



HYDROTHERMAL PROCESSES INVOLVED IN CEREAL PUFFING

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1 OBJECTIVE AND PURPOSE OF THE HYDROTHERMAL PROCESSING OF CEREALS

Hydrothermal processes play a key role in the conversion of cereals into digestible and appetising food products that are suitable for both human and animal consumption.

Cereal products, as is widely known, consist largely of starch, the macromolecular structure of which makes it difficult or almost impossible to digest. The controlled supply of heat, combined with the moisture contained in the product and the targeted addition of further moisture to the product being processed, causes the macromolecules of starch to oscillate, which leads – during subsequent mechanical processing involving rolling, cracking or shredding – to varying degrees of disintegration. The starch is thus modified in such a way as to aid considerably the enzyme-actuated splitting that takes place in the digestive tract.

The classic hydrothermal techniques used in the processing of cereals include flaking, pellet-formation, extrusion and puffing. The last of these is the one that we will now examine in greater detail.

2 HISTORICAL BACKGROUND

The technique of puffing dates back to a process developed in 1901 by a Mr Alexander Pierce Anderson of Chicago, USA. However, it was not until the early 1930's that the first industrial puffing plants began to operate, almost simultaneously, in Norway and the United States.

The puffing process is based on the following physical principles:

If wheat or rice with a humidity content of 12% to 14% is placed in a sealed tube and heated over an open gas flame, the pressure within tube gradually rises. After 20 to 30 minutes, this pressure will have increased to about 12 bar. Abrupt opening of the tube cover causes the product within to shoot out with a detonation noise going off, whereas the instant drop in the pressure causes the water contained in the grain, to flash evaporate. This sudden release of energy detaches the starch molecules, culminating in the almost complete gelatinisation of the starch. The process also causes the grains of cereal to expand in volume to up to twelve times their initial size, although the grains retain their original shape. The cereal also acquires a pleasant, sweet to slightly nutty taste, which once resulted in most puffed cereals being supplied to the consumer without any further processing (such as sugar coating).

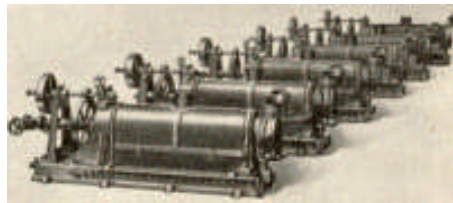


Fig. 1: Puffing guns, circa 1940



Fig. 2: Puffing plant, circa 1960

The cannon-like detonating sound caused by the process caused the technique to be known as “gun puffing” (figs. 1 and 2). Indeed, there are to this day puffing plants still being designed and built to operate at noise levels of 140 dB and over.

Unfortunately, these processes are not very efficient. As early as the 1940s in America the discovery was made, that the process cycle could be reduced to some six minutes' duration if saturated steam was injected directly into the gun.

In the early 1970s, additional preheating of the puffed cereal was adopted, thus allowing cycle times to be reduced to about four minutes.

This preheating was mostly carried out using inclined rotating flow tubes, which were heated from below with an open gas flame. With chamber lengths of 4 m to 10 m and diameters of 200 mm to 300 mm, it became possible to aim for retention times of four to six minutes with product temperatures of approximately 120 °C.



Fig. 3: Puffing system based on conventional techniques (some of which continue to be built today).

One of the factors involved, both with preheating and the puffing gun, was that the indirect supply of heat and very low amount of movement of the individual grains during the process led to them being subjected to widely varying hydrothermal conditions. The combination of an uncontrolled drop in pressure and the strong turbulence caused by the “shooting” of the grain resulted in highly inconsistent granule size distribution, which – depending on the quality specifications involved – led to yields of just 65% to 80%.

