High pressure processing for decontamination of meat

In a nutshell

Summary

Best practice is to use high-pressure processing for pasteurisation and cooking processes in the production of meat and poultry meat products, in order to reduce energy use. High pressures can be used in different ways for:

- replacing thermal pasteurisation,
- reducing the cooking stage: by using high pressures, the cooking stage can be reduced as the complete pasteurisation is carried out during the high-pressure processing pasteurisation stage.

Target activities

All food and beverage manufacturing	Processing of coffee	Manufacturing of olive oil	Manufacture of soft drinks	Manufacture of beer
Production of meat products	Manufacture of fruit juice	Cheese making	Manufacture of bread, biscuits and cakes	Manufacture of wine

Applicability

This best practice is applicable to all producers of meat and poultry meat products. However, investment costs for purchasing the equipment are high and could discourage SMEs. When this is the case, SMEs can use a rental service for high-pressure processing, if available.

Environmental performance indicators

- Total energy use per amount of meat and poultry meat processed (kWh/kg of product)
- Energy use in high-pressure processing (kWh/cycle of processed product or kWh/kg of product)

Benchmarks of excellence

- High-pressure processing (owned or outsourced) is used to treat suitable meat products (e.g. cooked products, cured and cooked products, raw-cured).

Description

The decontamination of meat is a required process, which improves the safety of the food and reduces the number of undesirable microorganisms. Nowadays, thermal techniques involve the traditional and most commonly used method to achieve microbial stability and safety in the production of meat products (Torres and Velazquez, 2004; Purroy, 2013 pers. comm).

Two types of thermal treatment can be distinguished for meat and poultry meat products (Heinz and Hautzinger, 2007):

- Pasteurisation: heat treatment at temperatures below 100°C, mostly in the range of 60 to 85°C. Pasteurised products still contain a certain amount of viable microorganisms, which are more heat-resistant. The pasteurisation treatment is carried out by steam or heated water. Boilers are used to produce the steam as well as the heated water and they are usually placed in separate facilities. Two types of boilers can be used: shell and water-tube boilers. The choice of one or another is influenced by the steam pressure and quantity requirements. In these facilities, hot water tanks can also be found (Spanish Ministry of Agriculture, Food and the Environment, 2005).
- Sterilisation: Heat treatment at temperatures above 100°C. Sterilised products are completely free of viable microorganisms. At this temperature, the products are placed in glass jars, tin or aluminium cans or similar. These products, which have an extended shelf life, do not require refrigeration. The sterilisation treatment is carried out by autoclaves or retorts in which high temperatures are generated either by direct steam injection or by combined steam and water heating. This thermal process is performed under pressure which may vary according to the temperature (Heinz and Hautzinger, 2007).

Both treatments are completely effective, economical and readily available, although in many cases they have undesirable effects on food quality that a food processor must understand to be able to minimise (Torres and Velazquez, 2004).

In general terms, the pasteurisation stage is carried out in cooked and cured products. In the case of cooked products, once the product is packaged, cooked and chilled, the first packaging is usually removed and the product repackaged in another one. In this way, between the removal of the first packaging and the repackaging the product is exposed to external contamination, and as consequence, pasteurisation treatment is necessary. In the case of cured products, the pasteurisation stage is carried out due to the food safety requirements for exports to countries with more restrictive regulations (Grébol, 2010).

Once the pasteurisation has been carried out, the product undergoes subsequent chilling in refrigeration chambers or in cold water baths or showers (Spanish Ministry of Agriculture, Food and the Environment, 2005).

In the case of sterilisation, the process is carried out in raw cooked products. In these products, after the stuffing and the subsequent cooking or smoking, the product is packaged and subsequently sterilised. Otherwise, the cooking stage (in pasteurised as well as sterilised products) is currently carried out by hot water or steam ovens (Spanish Ministry of Agriculture, Food and the Environment, 2005).

Taking this approach into account, pasteurisation and sterilisation processes are really important from the point of view of energy and water consumption (Spanish Ministry of Agriculture, Food and the Environment, 2005, Azti tecnalia, 2013; European Bank for reconstruction and development, 2009). As a consequence, new measures have been developed to reduce those aspects.

One of these techniques consists of the use of high pressure for pasteurising and cooking processes. The combination of high pressure with heat is also taken into account.

