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High pressure processing of foods

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Introduction

Conservation of foods is an important step in their production. As a result of the longer stability and shelf life achieved in this way many degrees of freedom as regards storage, availability and product development result for both producers and consumers.

Some conservation methods alter the foods to such a great extent that a typical, new product emerges. Examples of this are heating, smoking, drying, and also fermentation. In other cases by contrast, it is desirable to retain the original freshness, so that gentle methods are needed. Accordingly, for instance freezing methods or the shortest possible introduction of heat are selected. Generally speaking, food conservation is an essential task that is being constantly developed further. In the last few years some new gentle methods have been introduced into the production process, one of the most outstanding of which is high pressure processing.

History

By high pressure processing (HPP) of foods, we understand the influence of pressures in the range of approx. 2,000 to 7,000 bar (200 MPa – 700 MPa) for a few minutes. HPP is not a new method in principle, but it has only been used to a greater extent in the past two decades. This method is known not only as HPP, but also as pascalization.

The idea of using not only temperature but also higher pressures was pursued already over a hundred years ago. For instance B.H. Hite was able to show the conserving effect of high pressure on fresh milk at the end of the 19th century. In the chemical industry pressure is frequently used as an influencing factor and is essential in a series of syntheses. Alongside the famous ammonia synthesis according to Haber-Bosch (140 to 200 bar), another method that can be cited here is the production of low density polyethylene (PE-LD), which takes place at 2,000 to 3,500 bar. Such high pressures between 1,000 and 4,000 bar are also applied to produce high-performance ceramics. The developments in the chemical industry and plant construction especially have led to matured high pressure installations being offered for the food industry today.

Effect

As described above, HPP is carried out at pressures from around 2,000 bar to 7,000 bar. The processing pressure is typically 6,000 bar. Such pressure corresponds to a weight force of 6,000 kg/cm², or to put it figuratively the weight of three wide-bodied aircraft of type Boeing 747 on a smartphone. With such forces it appears impossible for a food to endure these conditions undamaged and to imagine that this is a gentle method. However, these images especially are misleading, as they suggest that force is introduced via a single axis. In the case of HPP, however, the product is in a container filled with water which is pressurised. The water transfers the pressure uniformly throughout the container and so the resulting forces act evenly from all sides and no shear forces destroying the product result (Figure 1).

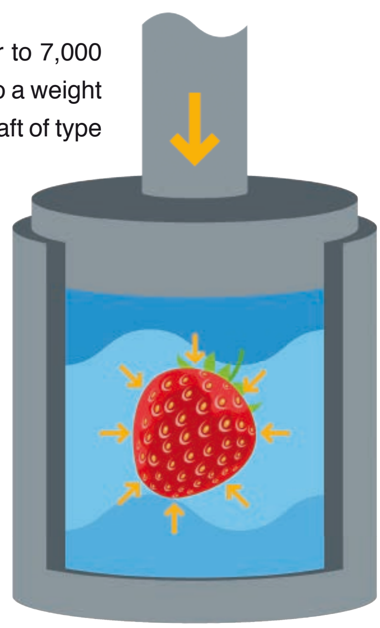

Figure 1: Isostatic pressure transfer

In this connection the term isostatic pressing is often used. Moreover the pressure is distributed in the container and in the products almost simultaneously, so that no major pressure gradients are formed. By contrast with thermal processes in which temperature differences are balanced relatively slowly, HPP works more quickly and homogeneously. In particular the pressure effect is independent of the size and form of the product to be processed, so that the process parameters worked out are independent of the product design.

In a first approximation and also by comparison with gases, liquids are considered to be incompressible. At low pressures and only slight pressure differences, this assumption is certainly justified. However, when designing and operating HPP installations, the compression of the process water and of the product must also be taken into account.

