Ready-to-Eat Breakfast Cereal Manufacturing: Use of Twin-Screw Extrusion Technology to Produce Multiple Products

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Breakfast is an essential part of a well-balanced diet. Nutritionists say it should represent 20–25% of the total daily energy consumption for children and 15–20% for adults. Today, dietary guidelines issued in many Western countries emphasize the need to include adequate amounts of whole grain and enriched cereal products to increase complex carbohydrates and fiber in the diet. The position of the bread and cereals group at the base of the U.S. Government’s food pyramid for good eating shows the importance of the grain-based diet. Breakfast cereals are just one of many forms of grain products that make it easier for each person to meet these recommendations (6).

Ready-to-eat (RTE) breakfast cereals are processed grain formulations suitable for consumption without any further cooking at home. They are relatively shelf-stable, lightweight, and convenient to ship and store. They are made primarily from corn, wheat, oat, or rice, usually with added flavor and fortifying ingredients. Breakfast cereals debuted at the end of the 19th century, and cereal styles advanced throughout the 20th century as manufacturers in Europe and America worked to develop new products and processes. As technology improved, the range of prepared cereals evolved from single cooked oats and cooked flaked corn to more sophisticated products including flakes and direct-expanded cereals. Today, breakfast cereals can be grouped into more than 12 general categories depending on their manufacturing processes: traditional flaked cereals, extruded flaked cereals (including rice, wheat, corn, and multigrain flakes), puffed whole grains, extruded puffed cereals, shredded whole grains, extruded and other shredded cereals, oven-puffed cereals, granola cereals, extruded expanded cereals, coflillet extruded expanded cereals, baked cereals, compressed flake biscuit, muesli-type product, and filled bite-size shredded wheat (4).

Since 1965, RTE breakfast cereal consumption has increased dramatically. The United States has the fourth highest per capita consumption rate of cereal in the world (behind Ireland, England, and Australia). It is estimated that over 2.7 billion packages of cereal are sold in grocery stores each year, which make it the third most popular supermarket product (behind carbonated beverages and bread). Over the past several years, a slight decrease of the sales volume has been observed. However, dollar sales show a continued growth (2002: increase of 0.2% with dollar sales at $6,855,412,224) as cereal companies successfully market value-added breakfast cereal products (7).

Clextral pioneered twin-screw extrusion technology for breakfast cereals in the early 1970s, introducing a process that was faster, simpler, and more economical than the traditional batch processes. The advantages of the twin-screw extrusion technology compared with the traditional processes are many and include: faster manufacturing times (30 min for extrusion cooking versus 6 to 7 hr for traditional process); reduced space requirements; continuous production system that can be automated; quick start up, shut down, and cleaning procedures; quick changeovers from one product to another; simplified maintenance; the ability to accommodate a very large range of processed raw ingredients; and consistency of product quality.

Analyses like rapid visco analyser (RVA) and texture and acoustical emission have been useful in the characterization of commercial corn flakes produced by a traditional process versus twin-screw extrusion technology. Thanks to these techniques, it has been demonstrated that commercial corn flakes produced by a traditional process and twin-screw extrusion technology present similar profiles and sensory analyses.

Twin-Screw Extrusion

Twin-screw extruders (TSE) are processing machines that consist of two identical corotating, intermeshing, self-wiping screw profiles operating within a closed barrel (3). During extrusion, the dough material is forced to flow under controlled conditions along the length of the extruder barrel and through a shaped opening (also called die assembly) at a defined throughput. TSE can perform various functions that include feeding, conveying, mixing, forming, compression, hydration, heat transfer, shaping, and cooking. Variables that influence extrusion processing can be separated into three main components: 1) raw materials composition and formulation; 2) thermomechanical cooking factors, including technology design (screw profile and L/D of the machine) and operating conditions (screw speed, temperature profile, water content, and dry mix rate); and 3) die texturization factors (die design, insert shape, and opening section). Using complex combinations of all these variables allows the production of a wide variety of products in a range of shapes, sizes, bulk densities, and textures.

Because of its operating mechanism, TSE offers many more advantages compared with single-screw extruders. The TSE is a continuous mixer/cooker/former that performs a positive pumping action; it can operate at high pressures and high moisture levels and does not rely on internal friction between screws and barrel to convey the cooked mass toward the die. It can process a variety of particle sizes and variety of raw materials composition while maintaining uniform product size and production flow (5).
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In addition to the basic features of the TSE, some extruder manufacturers offer additional opportunities to enhance flexibility, including the use of modular barrel designs, accurate temperature and shear devices, automatic barrel opening for easy access to screws, and computerized operation and control (Fig. 1).

**Direct Expanded and Indirect Expanded with the same TSE**

Products obtained with twin-screw extrusion technology can be divided into two categories: direct-expanded and indirect-expanded products. Direct-expanded products are extruded products that expand just after exiting the die because of moisture flash-off. The configuration for direct expansion requires a high-shear screw profile, high temperature, and low water content. Indirect-expanded products do not expand after exiting the die, but are expanded later in the process. Extruder configurations for indirect-expanded products usually includes a first step to perfectly cooking the starch components, followed by a cooling section that controls the expansion of the product at the end of the machine (1).

The change of configuration between direct-expanded and indirect-expanded products can be done very easily and quickly while performing other maintenance activities on the line. This change usually requires making slight changes to the screw profile, the die, and a few ancillary devices. These set-up changes are made very easily thanks to equipment features such as the hydraulic opening of the barrel, quick access to the screw profile, quick and automated change of die assembly, and quick adjustment of ancillary equipments.