High Hydrostatic Pressure (HHP) is a non-thermal or minimal processing technique (Nunes and Grebol, 2011), also known as Ultra High Pressure (UHP) or High Pressure Processing (HPP) in which the packaged food is subjected to water pressures from 200 to 600 MPa(Purroy et al., 2012). The process is generally carried out at temperatures between 5°C and 30°C (Hiperbaric, 2013).

A HPP machine has the following parts:

- Vessel: it is the cylindrical component in which the food is introduced and subjected to high pressures.
- Yoke: it is the frame of a high-pressure machine, which supports all the tensions generated during the process. It is a key component for the safety and reliability of the process.
- Baskets: they are cylindrical product carriers filled with the food product to be high pressure processed, then automatically introduced into the chamber and unloaded from the vessel once processed.
- Intensifiers: there are components that allow the pumping of high-pressure water into the vessel. They are sophisticated, pressure multiplier components that are powered by a hydraulic pump and piston and plunger systems which are able to pump up to very high pressures of 6000 bar and beyond.

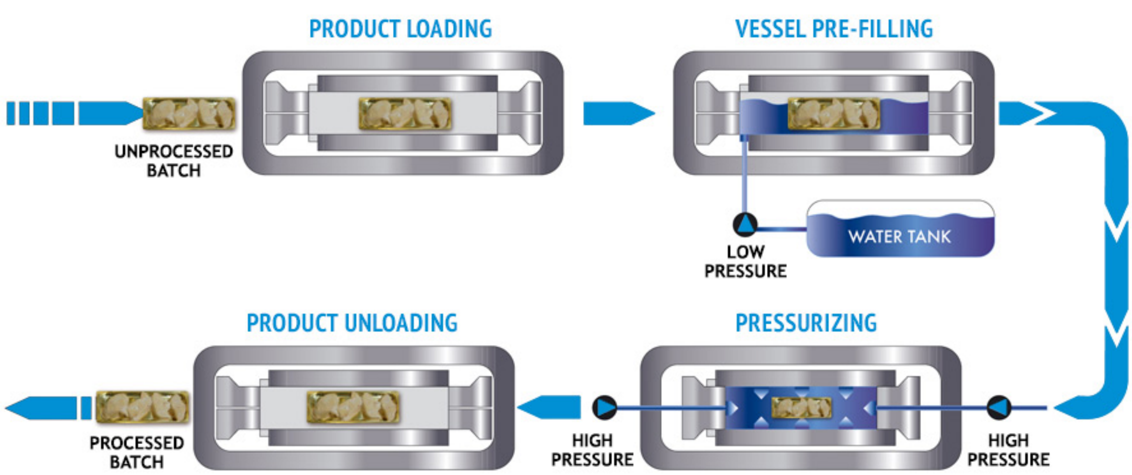
The applied pressure acts uniformly and instantly all around the product whatever its size and dimensions (Nunes and Grebol, 2011; Murchie et al., 2005; Torres and Velazquez, 2005). This pressure is isostatically transmitted (Pascal's law and Le Chatellier principle) inside the vessel (Aymerich et al., 2007). This results in a shorter process time in comparison with thermal treatment (Purroy et al, 2012).

Currently, two kinds of high-pressure equipment can be found in the industry, vertical and horizontal (Leadley et al., 2008), with the latter the most commonly used (around 97.5%) (Purroy et al., 2012).

In the case of horizontal equipment the product is loaded into plastic baskets and then pushed inside the vessel. Afterwards, the plugs hermetically close the vessel. Then the vessel is filled with low-pressure water with the plugs closed and when it is full, the intensifiers start to pump high-pressure water up to the desired pressure. When the holding time is over, water is discharged in a few seconds by opening the release valves. Finally, the vessel returns to the first step and is loaded again. The new product in the basket will then push out the processed product and a new cycle can start (Figure 1) (Purroy et al., 2012).

Thus, a cycle includes filling the high pressure vessel with food product, which must be packaged. The package must be more flexible than the product inside, resistant and waterproof (Azti tecnalia, 2013). A complete cycle usually requires around 3-4 minutes (holding time excluded).

Figure 1: Diagram of operation of a HPP unit (Hiperbaric, 2013).



Key HPP equipment technologies are the pressure vessels and the high hydrostatic pressure generating pumps or pressure intensifiers (Torres and Velazquez, 2004).

The microbial inactivation achieved with the technology depends mainly on two factors: the pressure applied and the process duration. Thus, the higher the pressure applied and the longer the holding time, the more microbial inactivation (Black et al., 2011).