3 MODERN REACTOR-PUFFING

This unsatisfactory situation is what inspired the author of this article, in the mid-1990s, to develop a radical new process designed to optimise conditions for the puffing of cereals. The process, as illustrated in fig. 4, revolves around three connected subsystems:

- Preheater
- Reactor
- Expansion conduit

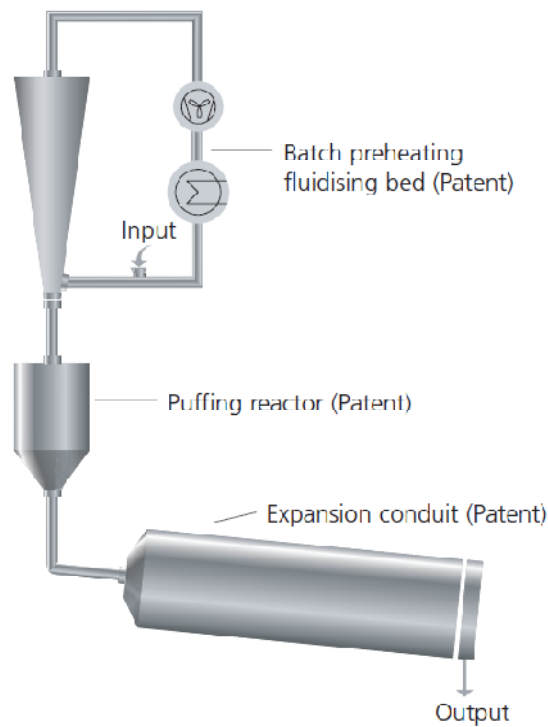


Fig. 4

The process is patent-protected in the western industrialised countries.

This new technique is characterised, along with fully automatic operation, by yields of over 95% and availability rates of 98% with respect to constant operation.

There are two levels of output:

- 350 kg/hr with single puffing
- 700 kg/hr with double puffing

3.1 PREHEATING

The objective of this procedure is to ensure the preliminary heating of the product to over 100 °C, without reducing the humidity content that is of vital importance to the puffing process. The whole procedure should take place during the same cycle as the puffing process (i.e. within about 90 seconds).

The indirect application of energy to the product in a heat chamber – as is the case with conventional puffing technology, for example – involves heating the outside wall of the rotating chamber with a gas flame. The transfer of heat from the outer wall to the product moving along the inside of the container takes a relatively long time, with a large amount of heat energy being wasted in the process. The main disadvantage is that there is no way to guarantee the consistent heating of the product, as the rotating mass of cereal grains is mixed in a relatively random way. This means that the starch in the grains that have more direct contact with the hot wall of the chamber is heated more than that contained in the grains that remain at the centre of the moving mass. The same applies to preheaters, which work by feeding hot air into an upright product-filled silo.

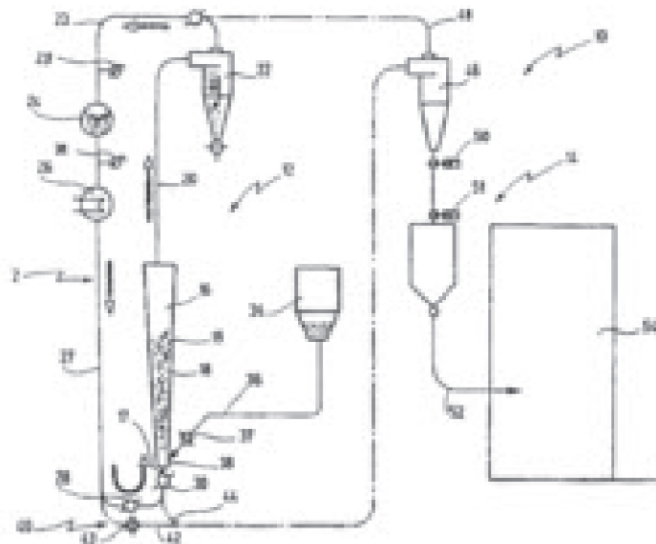


Fig. 5: Schematic illustration of the patented preheater used in the Bichsel System.

The patented Bichsel preheating system (see illustration) eliminates all these disadvantages at a stroke. In this invention the process is performed by a system where the heating device includes a free-jet fluidized bed without air dispersing bottom. One batch of the product being processed is heated by means of hot air of up to 170 °C, carried out in synchronisation with the puffing process. The air, which is in a virtually saturated state, moves around a closed circuit. The level of fresh air in the system is maintained at approximately 5% to prevent the outward condensation of moist air. The entire system is also fully heat-insulated.

The term “fluidized bed without air dispersing bottom” refers to a system in which a batch of the product being heated is blown by a powerful stream of the heat-conducting air, forming a radiating fluidized bed, which supposes no mechanical barriers to the free movement of the stream of material. There is no air dispersing bottom. The entry conduit is thus used as a blowing inlet.

