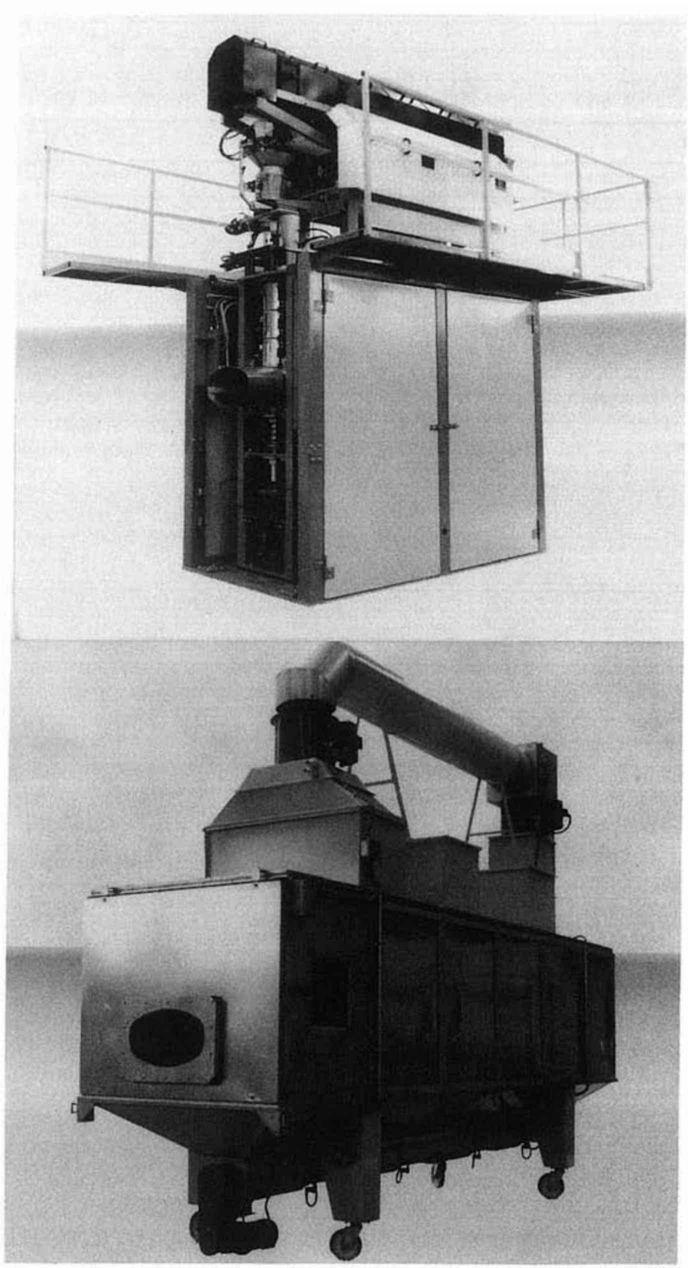

Figure 4. Photographs of Socori automatic puffing gun with top-mounted preheater (top) and of Socori expansion tunnel (bottom). (Courtesy Fell & Co. International, Inc.)

ting grain to an already steam-pressurized puffing chamber by means of a special valve and subsequently releasing the thoroughly heated grain to the atmosphere through an orifice without loss of pressure in the chamber. One such system is diagrammed in Figure 5.

Final Processing

After the puffed grain is caught from the puffing guns, it must be processed further before packaging. The first step is to screen the