Most of the pathogenic microorganisms (vegetative cells) can be inactivated through high pressures. This inactivation is caused by the break-up of the cell walls and by the disruption of the vital functions of the cells (Murchie et al., 2005; Torres and Velazquez, 2005) due to the denaturalisation of proteins and DNA. High Pressure Processing may induce some colour changes (depending on the pressure level) due to the state of oxidation of Fe in some pigments. For instance, in native myoglobin and haemoglobin, Fe^{2+} is changed under pressure to Fe^{3+} and the pigment changes colour. Similarly, in some matrices like raw salmon, the pigment is not affected, but the colour fades by protein denaturation and the consumer's visual perception may change.

High pressures can be used in different ways with potential energy consumption savings:

- By replacing thermal pasteurisation: conventional thermal pasteurisation is replaced by using high pressures in the case of re-pasteurization of cooked meat products.
- By reducing the cooking stage: as one of the objectives of the cooking stage is the decontamination of products, many companies usually increase this stage in order to increase the disinfection power during the cooking stage, although they continue to carry out the thermal pasteurisation. Thus, a great amount of energy is consumed. By using high pressures, the cooking stage can be reduced since the complete pasteurisation is carried out during the HPP pasteurisation stage. However, it should be mentioned that the reduction of the thermal energy consumption may not be greater than the required HHP re-processing energy.

Semi-continuous operation systems can also be used to improve the efficiency of the process. By coupling a number (usually two) of pressure systems, most of the energy stored in a pressurised vessel can be used to pressurise the second vessel, improving productivity and saving energy and process time (Hernando-Sáiz et al., 2008; Van der Berg et al., 2001).

High pressures can also be applied together with temperature, which become necessary to inactivate spore-forming bacteria. The so-called High Pressure Thermal Sterilisation (HPTS) technique involves the use of initial temperatures between 60°C and 90°C at pressures of up to 630 MPa (Barbosa-Cánovas and Juliano, 2008). HPTS combines the synergistic effects of elevated temperatures (90-121°C, under pressure) and pressures to realize a quick and sufficient inactivation of the microorganisms as well as spores, so the final product is free of viable microorganisms.

In the HPTS process, the increase in temperature is not due to heat transfer but to adiabatic heating by compression. As the pressure transfer is homogeneous and instantaneous, the increase in the product temperature due to pressure is also homogeneous and instantaneous, independent of the size and shape of the product (Wilson and Baker, 2000; Ramírez et al., 2009). In the same way, after the pressure is released, immediate decompression makes the temperature in the product also immediately decrease. This effect permits the time of processing to be reduced cosniderably, maximising process efficiency (Toepfl et al., 2006) and reducing energy costs and heat damage in the product.

Summarising, best practice is to use high-pressure processing for pasteurisation and cooking processes in the production of meat and poultry meat products, in order to reduce energy use. High pressures can be used in different ways for:

- replacing thermal pasteurisation,
- reducing the cooking stage: by using high pressures, the cooking stage can be reduced as the complete pasteurisation is carried out during the high-pressure processing pasteurisation stage.

Environmental benefits

In general terms, alternative technologies may lead to environmental impact reduction in comparison to traditional thermal processes (Pardo and Zufia, 2012).

HPP equipment are very efficient systems, with a low energy input (Hogan, Kelly and Sun, 2005). The required level of pressure is usually generated with the use of intensifiers that use electricity. Once the required pressure is reached (usually, in a few minutes), it can be maintained with no additional energy input (Murchie et al., 2005). Moreover, pressure processing uses cold (or room temperature) water as transmission fluid, so no additional energy is needed to generate steam or hot water, and used water can be recycled (with no loss due to evaporation). Finally, once the pressure cycle is complete, the pressure release takes place in less than one minute without any additional energy being required, which is another advantage relative to thermal treatment which often involves additional energy to rapidly decrease the product temperature (Lavilla, 2014 pers. comm.). High pressure energy consumption is shown in Table 1.

Table 1: High pressure energy consumption per cycle and per hour (Purroy, 2014)

	Vessel (s) volume (l)			
	55	135	300	420
Energy consumption per cycle (kW)	2.05	5.57	11.3	15.86
Energy consumption per hour (kW)	20	46	90	140

1. Standard pasteurization cycle conditions: 6,000 bar and 3 minute's cycles.
2. Number of cycles which are carried out by the machine per hour (in standard conditions).