Because of the versatility of twin-screw extruders, flaked or expanded products made from various grains are easily produced in the same plant using the same extruder and barrel configurations and ancillary equipment upstream (feeder, preconditioner, liquid injection) and downstream (flaker, toaster, coating unit).

There are several major steps in the breakfast cereal complete line process (2; Fig. 2).

**Raw Materials Handling and Premix Station.** Raw material handling presents a range of options from sack tipping to fully automatic bulk systems. Weighing platforms accommodate major and minor ingredients for weighing. Once the recipes have been chosen and the flours/grains and minor ingredients readied for use, it is usually necessary to blend the defined ingredients to obtain a homogeneous cereal mix. Typical mixers for dry mixes are ribbon mixers, also called horizontal batch mixers. The blender delivers the mix to a surge hopper, passes through a metal detector, and is fed continuously and uniformly to the extruder platform through a loss-in-weight feeder or a volumetric feeder. Today, weighing, assembling, inventory adjustment, and traceability of recipe/ingredients have been much improved by the use of programmable logic controllers and computer controls.

**Preconditioning.** Preconditioning essentially involves heating and prehumidifying the raw materials to initiate starch gelatinization. This process takes place in a...
preconditioner. This continuous piece of equipment has two shafts fitted with variable pitch blades that stir the material and move it toward the outlet. The shafts are usually contra-rotating. The configuration of the blades and the speed of rotation play an important role in the quality of the mixture dispersion. During preconditioning, the mix is humidified by spraying water into the preconditioner via nozzles. Other types of liquids (e.g., colors or malt syrup) can be added via different injection ports at different steps into the preconditioner. The mix is preheated at the same time by steam injection via multiple injectors.

Extruding, Forming, and Shaping. After preconditioning, the mix continuously enters the twin-screw extruder. Twin-screw extrusion cooks the ingredients with a combination of heat and mechanical shear. Water is added to reach the appropriate moisture content (15–25% depending on the product). The extruder is equipped with a high-shear screw configuration, that when combined with the screw speed variation (200–450 rpm), allows the right level of thermomechanical cooking on starch components. The time-temperature-shear history in the screw-barrel assembly determines the expansion ratio at the die as well as the textural quality of the final products. If desired, liquids may be simultaneously added through a metering pump to add specific characteristics to the final product. For example, in the case of crisp rice or corn flakes, sugar-based melt syrup is added along the barrel to reinforce the toasted taste of the end product. The temperature is accurately controlled in each section of the modular barrel by internal cooling channels and external heating elements.

The dough coming out of the die can experience different levels of expansion depending on the process conditions. It can be directly cut on the die face (usually for direct-expanded products) or indirectly cut using post-process cutting systems (usually for indirect-expanded products).

Tempering and Flaking (Flakes Only). In the case of a flaking process, a tempering zone may be added between the extrusion process and the flaking unit. This stage may be essential to separate pellets that would otherwise stick together and to allow control of the dwell time before flaking. Following the tempering unit, the pellets are flaked between two chilled steel rollers. Product specifications such as stickiness, thickness, and surface characteristics are controlled by adjusting the roll pressure on the product.

Toasting/Drying. Direct-expanded products exiting from the extruder or the flakes exiting from flaking rolls are typically fed into a dryer/toaster to reduce moisture content to 3% and to contribute a toasted flavor to specific products. With toasted products, an air-impingement dryer is usually chosen that fluidizes the product and optimizes the contact surface between hot air and cereal. Temperatures and residence times can be adjusted for each product. It is during this heat treatment that flakes develop their specific blistering, crisp texture, flavor, and color attributes. Direct-expanded products are traditionally dried using belt-drying technology, but can be also dried with an air-impingement drying technique. For specific products such as crisp rice, this technique allows a quick Maillard reaction to develop and contribute the right quality profile to the final product in terms of texture, taste, and surface color. Subsequently, dried cereals are conveyed to a sifter to eliminate fines and to the coating/cooling unit if necessary.

Coating. Dried or flavored products may be fed to a coating unit where a sugar-syrup preparation is applied in the required proportion (10–35% of the final product, depending on the country and type of products). The spray system of the coating equipment is designed to ensure optimum contact between product and sugar syrup. The temperature and Brix levels are adjusted to control the surface aspect of the coating (from shiny to glassy surface appearance, according to market requirements). Dry additives can be added simultaneously to sugar coats to fine-tune product characteristics.

Coating of products usually entails additional drying, in particular, drying of the thin layer of sugar-syrup applied to the products). This drying step can take place at the same time as the coating step (Coater-Dryer) or can occur continuously in an additional belt dryer, immediately after the coating.

Packaging. Before packaging, products are cooled to approximately room temperature by convective heat transfer. They are then packaged in the desirable package materials, thanks to multi-weighing units linked to vertical baggers and vertical cartoning machines.

Conclusion

According to one breakfast cereal manufacturer that uses twin-screw extruders, “We wanted a very flexible and multi-purpose line as we provide high quality direct expanded cereals, flakes cereals, and co-extruded products.” Because of the versatility of twin-screw extruders, flaked or expanded products made from various grains are easily produced within the same plant, using the same processing line from the initial mixing of raw materials to the final packaging steps. Simple clip-on modules can be easily and quickly added to this unique line, allowing a variety of innovative products such as multiple colors, multiple shapes, co-extruded, or multigrain products. Complete lines that use twin-screw extrusion contribute market reactivity and flexibility to cereal manufacturers, opening the door to short-term and reactive innovation.

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References