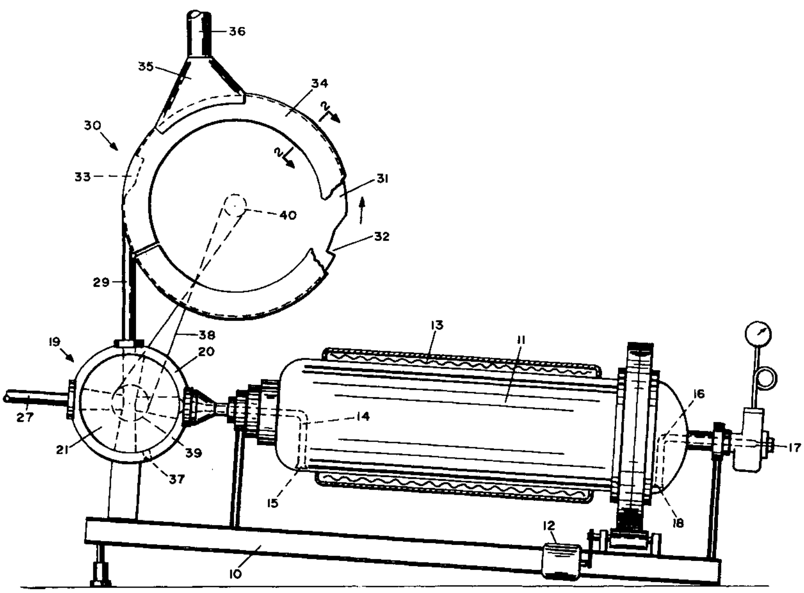

Figure 5. Apparatus for continuous puffing. Successive charges of preheated grain and pressurized steam are directed from a gravity-fed hood (35) by a centrifugal thrower (30) (which has two receiving pockets [32 and 33]) through a pipe (29) into one or another of the passageways of a rotary charging valve (21), from which they are directed successively through a fixed pipe (14) into a rotating pressurized chamber (11) equipped with electrical heating coils (13). The grain is further processed as it is moved to the lower end of the chamber by tumbling and mixing in the pressurized steam environment of the chamber. At the lower end, it is puffed as it leaves the high-pressure chamber through an orifice (17) into atmospheric pressure. A typical puffing chamber is 30 in. (0.75 m) in diameter, 50 in. (1.25 m) long, and has an orifice 0.5 in. (1.25 cm) in diameter. The centrifugal thrower is 36 in. (0.9 m) in diameter, turning at 72 rpm, and the charging valve rotor is 16 in. (0.4 m) in diameter, turning at 36 rpm. (Reprinted from Dahl, 1976)

product to remove unpuffed kernels, bran and dust particles, and small, broken puffed kernels. The moisture content of the grain from most guns is 5–7%, which is too high for a crisp cereal. Accordingly, the second step is to dry the grain down to 1–3% moisture. Since the grain is very porous, it takes up moisture very rapidly and easily, such that package materials with good moisture barrier qualities are needed.

Extruded Gun-Puffed Cereals

Extruded gun-puffed cereals originate from flours and not from whole grains. The cooking usually takes place in extruders. The cooked dough is then formed into the finished shape by means of extrusion through a die, with cooking and extrusion sometimes a one-step instead of a two-step process.

Mixing and Extruding

A typical sequence is as follows. First, the basic dry materials—flours, starches, and heat-stable microingredients—are premixed together in a uniform blend, and a solution of sugar, salt, malt, other flavors, color, and water is made up. The dry material is fed to a cooking extruder; the flavor solution is added through the barrel of the first section of the extruder, and more water is added separately. If the amount of flavor solution is kept in constant balance with the amount of dry blend, a constantly flavored and colored dough is produced. The separate addition of water can be adjusted as needed for extruder control and to compensate for minor fluctuations in the moisture content of the raw materials.

After the cooked dough exits the cooking extruder, it is fed to a forming extruder, which is usually controlled at noncooking temperatures below 160°F (70°C). The extruded shape here may not be the exact shape of the finished gun-puffed piece in miniature, because of differences in the expansion of its parts during puffing. The moisture content of the extruded cooked shapes is usually in the range of 20–24%.

Drying and Tempering

The next step after extrusion is drying and tempering, usually to a moisture content of 9–12%. The shapes are then gun-puffed as already described for whole grains. No pretreatment is needed, although with nonautomatic single-shot guns it may be necessary to add 2–4% water to assist in generating steam pressure. Most of these shapes puff adequately under pressures in the range of 150–200 psi (10–14 bar).

Final Processing

After puffing, the finished product must be screened to remove unpuffed shapes, broken pieces, and dust, and then it is dried to a moisture content of 1–3%, the normal level for a finished cereal.

Many gun-puffed extruded products are sugarcoated as well as nutritionally fortified before packaging. Sugarcoating and nutritional fortification are covered in detail in Chapters 7 and 10. Additives such as marshmallow bits in interesting shapes and colors may also be included.

Shredded Whole Grains

The grain used in whole kernel form for shredding is primarily wheat. White wheat produces shredded wheat biscuits that are light in color with a golden brown top and bottom crust when properly baked. Red wheats can also be used for shredding, but the shreds are more gray, and bran specks stand out more, because the bran is darker to start with. Rice, corn, and other grains also can be used for shredding; they are covered in the next section of this chapter.

The inventor of shredded wheat in rectangular biscuit shape was Henry D. Perky. His patent (U.S. 548,086), granted on October 6, 1895, was the first (Perky, 1895). Later in this section we will refer to patents for other than rectangular shapes.

Cooking

The process for shredding wheat begins with cleaning the wheat of all sticks, stones, chaff, dust, other grains, and foreign material. Once cleaned, the wheat is cooked in batches in excess water at slightly below the boiling point under atmospheric pressure. Cooking is achieved and stopped when the very center of the kernel endosperm turns from starchy white to translucent gray, which usually requires 30–35 min.

The cooking vessels usually have horizontal baskets about 3.5 ft in diameter and 8 ft long (1 × 2.5 m) that rotate within a stationary housing and are of sufficient size to hold approximately 2,900 lb (1,320 kg) of raw wheat. They are equipped with a water inlet and drains. The heating medium for the water is steam injected directly into the water inside the cooker. Water-temperature-sensing probes control the flow of steam to maintain the desired cooking temperature. The moisture content of the cooked grain at the end of the cooking cycle is 45–50%.