Real energy savings are produced when high-pressure treatment is used to replace the conventional thermal cooking stage (Purroy, 2014 pers. comm.; Bajovic et al., 2012; Lickert et al., 2010). For instance, this process is well known in the production of liver sausage. The liver sausage production process requires two thermal treatments (in the first one, before grinding, cured pork meat is cooked to 72?C; in the second, after stuffing, at 75-80?C), which may be replaced by two high-pressure treatments at 600 MPa for 2-5 minutes at room temperature (Bajovic et al., 2012). In addition, after the second HPP treatment the product is only stored, therefore the cooling operation is eliminated (Adapted from Bajovic et al., 2012).

Potential energy savings may also arise when high pressure treatment replaces conventional thermal post-pasteurisation. While the energy consumption of a high-pressure treatment can be easily determined since the pressure is transmitted uniformly and instantly all around the product whatever its size and dimensions, heat treatment depends on the size and shape of the product owing to the diffusion of heat around the product, therefore its quantification is very complicated.

The energy consumption needed for increasing the temperature in meat products from 4 to 70°C using conventional treatments is about 250 kJ/kg product. Depending on the design of the equipment and the energy losses, this figure may reach 300-450 kJ/kg product. By using the electrical resistance of products (ohmic heating) heat application is carried out directly, achieving a uniform temperature. Thus, energy consumption is in the range of 280-350 kJ/kg. High-pressure treatment energy consumption is less than other treatments (200-280 kJ/kg) (Toepfl, 2014)[1].

Energy consumption savings may also be achieved by using High Pressure Thermal Sterilisation (HPTS). According to Toepfl et al. (2006), the specific energy input required for sterilisation of cans can be reduced from 300 to 270 kJ/kg.

Water savings might be achieved if high pressure treatment replaces conventional heat water batch or steam treatment. In this case the potential savings depend on many factors such as the size of the batch or the frequency with which water is replaced. Therefore, a more exhaustive study is required.

Additionally, by using high pressures, the conservatives and chemical additives, which are used to increase the shelf life of the processed products can be reduced (Azti tecnalia, 2013) or even eliminated (Comercial logística de Calamocha, 2015; Jung, Tonello and De Lamballerie, 2011). Thanks to this increase, a great amount of waste can be reduced (Hiperbaric, 2013).

[1] Study carried out by comprising conventional and novel disinfection methods with a production of 1,000 kg/h. The study shows potential energy savings although they depend on many factors such as packaging (size, type, etc.) as well as process objective (disinfection,

denaturing, etc.) (Toepfl, 2014).

Side effects

Water recirculation within the high pressure process requires energy (e.g. filtration, de-pressurisation) therefore the corresponding emissions to air are the main environmental cross-media effect.

Applicability

This best practice is applicable to all producers of meat and poultry meat products. However, investment costs for purchasing the equipment are high and could discourage SMEs. When this is the case, SMEs can use a rental service for high-pressure processing, if available.

HPP allows achieving an increased shelf life of minimally processed products and products that are susceptible to thermal treatment such as foie, low-fat and low-salt products, which cannot be treated with heat. In products which can be treated with heat, while the shelf-life is maintained, the quality increases (Lavilla, 2014 pers. comm.).

Table 5: Shelf life extension in different meat products

Product	Shelf-life extension	Other benefits or adverse effects
Marinated beef loin (raw)	13-15 days	Some greying of meat
Cooked sliced ham	Up to 66 days (depending on HPP level)	None
Blood sausage	28 days	None
Pre-cooked sliced chicken	21 days	None
Cooked meat products free of nitrites: ham, sausages and bacon	4 weeks	None

Source: (adapted from CSIRO ANIMAL, FOOD AND HEALTH TECH, 2012; Lavilla, 2014 pers. comm.)

As far as the capacity is concerned, commercial equipment with a capacity of 10-300 litres are available and can be purchased from different suppliers (Aymerich et al., 2007). Nowadays equipment with a capacity of 420 litres and 520 litres are also available (Hiperbaric, 2013).

High pressures can be used in a large variety of products:

- Cured and cooked products and raw-cured products: these products, which may be affected by heat, are exported to other countries with more restrictive safety food regulations such as the USA, Japan, Canada or Australia (Grebol, 2010).

- Cooked products: HPP avoids over-cooking, producing energy savings and improvements in the productivity. These products can be subjected to high pressures in different ways (Purroy, 2013 pers. comm):
- By replacing the cooking stage: This is the case of the filet americain or the leberwurst sausage.
- By replacing thermal pasteurisation in both whole and sliced products.
- By reducing the cooking stage.
- Fresh products: carpaccio or fresh foie gras are usually treated with high pressures in order to develop a safer product. In addition, improvements in the flavour and structure are achieved (Zwanenberg food group, 2013).
- Raw-cooked products: for products which undergo a sterilisation process and are packaged in cans.