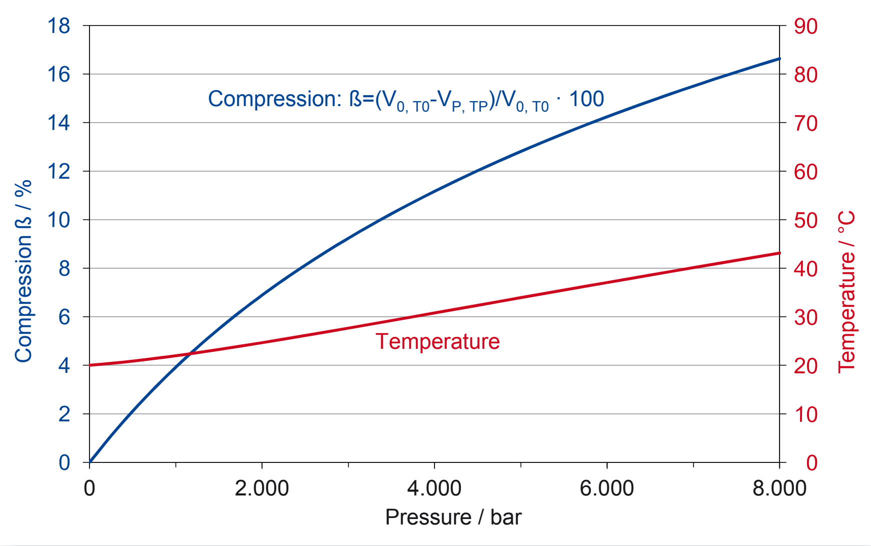

Figure 2: Adiabatic compression of water at 20°C starting temperature

Figure 2 shows the volume reduction of water in the range of an environmental pressure of up to 8,000 bar. At a starting temperature of 20 °C and 6,000 bar, the volume of water is reduced by approx. 16%. Such a reduction can also be assumed in most foods.

The temperature increase starting at 20 °C is also shown. As a rule of thumb, water warms up by approx. 3°C per 1,000 bar. In the case of fats or oils, the temperature increase can be up to 8°C per 1,000 bar. The temperature of foods containing fat therefore rises more strongly than that of low-fat foods or water. However, different carbohydrate and protein levels only alter the temperature course slightly. With the pressure relief at the end of the process the products cool down to the starting temperature again.

At the pressures considered here, gases are compressed to well below one per cent of their initial volume.

From the chemical perspective the pressure does not influence any covalent bonds (atomic bonds), and so simply constructed molecules such as vitamins, taste substances, secondary ingredients and also the primary structure of proteins are not influenced.

Chemical reactions, on the other hand, are accelerated or slowed down if these lead to an increase or decrease of the volume (principle of the smallest force or Le Chatelier's principle). In this way the formation of ions is favoured, which among other things reinforces the release of hydrogen ions. As a consequence the pH value of the water drops under pressure and rises during the pressure relief. Hydrogen bridge bonds on the other hand are stabilised by high pressures. Furthermore, spatial arrangements are compacted down to smaller volumes. All these effects lead to a change in the structure of enzymes, membranes and other cell components so that vital organisms are destroyed or at least damaged.

Organisms with a more complex structure such as e.g. parasites are killed off already at comparatively low pressures. In trials it was possible to kill off trichina larvae with pressures higher than or equal to 2,000 bar. For other organisms the following rules apply – arranged according to rising pressure:

- Viruses are pressure sensitive to differing extents
- Yeasts and fungi are more sensitive than Gram-negative bacteria. A few ascospores form exceptions here
- Gram-negative bacteria are typically more sensitive than Gram-positive bacteria
- Some endospores (dormant form of Gram-positive bacteria) are very pressure-stable

Alongside the influence of the high pressure on microorganisms, other complex structures are also affected. For example, at pressures of a few thousand bar enzymes first become more active and at pressures extending above this are partly or completely inactivated. Such influence is visible on raw meat, which becomes lighter in colour with increasing pressure and increasing treatment time and looks "as though it has been cooked". This effect can be explained partly by the conversion of haemoglobin to methaemoglobin. In the case of processed meat products, e.g. smoked or heated, on the other hand, no change can be ascertained.