Cooling and Tempering

After the completion of the cooking cycle, the water is drained from the cooker, and the wheat is dumped and conveyed to cooling units. These can be vertical, louvered units through which air is drawn, or they can be horizontal, vibratory, perforated pans through which temperature-controlled air is circulated. Whichever is used, the objective of this step is to surface-dry the grain and cool it to ambient temperature, to stop the cooking process.

After cooling, the wheat is placed in large holding bins and allowed to temper for up to 24 hr before shredding. This holding or tempering time for shredded wheat was first noted in Henry Perky's patent in 1895. It allows the moisture in the kernels to fully equilibrate. The kernels become more firm, probably because of retrogradation of the starch (Jankowski and Rha, 1986). This firming of the kernels is vital for obtaining shreds of good strength for cutting and for handling of the unbaked biscuits. If the holding time is insufficient, the shreds will be crooked rather than straight, as well as gummy and sticky, and cannot be cut properly.

Shredding

In the shredding operation, the wheat kernels are squeezed between two rolls—one with a smooth surface, the other grooved. Although simple in concept, in actual practice this operation requires a good deal of skill and attention. The wheat is squeezed into the grooves of the grooved roll. Positioned against this roll is a comb, each tooth of which fits into one of the grooves in the roll. As the roll revolves with its grooves filled with cooked wheat, the comb teeth pick the wheat shred out of the groove. The shreds are laid down on a conveyor under the rolls running parallel to the shredding grooves. In the traditional process, each pair of rolls forms one layer of the finished biscuit.

Many different variations in rolls and grooving are used in the cereal industry today. Typical single-layer rolls are 4 in. long and 5 in. in diameter (about 10 × 13 cm), with up to 20 grooves per linear inch (8 per cm) of roll length. Some also have grooves running across the roll. The resulting cross shreds provide extra strength in the cooked wheat web.

Other variations include the shape and dimensions of the grooves themselves. Some are U-shaped, and others are V-shaped. They are generally 0.017–0.022 in. (0.43–0.56 mm) in width and depth, these being the determining factors of the texture and appearance of the finished biscuit. Grooves of different dimensions can be used on the same shredding line to maintain proper weight control of the unbaked and baked finished cereal. The roll size also varies depending on the output desired, the type of product being run, the power available to drive the rolls, and the composition and wear qualities of the roll steel.

With the two rolls touching each other, frequently revolving at different speeds, there is bound to be wear of the roll surface. As this occurs, the groove dimensions change, and so do the shred size, weight, and texture. The speed differential is usually in favor of the grooved roll by 4–20%, since the material being shredded has a tendency to stick better to the faster roll.

Roll surface temperatures at optimum shredding are in the range of 95–115°F (35–46°C). Sometimes it is necessary to water-cool the rolls to optimize the roll temperature.

Figure 6. Sixteen-station shredded wheat cereal biscuit forming line. This state-of-the-art line can produce 2,500 lb (1,135 kg) of dry, uncoated shredded wheat mini-biscuits per hour. (Courtesy Wolverine Proctor and Schwartz)

Forming Biscuits

If each pair of rolls lays down only one layer of shreds, 10–20 pairs of rolls are needed to produce a sufficiently deep web of shreds to form large shredded wheat biscuits (Figures 6 and 7). However, it is also possible and may be economic to use fewer and larger-capacity rolls operated so as to lay down the equivalent of several layers each. Bite-sized products require fewer layers (Figure 8). After the web of many layers of shreds reaches the end of the shredder, it is fed through a cutting device to form the individual biscuits (Figure 9). The cutting edges of the cutter are usually dull rather than sharp, so that the cutting action is in part a squeezing, which compresses the shreds and makes them stick to each other. This forms a crimped joint, which holds the shreds together in the biscuit form.

In the early 1900s, William Erastus Williams of Chicago, Illinois, worked out the details of machines that were capable of forming shreds into cup and round biscuit shapes. During the years 1906–