This turbulent movement of the product caused by the heat-conducting air in the free-jet fluidized bed, ensures the separation and even dispersion of the individual grains. This hot air can then circulate completely around each individual grain, which leads to an efficient transfer of energy and fast heat-up times.

The free-jet fluidized bed thus permits immediate and intensive contact of the heat-conducting medium with the product being processed, ensuring efficient energy transfer without heat loss via the walls through which the transfer takes place, in the shortest possible time and in a consistent and reproducible way. The moisture that is required for the puffing process is retained, or can be set to an optimum level by adjusting the inflow of fresh air.

3.2 THE REACTOR

In terms of energy input, the puffing process requires about 250–300 kJ per kilo of product being puffed. This energy is supplied in the form of steam, which must be in a 100% saturated state for expansion to take place. If the process involves any condensate, the evaporation of each kilo of condensate requires approximately 4 kg of steam in addition. Even minute quantities of condensate therefore require the input of disproportionate amounts of energy, which has to be deducted from that used from the puffing process.

The presence of condensate in the puffing process leads to irregular puffing and soggy grains, with a consequent increase in the amount of waste.

In order to avoid the formation of condensate in a “cold” puffing product, the saturated steam has to be loaded with additional energy from an external source. This can be carried out as follows:

- with a gas flame or electrical heating element acting directly on the reactor tube, as is the case with conventional puffing guns/reactors, or
- by working with high-pressure, superheated steam, as with the CEREX process used by the Bichsel system.

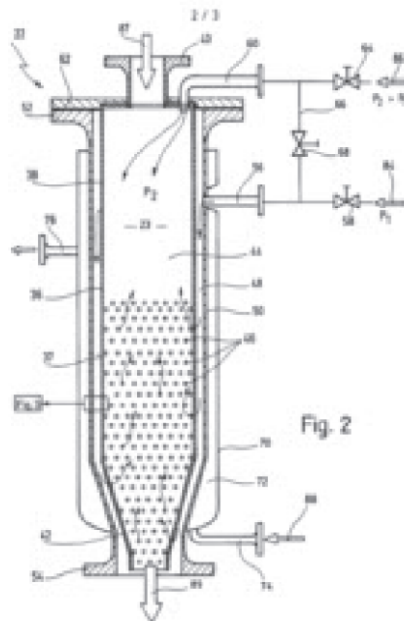


Fig. 6: Schematic illustration of the patented reactor in the Bichsel System.

In the CEREX puffing process used by the Bichsel system (see fig. 6), the invention meets all these requirements by ensuring that the product container has multiple perforations for the supply of energy-bearing superheated steam.

This is injected from outside – via inlets located all around the vessel – and into the product, where it is distributed evenly. This technique makes it possible to operate with shorter cycle times and, above all, to distribute the transferred heat around the product with greater consistency. At the end of the cycle, the processing steam acts as a propellant for the product in the silo during the “shot”, allowing the product to be pushed out of the reactor.

The slamming open of the cover and gun-like detonation that are typical for conventional systems are replaced with a fast operating valve. This eliminates the loud bang, allowing the product to flow out accompanied only by an externally audible hissing sound that does not exceed approximately 85 dB.

The reactor is dried by the surplus energy, and the inlets around the vessel are cleaned out by the superheated steam as it escapes under enormous speed. The reactor is thus cleaned out automatically between one shot cycle and another, a practice that has been tried and tested during the 24/7 operation of these systems over many years.

A further major advantage of the CEREX puffing technique over conventional puffing systems is the fact that all parts of the reactor can be heated to the maximum temperature of the superheated steam. Conventional systems, where the heat energy is provided externally by means of an open gas flame or electrical heating element, work with temperatures that overheat and scorch the puffed product grains that come into direct contact with the walls of the container, which results in inconsistent heating of the puffed product and the creation of soot particles. Depending on their size, these soot particles can then pass through the downstream inspection sieve and end up in the finished product.

The table below shows the levels of saturated steam and superheated steam for various different pressures. The readings have been rounded accordingly.

Superheating to approx. 300 °C	Pressure bar	Energy content before superheating kJ/kg	Energy content after superheating kJ/kg	Specific density kg/m ³	Evaporation heat kJ/kg	Evaporation heat kJ/m ³	Surplus evaporation heat at 15 bar (available heat) kJ/m ³
no	15	2800	2800	8.1	1930	15'500	0
yes	15	2800	3050	8.1	2180	17'700	2100
yes	20	2800	3050	10.5	2130	22'400	6800
yes	30	2800	3050	15.0	2030	30'500	15'000

Depending on the filling level, approx. 4–6 kg of steam is processed in the reactor during each cycle, thus supplying the system with about 5000 kJ of freely available energy.