The success of the HPP process is essentially determined not only by the pressure level, but also by the pressure retention time. That is the time during which the product is exposed to the selected process pressure. Furthermore, the food itself influences the processing result. Microorganisms are inactivated more quickly in an acidic orange juice or at lower pressures than in juices with a higher pH value.

Lower water activity can also have protective effects on the microorganisms. Interestingly, however, such an effect cannot be observed in the case of raw ham.

The treatment temperature also influences the HPP result. In many cases a low starting temperature leads to better treatment results. This is favourable as regards the process integration, as the finished products can be passed chilled into the HPP process and leave it again at almost the same temperature. Additional tempering steps are then not necessary.

HPP systems

The core of an HPP system is a tubular container, generally arranged horizontally. The high working pressures require containers that are thick-walled and made of special steels. The container is closed with lids at the opposite ends. The lids on which the pressure forces act are supported with a frame system which is also robustly executed. In operation, a massive spacer block is inserted between the frame and lid to pass on the forces. Furthermore, high pressure pumps and high pressure and low pressure piping with fittings are required. Feeding systems, a hydraulic system for movements, control and housing complete the installation. Figure 3 shows an overview of a production system. Figure 4 shows a production system with container and sealing system.

For a few years now HPP installations specially designed for the needs of the food industry have been available on the market. The container volumes of these production installations lie in the range of around 50 to around 350 litres. The maximum working pressure, which is in fact frequently applied, is generally 6,000 bar. With such installations

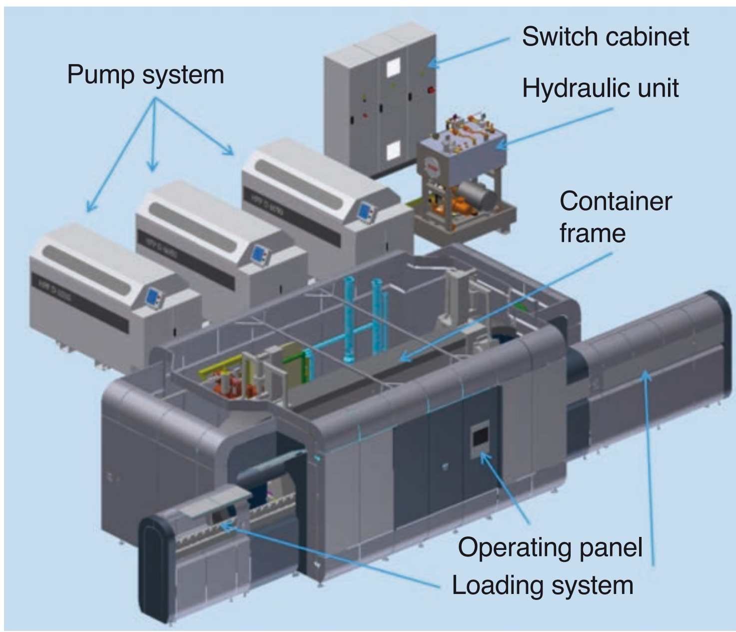

Figure 3: HPP production installation - an overview

Figure 4: HPP production installation with opened housing

production rates of over 3,000 kg/h are possible. The high weights of the HPP installations – which may be over 70 metric tons – are unusual in the food processing sector.