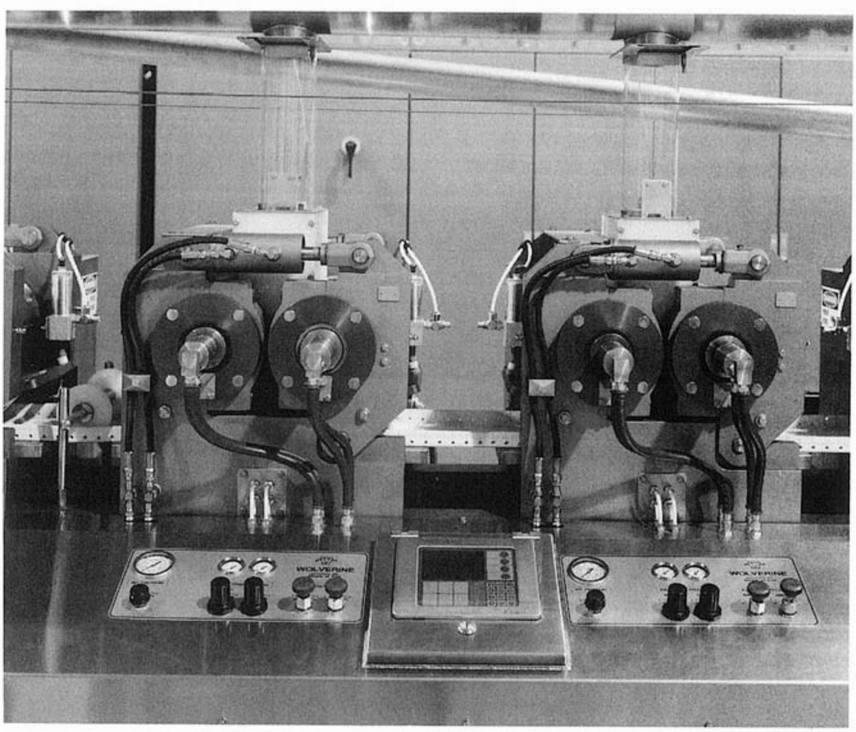

Figure 7. Detail of two shredding roll stations. Controls are at each roll stand and include a status monitor. (Courtesy Wolverine Proctor and Schwartz)

1911, he was awarded three patents for these units (Williams, 1906, 1909, 1911). The round biscuit shape is still being manufactured in Canada by The Quaker Oats Co. for sale there and in the United States. After the shreds are formed via conventional shredding rolls, segments of shreds are deposited in cups that are rotated to form the round shape. These biscuits have a somewhat different texture from that of the rectangular ones.

Baking

The individual biscuits are then baked in a band or continuous conveyor-belt oven. This is zoned and controlled so that the major heat input to the biscuits is in the first few zones, a rise in biscuit height occurs in the middle zones along with moisture removal,

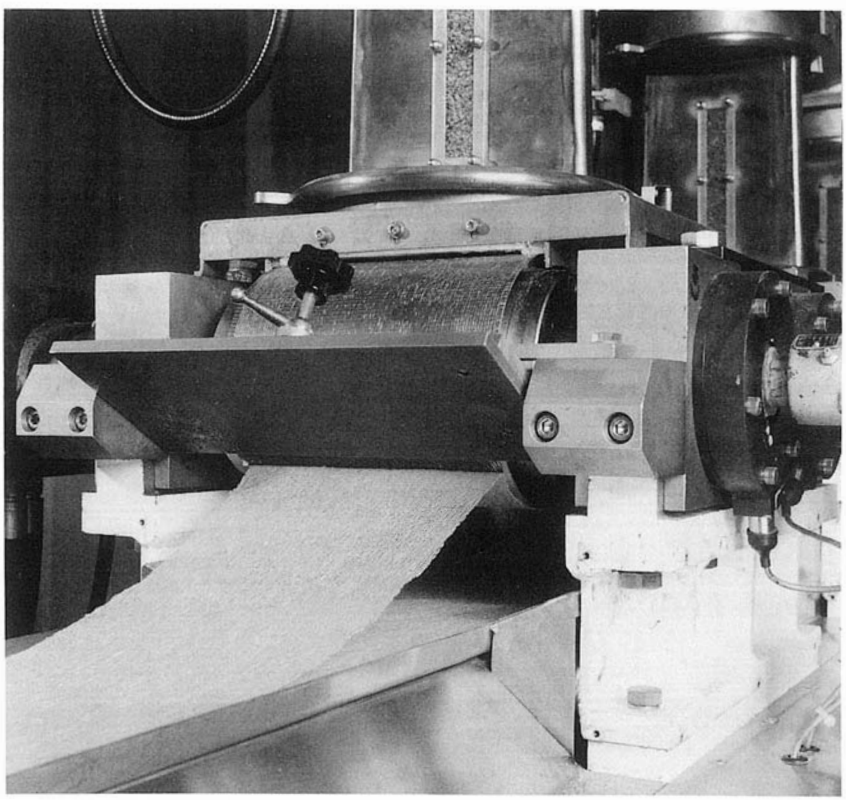

Figure 8. Close-up of top layer of shreds emerging from rolls and being laid down on previous layers. (Courtesy APV Baker)

and color development and final moisture removal occur in the last few zones. The temperatures are in the range of 400–600°F (200–315°C). The moisture content of biscuits going into the oven is usually about 45%, and the final moisture content out of the oven is about 4%.

Shredded wheat is susceptible to oxidative rancidity, so most manufacturers protect it by adding antioxidants via the package materials. This technology is dealt with in Chapters 9 and 10.