As the table shows, this amount of energy is not obtainable at pressures of 15 or 20 bar. Condensate would be produced under such conditions, and the process would not take place correctly or would break down completely.

Indeed experience shows that the process is seriously affected at steam pressures of below 24 bar, and can no longer function at all if the pressure drops to below 22 bar.

The supply of energy exclusively by means of superheated, high-pressure steam is a special feature of the Bichsel process. Only in this way is it possible to keep the energy density up to a level that allows the four to six-minute cycles typical of traditional systems to be reduced to cycles of around two minutes' duration.

An additional benefit is that the fast, targeted transfer of heat and much higher yields delivered by the Bichsel process lead to a reduction in energy consumption of about 40%.

3.3 THE EXPANSION CONDUIT

The three main functions of the expansion conduit are:

- To supply a spatial and time dimension for the conclusion of the expansion effect during the shot procedure
- The capture and collection of the puffed product
- Absorption of the shock caused by the release of energy during puffing

While the conventional puffing process results, due to the slamming open of the cover, in the product shooting out of the cannon and into the adjacent expansion chamber, the controlled and time-limited exit from the reactor provided for by the CEREX puffing process of the Bichsel system ensures that the product does not swirl around out of control. The product flows through the expansion conduit as a steady stream to the outlet doors, where an air-suction system immediately picks up the puffed grains.

Flow turbulence is characterised by the familiar uncontrolled fluctuations in pressure, while a regular flow is accompanied by a constant positive or gently falling pressure.

In the CEREX puffing system, this smoothness of flow is provided by the reactor outlet orifice. The expansion process also begins as soon as this point is reached, and has shown to be complete by around the mid-point of the eight metre-long expansion conduit.



Fig. 7: Patented expansion conduit used in the Bichsel System.

With the conventional puffing process, there is no reliable evidence to show when and where the expansion process begins and ends. The fact remains that turbulence-based processes result in product settling everywhere along the length of the conduit, therefore worm and belt-conveyor systems are used to extract grains from the conduit. The humidity entering the expansion channel as a side effect of the puffing process almost always results in the formation of deposits in «dead» corners, both in the conduit itself and also in the discharge conveyors, which – given the temperature conditions and already existing humidity – provide an ideal environment for mould and fungi.

In this invention, the CEREX expansion conduit solves all these problems by using a drumshaped expansion chamber designed to rotate lengthways. The arrangement of horizontal ribs along the direction of flow prevents the product from forming deposits upstream of the expansion conduit outlet and promotes the axial flow movement towards the conduit outlet. The product flies through the expansion conduit following a practically concentric pattern, which ensures that its flow is laminar at virtually all times. The combination of complete drum insulation and the controlled passage of process steam, augmented by hot purging air, prevents any forming of condensation in the expansion conduit – even during longterm operation.



Fig. 8: Expansion conduit with open door.

3.4 SUMMARY

Successful cereal-puffing involves the synchronised interplay of three process stages:

- Preheating
- Puffing reactor
- Expansion conduit

The Bichsel system-based CEREX puffing process, with its patented preheater, puffing-reactor and expansionconduit subsystems (see fig. 9), fulfils all the requirements for a controllable, optimised system for the puffing of all types of cereal.

The advantages of the CEREX puffing process can be summarised as follows:

1. High yield (up to 95%)
2. High level of availability in 24-hour operation (up to 98%)
3. No expansion bang
4. Preheaters and reactors are self-cleaning
5. Simple operation: system runs without operator, requiring only monitoring
6. Pressure and timer curves are controlled by preset values for greater operating accuracy
7. Less wear
8. Consumable parts are readily-available standard items
9. Recipe programming ensures absolute consistency
10. No emission of unpleasant odours, as there is no uncontrolled overheating of the product
11. Preheaters, reactors and expansion conduits form a seamless, self-contained, dustproof system
12. The entire plant system is made of stainless steel



Fig. 9: Production-line view of a CEREX standard puffing system, ready for installation in a production plant.