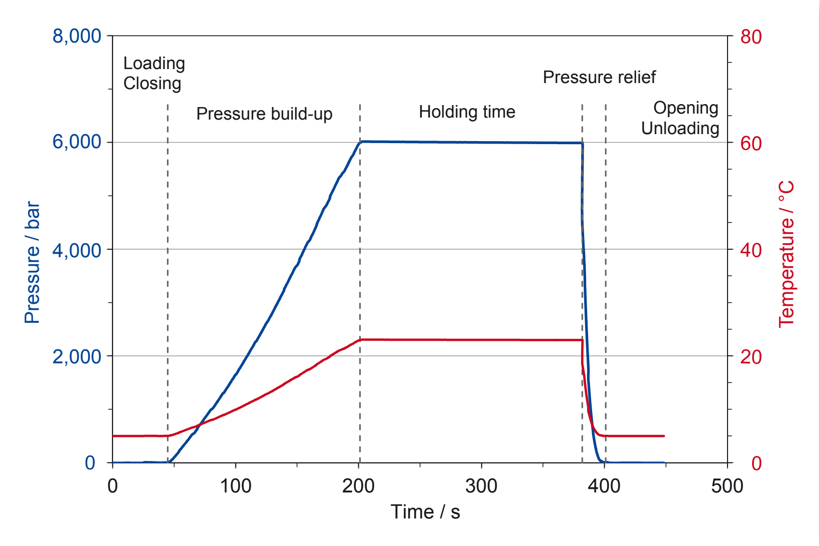

Figure 5: Pressure and temperature profile during an HPP cycle

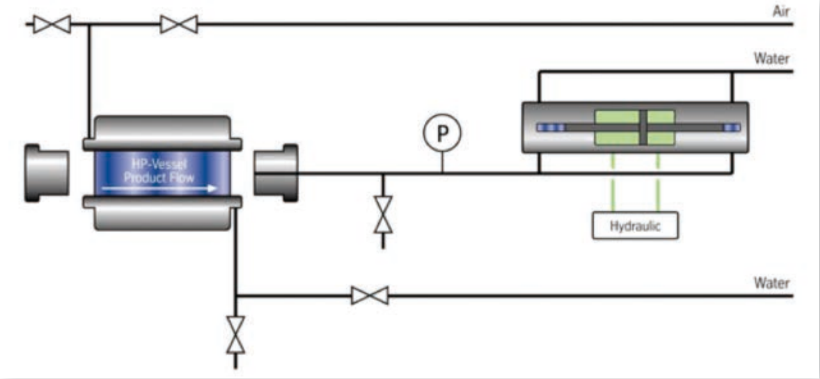

Figure 6: Simplified scheme of an HPP system

Process

Given the high pressures applied, the HPP process can only be carried out batch by batch. For fast loading, the high pressure container is moved out of the frame and loaded from one side via a conveyor system with the desired product in its end packaging placed in an insert basket. The container then moves into the frame, is closed and filled with the process medium – generally water – initially at low pressure and the air between the products is displaced. After this the closing lid is locked. Further process water is pumped into the container via the high pressure pumping system consisting of a number of high pressure intensifiers until the required process pressure is reached. This pressure is maintained for a pre-selected time. At the customary pressure of 6,000 bar the pressure retention time is a few minutes – typically one to four minutes. After expiry of the retention time the pressure in the container is relieved via high pressure valves, and after complete drainage of the process water the opened container is moved to the loading position and unloaded on the opposite side via the conveyor system. The course outlined here is characterised by short cycle times and the complete system can be integrated well into existing production workflows. The continuous flow principle effectively prevents confusion of unprocessed products with processed products, which are otherwise difficult to distinguish. After the HPP process, the packaged foods are dried and labelled.

Figure 5 shows the pressure and temperature profile of a typical cycle, starting with the unpressurised loading and closing operations, via the period under pressure, right through to the opening and unloading. Figure 6 shows an outline sketch of an HPP system.

Packaging

The HPP process is nearly always carried out on foods in their end packaging. Consequently not only the food is treated, but also the packaging, which must therefore be suitable for the process. Sufficient flexibility is important here in order to be able to follow the reduction in volume of approx. 16% without damage and to afford good resistance to water. Glass containers, cans and also laminated cardboard are therefore ruled out. Flexible or at least partially flexible packagings such as skin films, trays with flexible sealing film and plastic bags are generally suitable. The barrier properties such as for instance gas permeability must of course be adapted to the targeted extended shelf life.