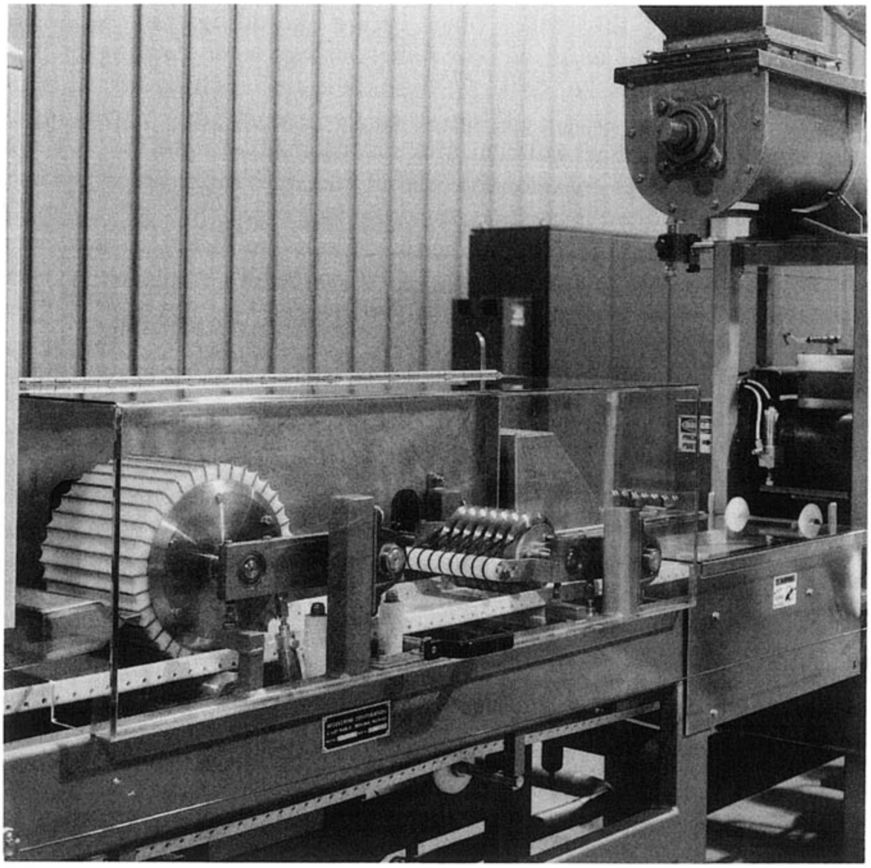

Figure 9. Finishing end of multiple-station shredded wheat forming line, including longitudinal and cross-cutting units. (Courtesy Wolverine Proctor and Schwartz)

Extruded and Other Shredded Cereals

Raw materials used for extruded and other shredded cereals are wheat, corn, rice, and oats—alone or in mixtures. These basic grains can be in the form of whole kernels, parts of kernels, or flours, depending on the product being made and the form of cooking used before shredding. Other ingredients also can be incorporated (e.g., starches, sugar, corn sweeteners, malt, salt, color, flavors, and vitamin and mineral fortification mixes), just as in extruded flaked or puffed products.

Pressure Cooking and Extrusion

The precooking that takes place before shredding may be either pressure cooking, as described for flakes, or extrusion cooking. If it is done in normal pressure cookers, there is a major difference in handling after cooking for shredding as opposed to flaking. Unlike flaking, in which flakes of uniform size are desired, shredding does not require any attempt to keep the size of the individual pieces within exact, narrow limits. It is necessary only to reduce the cooked lumps sufficiently in size that they can be cooled and can be fed uniformly to the nip of the shredding rolls. Extrusion cooking allows better control over the size of individual pieces, as determined by the cut at the die face of the extruder.

The moisture content of the cooked dough pieces for shredding is much lower than that of cooked whole wheat (25–32% for either pressure-cooked or extruded wheat vs. 45–50% for wheat atmospherically cooked for shredding). Normally no drying step is needed between cooking and shredding, but cooling is required to remove the heat of cooking and stop further cooking from taking place. Furthermore, in the case of pressure-cooked formulas, tempering is required after cooling. This allows the material to equilibrate in moisture content. The tempering time can range from 4 to 24 hr. Tempering is usually not needed for extrusion-cooked formulas.

Shredding

Shredding takes place much as already described for whole grain shredding. However, where wheat, corn, or rice with sugar, salt, and malt make up the formula, heat is generated in the shredding rolls at a much faster rate. Water-cooled rolls are essential unless roll pairs can be switched very frequently, such as every 1–4 hr. The heat is generated because the formula has a lower moisture content (30% vs.

45% for whole wheat shredding) as well as a tougher cooked mass at the time of shredding, compared with whole-cooked wheat.