4 OPERATION, MARKETS, MARKET OPPORTUNITIES

Puffed products take many different shapes and forms. The most widely known of these is undoubtedly puffed hard wheat with sugar coating, marketed under such well-known brand names as Smacks®, Sugar Puffs® and so on.

Other food-industry applications include puffed products in the form of rice, wheat, barley, etc. in the chocolate sector, in muesli-type breakfast cereals and in confectionary bars – often as easily-digestible “volume fillers”.

The great advantage of puffing is undoubtedly the fact that the products concerned continue to resemble very closely the original grain from which they are derived, even after the total breakdown of the starch contained in them and their expansion.

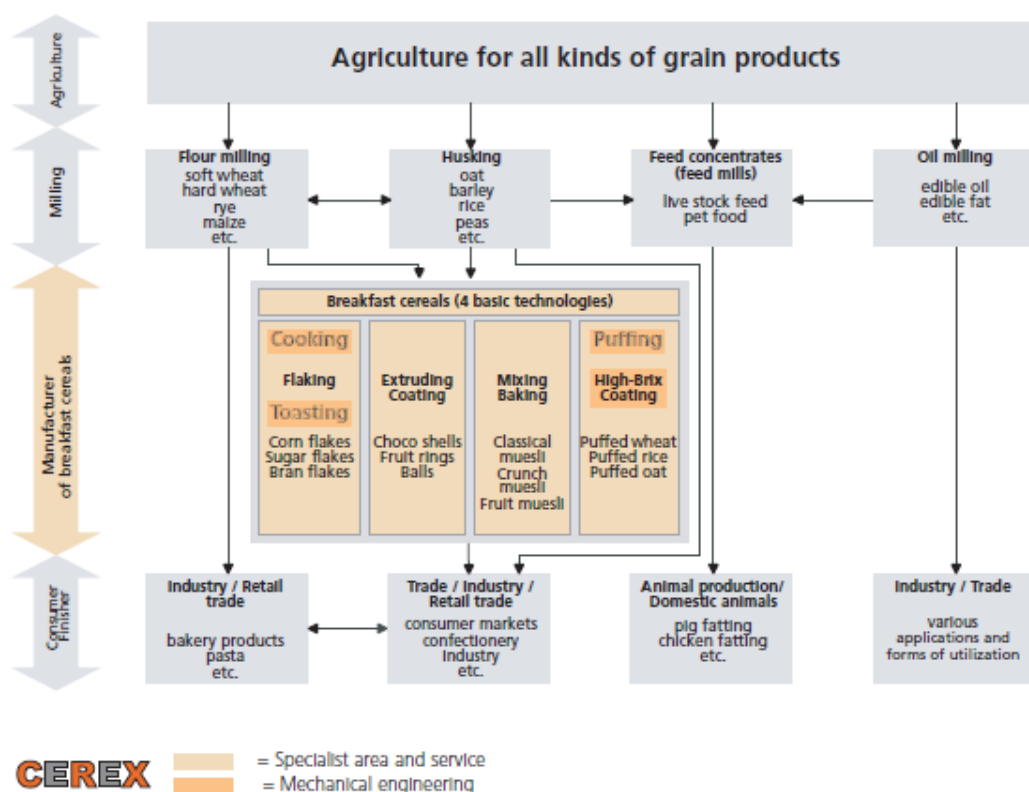


Fig.10: Basic technologies of cereal production

Puffing is in fact one of the classic basic processes of cereal manufacturing (see fig. 10). The high degree of complexity of the technology involved, and the low yields produced to date, meant that this method of cereal processing was until very recently (with the exception of the wheat-based sugar-coated breakfast cereals mentioned above) used relatively rarely in other areas.

Now however, thanks to the CEREX puffing process – which has been tried and tested in various sectors since 1997 – it is possible to achieve demonstrably high levels of availability, high yields, fully-automated operation and high quality standards for puffed products, which are becoming ever more popular among consumers.

Puffed products offer the manufacturer high added value. And CEREX puffing technology offers the chance to move into totally new areas of application, such as the puffing of tobacco stalks (a technique already in use) and the puffing of raw coffee beans, which is awakening the interest of the coffee-processing sector.

Yet another great area of promise for puffed products (both coated and non-coated) lies, thanks to the recognisable grain shape, in the organic-food sector. A marketing opportunity of recent years lies in the area of food for pets and horses, where the easily digestible and visually appealing properties of puffed grains help in their promotion as “healthy” feed products.