Economics

Calculations of the operation costs depends on the type of machine as far its capacity, pressure applied and operation time are concerned (Table 6).

The investment needed for a HPP machine is in the range of EUR 500 000-2 000 000 depending on the volume of the vessel (Purroy et al., 2012). Although the initial investment is high, the processing cost has been estimated at EUR 0.14/kg of product treated at 600 MPa, including investment and operation costs (Aymerich et al., 2007).

Table 6: Economic model for 600 MPa operating machines (Purroy, 2013 pers. comm.)

EQUIPMENT						
Vessel(s) volume	litres	55	120	135	300	420
COSTS AND COMSUMPTIONS						
Investment cost	EUR thousand	540	790	990	1,420	1,950
Depreciation period	year	5	5	5	5	5
TREATMENT COST PER LITRE OR KG						
Depreciation charge	EUR	0.090	0.063	0.067	0.046	0.038
Wear of parts	EUR	0.055	0.042	0.046	0.030	0.024
Energy	EUR	0.007	0.008	0.006	0.006	0.006
Total	EUR	0.151	0.113	0.119	0.082	0.068
TREATMENT COST PER CYCLE						
Depreciation charge	EUR	2.46	3.81	4.99	7.53	9.67

Wear of parts	EUR	1.50	2.50	3.40	5.00	6.00
Energy	EUR	0.18	0.46	0.46	1.02	1.43
Total	EUR	4.15	6.77	8.85	13.54	17.10

(*) Investment cost includes: Equipment, loading/unloading basket systems, installation and start-up

Driving forces for implementation

Companies implementing HPP can improve its image thanks to a higher product quality and the achievable microbial risk reduction potential (Azti tecnalia, 2013).

Furthermore, companies can reduce energy and reduce the process time in some meat and poultry meat products (Purroy, 2013 pers. comm.). In addition, conservatives and chemical additives may be eliminated or reduced significantly (Comercial logística de Calamocha, 2015) increasing the shelf life of the products.

High Pressure Processing allows companies' to increase their turnover in two ways (Grebol, 2010):

- By developing new products (such as omega 3, low-salt or natural products with no additives).
- By exporting to other countries with more restrictive safety food regulations (such as the USA, Japan, Canada or Australia).

Reference organisations

There are more than 170 HPP machines all over the world (Nunes and Grebol, 2011), and two manufacturers at industrial level (Leadley et al., 2008). Nowadays, this technique is well established in the meat and poultry meat sub-sector. Espuña was the pioneer in implementing High Pressure Processing. In 1998 the company installed HPP equipment for sliced cured products such as ham which is exported to countries with more restrictive food safety regulations. Nowadays, the company has two pieces of high pressure equipment of 6000 and 4500 bar (Espuña, 2015).

Campofrio has been employing the technology since 2002. It started implementing High Pressure processing for cured ham for Listeria Free exports to the USA. In 2003 the company installed equipment for sliced ham, turkey and chicken, increasing its shelf life to eight weeks and using less additives.

In 2008 more equipment was installed in order to launch marinated chicken and turkey with six week shelf life onto the market (Adapted from Hiperbaric, 2013).

The company Hormel has been treating dry cured ham since 2001. Nowadays it treats a wide range of products including ham, turkey and beef. Treated products have longer shelf life and zero preservatives (Adapted from Hiperbaric, 2013).

Table 7: Companies worldwide that have High Pressure Processing installed (Hiperbaric, 2013).

Itohan	Japan
Ferrarini	Italy

Golden Valley Farms	Canada
Columbus Salumeria	US
Jamcal	Spain
Freybe	Germany
Foster Farms	US
Cooper Farms	US
Maple Leaf	Canada
Martiko	Spain
Moira Mac’s	Australia
MRM	Spain
Casa Italia	Italy
Espuña	Spain
Quantum Foods	US
Rovagnati	Italy
Safe Pac	US
Tyson Foods	US
Deli24	United Kigdom
Zwanenberg	Holland
Campofrio	Spain
Creta Farms	Greece
Cooper Farms	US
Mondelez Int	US
Abraham	Germany

Santa Maria Foods	Italy
Viau	Canada
Angst	Switzerland

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