Shreds from cooked dough are almost exclusively formed into bite-sized finished products, requiring many fewer layers of shreds. In corn and rice products, the number of layers can be as few as two to four, and in wheat and oat products four to eight. Usually these products are made with cross grooves on the shredding rolls. These aid in adding extra strength to the web of shreds and produce finished products with a more uniform appearance and fewer "crippled" or distorted pieces.

Cutting

Cutting is performed very much like the cutting of whole-grain products. The cutting edges are dull and squeeze the web of shreds together. After cutting, these products are usually baked while still tied together in sheet form. They tend to shrink in length and width during baking, and the shrinking helps to weaken the cut point and makes it very easy to break the individual pieces apart after baking.

Baking

Shredded wheat and oat products are usually baked in long, continuous band ovens, with bake times of 1–4 min. If the products are cut all the way through the web of shreds, they can be baked in a fluid-bed toaster in about the same time. The moisture content of the finished product should be in the range of 1.5–3.0%. As mentioned earlier, antioxidant treatment may be required, to protect the product against rancidity and ensure a reasonable shelf life.

Corn- and rice-based shredded cereals are toasted or baked in a more specialized manner. These shreds must be puffed or opened up during toasting. They become extremely hard and flinty in texture if they are not puffed. To achieve the puffing, the first part of the oven is usually at a lower temperature and dries the shreds. In the last half of the oven is a section of extremely high temperature (550–650°F, or 290–350°C), causing the rapid flash-off of the remaining moisture, thus puffing the shreds.

Oven-Puffed Cereals

Oven-puffed cereals are made almost exclusively from rice or corn or mixtures of these two grains. The two grains inherently puff in the presence of high heat when the moisture content is correct, whereas wheat and oats do not.

Formulation and Cooking

Usually medium-grain rice is the starting material for oven-puffed rice. It is pressure-cooked with sugar, salt, and malt flavoring for about an hour at 15–18 psi (1.0–1.25 bar). A typical formula is as follows: medium-grain white rice, 100 lb (45 kg); sugar, 6–10 lb (2.7–4.5 kg); salt, 2 lb (1 kg); malt extract, 2 lb (1 kg); and water sufficient to yield cooked rice at 28% moisture.

After cooking, the rice is conveyed through a cooling and sizing operation, which removes the heat of cooking and returns the rice to ambient temperature. It also breaks agglomerates into individual kernels.

Drying and Bumping

Drying is a two-stage process, with additional steps between the first and second drying. First, the rice is dried to reduce the moisture content from 28% to about 17%. Then it is tempered 4–8 hr, or long enough for good moisture equilibration. After tempering, it is bumped, that is, run through flaking rolls to slightly flatten the kernels but not make thin flakes out of them. Bumping presumably creates fissures in the kernel structure, which promote expansion at high oven temperatures. The thinner dimension also allows for faster heat penetration. Bumping is essential for proper puffing in the heat of the oven.

After bumping, the rice is dried a second time, to reduce the moisture content from 17% to 9–11%. This second drying is needed for good oven puffing, an operation that requires a proper balance between the grain moisture content and the oven temperature.

Oven Puffing

Generally, oven puffing is characterized by extremely high oven temperatures of 550–650°F (290–340°C) in the latter half of the oven cycle. Final toasting and puffing are accomplished in about 90 sec in rotary flake-toasting ovens or other fluid-bed ovens. After oven puffing, the cereal is cooled, fortified with vitamins if used, and frequently treated with antioxidants to preserve freshness.

Granola Cereals

While the term "granola" was coined by the Kellogg brothers at their Battle Creek, Michigan, sanitorium before 1900, the products made today are vastly different. The major raw material now used to make a granola cereal is rolled oats, either regular whole-rolled (the old-fashioned type) or quick-cooking oats. Mixed with the oats are other interesting raw materials, such as nut pieces, coconut, brown sugar, honey, malt extract, dried milk, dried fruits such as raisins or dates, water, and vegetable oil (Bonner et al, 1973). Spices such as cinnamon and nutmeg can also be added.

The water, oil, and other liquid flavorings are made into a suspension. The oats are blended with the other dry materials. The liquids and dry blend are mixed together in the proper amounts, and the wetted mass is then spread in a uniform layer on the band of a continuous dryer or oven (Figure 10). Small volumes can also be produced by spreading the wetted mass in a uniform layer on baking pans for batch baking.

Baking takes place at temperatures in the range of 300–425°F (150–220°C) until the mat is uniformly toasted to a light brown and moisture reduced to about 3%. After toasting, the mat is broken up into chunky pieces (Figure 11).