Vacuum packagings are often used, but also modified atmosphere packagings (MAP) can be processed using HPP. Examples of this are various cold sliced meat varieties. The packaging form and the gas composition have to be adapted and the decompression should also be monitored particularly, as otherwise diffused gas can damage the packaging film.

Use of HPP

All the positive features of the HPP process satisfy the wishes of consumers seeking unchanged, natural and fresh foods while at the same time requiring greater safety and longer shelf lives. Especially the latter aspect is important for careful handling of available resources, while food safety represents a fundamental condition in any case. In this connection many studies conducted on real foods demonstrate the effective inactivation of pathogenic germs such as Listeria, salmonella, E. coli, staphylococci and also viruses.

HPP is being used ever more frequently around the world as a conservation method. The reasons for this are the altogether gentle process which in many applications does not alter the food at all or only minimally. This is due on the one hand to the basically only slight influence of the high pressure on the foods, but also to the simultaneous and uniform action, which leads to short processing times. Furthermore, in almost all cases the applications take place in the final packaging, so that in connection with the homogenous effect a very good level of food safety is achieved. Moreover a purely physical process is used that is easy to understand and only requires electricity and water, with the water being largely recyclable.

In particular users with a diverse product portfolio welcome the fact that different foods in fluid, pasty and solid consistency can be treated with one method and one type of installation system.

HPP-treated foods have a much extended shelf and storage life by comparison with unprocessed foods, but nevertheless in most cases it is not possible to do without the cooling chain. This is due above all to the high pressure stability of some endospores, including the dangerous germ Clostridium botulinum.

A classic example of an HPP application is the production of avocado puree which, if untreated after preparation, discolours to an unattractive brown shade within a few hours after preparation. Pressure treatment inactivates not only microorganisms, but also the enzymes that are responsible for the browning reaction. It is only HPP that makes fresh avocado puree suitable for sale by the retail trade.

Fruit juices and smoothies are also ideally suitable for HPP treatment. For example, the flavour profile of pineapple is almost unaltered after HPP, while thermal treatment leads to distinctly perceptible changes. That is why in the premi-

Figure 7: Fruit salad – left untreated, right HPP-treated at 6,000 bar

um sector especially, many high pressure-treated juices and smoothies are offered for sale on the market worldwide. HPP-treated orange juice was produced and offered in Europe already in the mid-1990s.

Fruit preparations produced with HPP were on the market in Japan already at the beginning of the 1990s. Figure 7 shows a fruit salad that has been processed using high pressure.

Meat products are subjected to HPP treatment after production and end packaging in order to increase the shelf life and also for safety. Looking at the example of raw ham in particular, it can be shown well that HPP is the only method usable if a reliably Listeria-free and unaltered product is required.

Various HPP-treated dairy products are now available. These include colostrum produced in Oceania, with a shelf life increased by HPP without destroying valuable ingredients. HPP is generally a method for making raw milk products safer.

HPP simplifies the processing of seafood and also makes it more efficient. For instance the closing muscle of oysters is detached from the shell by pressure treatment and this makes opening easier and safe. In addition the pressure of approx. 2,500 bar kills off possible parasites. In the case of lobsters a pressure of approx. 3,000 bar loosens the link between the meat and the shell. After HPP treatment it is therefore possible to remove the meat with only little loss. The stability and safety of smoked fish can also be distinctly improved by HPP.

In the USA especially, many producers use HPP for processing ready dishes in order to increase the safety and shelf life of these products too. In Europe HPP-treated tapas have been on the market for many years.

Global application and perspectives

Viewed altogether, a very wide variety of foods are HPP-treated throughout the world. It is estimated that across the globe there are currently more than 350 production systems in operation at over 200 firms. Figures 8 and 9 show the use of HPP in the different product sectors and application in the different countries. In this connection North America, where the largest number of HPP systems is now in operation, is particularly prominent. The main fields of application are plant-based products (e.g. avocado) and also meat and sausage products. Ready dishes, juices, dairy products and seafood make up the remaining third.