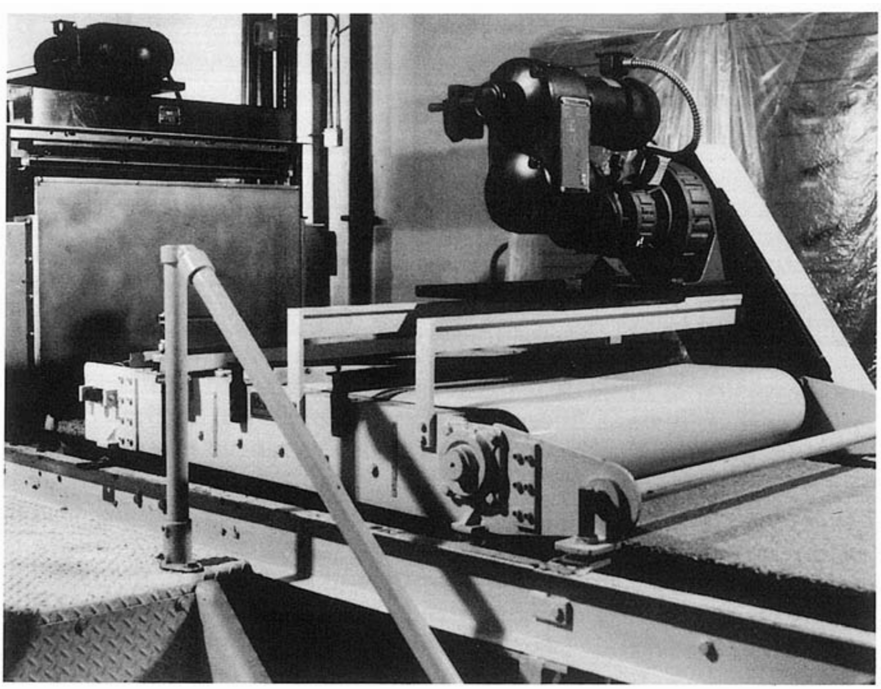

Figure 10. Detail of granola spreader and compression assembly. (Courtesy APV Baker)

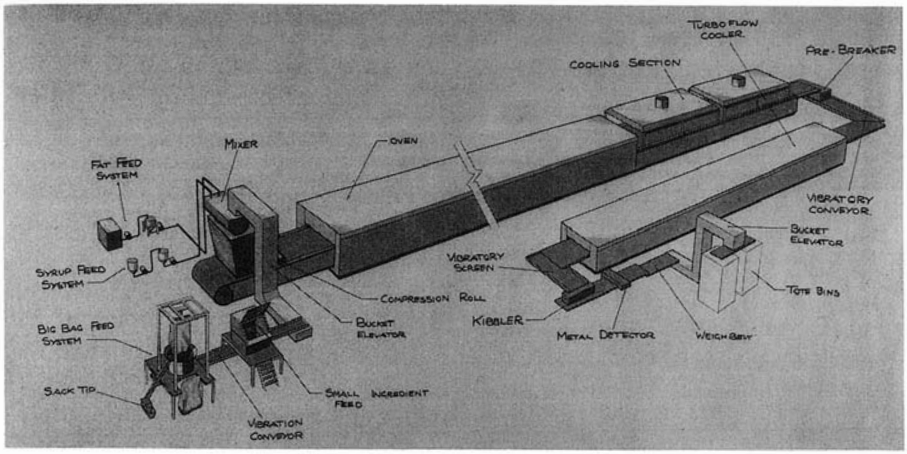

Figure 11. Diagrammatic sketch of a baked granola plant. (Courtesy APV Baker)

Since most of the granolas on the U.S. market are sold as "natural," they are not treated with antioxidants, nor do they contain artificial flavors or colors. Efforts have been made in the United States to reduce the fat content of granolas so they can be marketed as fat-free, reduced-fat, or low-fat products.

Extruded Expanded Cereals

The basic cereal processes of flaking, gun puffing, and oven puffing are methods of converting raw, dense grain (48 lb/ft^3) (7.7 kg/100 cm^3) into friable, crisp, or chewable products suitable for human food, with a bulk density in the range of 4–10 lb/ft^3 (0.6–1.6 kg/100 cm^3). Extrusion is merely another technology operating on a continuous basis for the conversion of basic dense grain formulations into light and crisp products that humans find enjoyable and nutritious. Typically, however, the grain in the formula for extruded expanded cereals is flour or meal rather than whole or broken kernels. Cooking with water and flavor materials is accomplished by means of a cooking extruder or the cooking section of a cooking-expanding extruder.

Once the formulation has received its cooking, either in the cooking section or in its own cooking extrusion unit, it is expanded when the moisture in the formula (whether natural or added) is released from a zone of elevated temperature and pressure to ambient conditions. Holes in the die at the end of the extruder control the shape of the finished cereal pieces once they are cut. The cutting of the expanded or expanding extrudate is usually done by a knife rotating on the outer face of the die. The extruded expanded pieces can be sugar-coated or colored and flavored to produce a variety of products for various tastes.

One early process for the production of an extruded expanded cereal was described by Fast et al (1971) and another by Rosenquest et al (1975). Many more exist. The use of extrusion for continuous cooking is covered in Chapter 3, and Chapter 6 is devoted in detail to extrusion and extruders in breakfast cereal manufacturing.