Given the advantages regarding the freshness and safety of high-pressure processed foods, it can be expected that

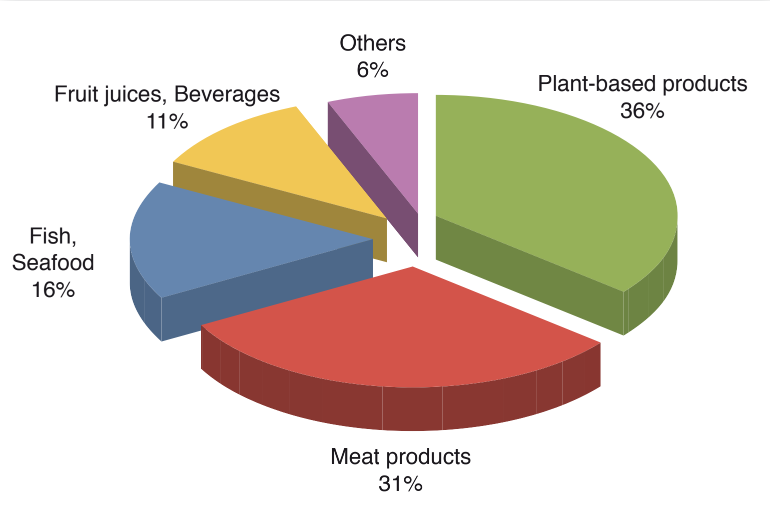

Figure 8: Distribution of the different HPP applications

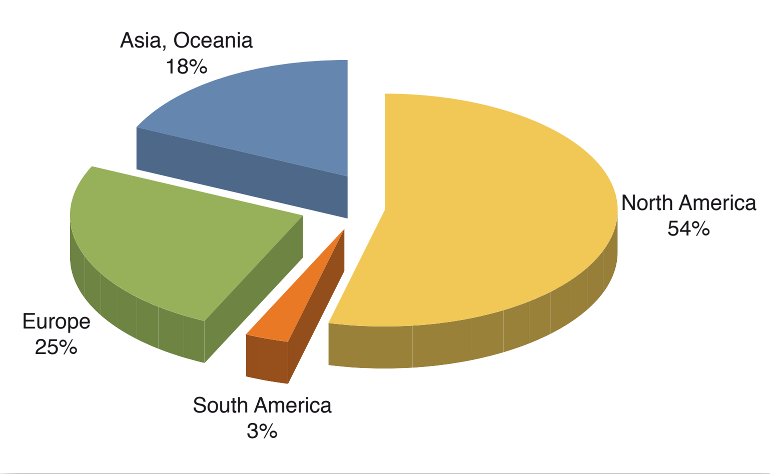

Figure 9: Worldwide distribution of the HPP production systems

use of the process will continue to become more widespread. A constant rise in interest in HPP products and installations can be ascertained at many national and international conferences and trade fairs. Various studies also forecast a growth of over 15% in HPP-treated products in the coming years.

Author:

Dr. Peter Nünnerich, Uhde High Pressure Technologies GmbH, Buschmuehlenstr. 20, 58093 Hagen,
peter.nuennerich@thyssenkrupp.com

Contact:

Dr.-Ing. Annette Schmelzle, Fachzentrum Lebensmittel, DLG e.V., A.Schmelzle@DLG.org

In cooperation with the DLG Committee for Food Technology, www.DLG.org/lebensmitteltechnologie.html

DLG e.V.
Competence Center Food
Eschborner Landstr. 122 · 60489 Frankfurt am Main · Germany
Tel. +49 69 24788-311 · Fax +49 69 24788-8311
FachzentrumLM@DLG.org · www.DLG.org