Baked Breakfast Cereals

Baked cereals were made before 1900, one of the early products being Grape-Nuts, developed by C. W. Post. The cereal was traditionally produced by baking loaves of bread that were cooled and ground to a granular form. The granules were then retoasted to the desired degree of flavor and moisture. The advent of twin-screw extrusion, enabling users to control and reduce the effects of gelatinization and shear, has resulted in these units being used in a continuous flow in place of loaf baking.

Another baked RTE breakfast cereal is made by the same rotary molding technology and equipment as are used by cookie manufacturers to form cookies of the shortbread or sandwich base-cake type. A dough made of ground grain materials, water, sugar, shortening, and flavorings is passed into the nip of two rolls, the rearmost of which carries around a layer of the dough mass and acts as a feeder to the front or die roll. The shapes to be formed are cut or engraved into the die roll in reverse. Running under (and compressed up onto) this die roll is a canvas takeaway belt or apron. The dough pieces in the die cups have greater adhesion to the canvas belt than to the die roll and are pulled away and deposited onto the apron. From there, they are transferred to the baking band of the oven and baked to final flavor and moisture.

Compressed-Flake Biscuits

Compressed-flake biscuits are just what the name implies—biscuits formed from the compression of previously cooked and flaked grains or grain mixtures with other ingredients. The flakes are usually made from wheat with added sugar, salt, and flavorings as described earlier in this chapter. One such product, made by Weetabix, Ltd., is well liked in the United Kingdom. Similar products are made in Canada and exported to the United States, as well as being made and marketed in Australia.

Although the manufacturing process is proprietary, examination of the products indicates that the wheat has been precooked with sugar and other flavorings, dried, tempered, and flaked rather thin before being formed into the biscuit shape while still untoasted. The biscuits could be molded individually or the flakes sheeted into a mat of the desired thickness and then sawed into individual rectangular biscuits. After initial formation of the biscuits, they are dried and toasted to the desired color, flavor, and moisture content. Radio frequency ovens may be used to extract moisture from the biscuit centers.

Muesli-Type Products

These RTE breakfast cereal types are mixtures of several ingredients. In Europe, the major ingredient is otherwise-unprocessed rolled oats of the quick-cooking type mixed with other flavoring components and intended to be served and eaten as is, after the addition of milk and sugar but without further processing. In North America, the grain components are usually corn, rice, wheat, and/or barley flakes that have been processed in the same way as for making separate RTE flaked breakfast cereals. Rolled oats can also be a component. Brown sugar, crystalline or liquid sucrose or dextrose, and corn syrup may be used for sweetening, while raisins; dates; almond, walnut, or pecan slices or pieces; and salt add interest and flavor appeal.

The RTE grain flake pieces are kept to a small size to deter separation of the raisins, dates, and nut particles. An interesting aspect of these products upon visual examination is that they are obviously mixtures of as many as six or seven dry components. All of these must be fed individually to the finished product stream in their correct proportions and mixed before packaging, such that the finished cereal appears uniform. Modern high-speed scaling units are responsible for most of this technology.

Filled, Bite-Size Shredded Wheat Biscuits

A more recent arrival in the bite-size shredded wheat category is fruit jam-filled pieces. Inserting the jam into the pieces is done between shredding the wheat and forming the biscuits.

Most bite-size pieces are composed of about 10 layers of shreds of cooked wheat. To make jam-filled pieces, four or five layers of shreds are progressively laid down on the belt below the shredding rolls. At that point, the belt enters a section where a manifold of small tubes, each about 0.25 in (0.6 cm) in diameter, is mounted over the web of shreds. The tubes are spaced so that they are aligned between the points at which the slitter wheels will eventually cut the finished web lengthwise. Through them the fruit jam is deposited onto the web of shreds, which then proceeds along the belt and receives an additional four or five layers of shredded wheat. Slitting and cross-cutting then take place as usual, and the product is baked in a band oven.

Breakfast-Cereal-Like Products for Ingredient Use

For many years, cereal grains were processed for use as ingredients in other products such as breads, soups, breading mixes, or confectionery. These products were typically pearled or steamed, cut into pieces, and flaked or otherwise processed via traditional grain-handling methods.

A notable exception was the processing of rice by the conventional breakfast cereal methodology of oven-puffing to make crisp rice for use in the chocolate confectionery industry. Rice adds crunchiness to some varieties of chocolate bars. This business has grown and expanded to a full line of such products from corn, wheat, and wheat bran as well as rice. They are used in breads, muffins, and snacks as well as replacing other higher-priced ingredients such as nuts and nut meal. Products can take the form of flakes, granules, or puffs and can be custom-tailored for specific applications such as use in frozen desserts and yogurt. Thus, uses for breakfast cereal technology (other than to make products for consumption at breakfast or bedtime) seem limitless.

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