1 History of Thermal Processing

The application of high temperatures is one of the most commonly used methods to kill or control the numbers of micro-organisms present within foods and on packaging surfaces. Evidence for its importance in today's food industry can be seen in the percentage of shelf space taken up in any retailer by foods preserved by heat. Along with low temperature storage (e.g. refrigeration and freezing) and dried foods, thermal processing remains of key importance to the worldwide food industry. There have been many attempts to introduce foods preserved by new technologies (e.g. ultra high pressure, pulsed electric fields) into retail food markets, but their significance is still relatively minor in comparison with thermal processing.

Thermal processing is a general term that describes all forms of heat treatments in which micro-organism numbers are controlled by heat. This includes heat processed container types such as metal cans, plastic trays, pouches, glass jars, and even cartons. It also includes continuous thermal processes that take place outside of the package and are usually linked with aseptic or hot filling. Nowadays, the terms 'canning' and 'thermal processing' are often used interchangeably; however, as most of the original work was done in cans, thermally processed foods that are in other packaging formats are still often referred to as 'canned'.

1.1 A BRIEF HISTORY OF THE SCIENCE AND TECHNOLOGY OF THERMAL PROCESSING

The early Greeks believed in 'spontaneous generation' (that living things could originate from non-living matter). Although Aristotle discarded this notion, he still believed that animals could arise

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spontaneously from other unlike organisms or from soil. His influence regarding this concept of spontaneous generation was still felt as late as the seventeenth century.

The sixteenth and seventeenth centuries were a time of great scientific advancement in areas of chemistry, mathematics, and physics. This was known as the Scientific Revolution which laid the foundations for the Age of Enlightenment in the eighteenth century, a period where science became popular with the ordinary person, and an increasingly literate population was hungry for knowledge, information, and to learn. Evening Science lectures, with demonstrations, were very popular as a form of entertainment for the working class.

In addition at that time, the Industrial Revolution was taking place in Europe in the eighteenth and nineteenth centuries. Great strides were made in the areas of textiles, steam generation, and metallurgy. Steam generation was much more efficient; fossil fuels were used for the first time, instead of wood based fuel, resulting in a much more efficient source of energy. Advances in mining techniques and metal-working, especially iron founding, resulted in many new uses for metals like iron, copper, and tin (http://www.wikipedia.org).

Towards the end of the seventeenth century, a chain of observations, experiments, and arguments began that disproved the belief that life could be generated from non-life. Microbiology, as a science, can be said to have begun with the development of the microscope. In the mid-seventeenth century, although not the inventor of the microscope, Antonie van Leeuwenhoek (1632–1723) (Fig. 1.1), a Dutch draper, ground his own lenses and made small microscopes that could magnify up to 500 times. He had exceptional attention to detail and was the first to provide proper descriptions of his observations, which included protozoans from the guts of animals and bacteria from teeth scrapings. His descriptions and drawings were excellent, and he conveyed his findings in a series of letters to the British Royal Society during the mid-1670s. Although the observation of his 'animalcules' stimulated much interest, it remained as an oddity until the eighteenth century.

In France, the French Revolution (1789–1799) took place, largely as a result of growing dissatisfaction due to poverty and a shortage of food and increasing malnutrition. The Napoleonic Wars (1803–1815) further influenced the economy and developments in Europe.

It was in this time that Nicolas Appert was working as a confectioner. He was born on 17 November 1749 at Charlon-sur-Marne.

Fig. 1.1 Antonie van Leeuwenhoek, painting by Jan Verkolje.

His family were not wealthy, and young Nicolas acquired an education largely through personal effort. He was trained as a chef and worked and experimented with different kinds of food processes (fermenting, distilling, and preserving) for his own interest all of his life (http://www.appert-aina.com).

The French Army was busy with many military campaigns, and a major concern to the French Government was that they were losing more troops to diseases like scurvy and malnutrition, than to battle casualties. In 1795, they offered a prize of 12 000 Francs (a lot of money at that time) to anyone who could find a way to safely preserve food. This offer caught the attention of Nicolas Appert. He had noticed that the sugar syrups that he used for his confectionary, kept almost indefinitely when heated, and stored in stoppered glass bottles. He began experimenting with preserving other types of food, also by heating them and storing them in stoppered jars. He worked scientifically and had a keen attention to detail. He started with using champagne bottles, but soon had them modified with a wider mouth, so that he could fill them more easily.

By 1804, he felt confident enough to test some product on the French Navy. The test was a huge success. In 1806, more tests were conducted. His invention was assessed, and early in 1810, he was informed that he could claim the award of 12 000 Francs, but had to publish the exact details of his discovery, which he did (Goldblith 1971b).

Appert is known as the Father of Canning. Heat sterilization is also known as Appertization. Although his first products were in glass bottles, he soon started using metal cans at the cannery he built with the prize money he won for his invention. He had to deliver 200 copies of his processing methods (printed at his own expense) to the French Government before they would give him his award. The book was very detailed and described the canning process much as it is still today (Appert 1810). Appert described the process as follows (Featherstone 2012):

- Enclose the foods to be preserved in bottles.
- Cork the bottles carefully.
- Boiling the bottles in water for various lengths of time (depending on the foods).
- Remove the bottles and cool them.

In 1811, he has a second edition printed in French as well as English and Swedish, and in 1823 a third, and in 1831 a fourth. The later editions were translated into many other languages (Bitting 1937).

Although Appert's methods worked, no one at the time understood why. Appert thought it was due to the heating and exclusion of air. At that time, it was widely believed that air itself was the cause of spoilage (Fig. 1.2).

There were many other people working on methods of food preservation at the time: including the Englishmen, Donkin, and Saddington (who, in 1807, were awarded five guineas for their method of using heat to preserve fruits without using sugar).

Glass jars were soon largely replaced in commercial canneries with cylindrical tin or wrought-iron canisters (later shortened to 'cans'), following the work of Peter Durand in 1810. The cans were cheaper and quicker to make and much less fragile than glass jars. In England, the firm of Donkin and Hall manufactured large quantities of 'canisters', some of which were taken on expeditions to Baffin Bay in 1814 and on Arctic explorations in 1815.

The reason for lack of spoilage was unknown at the time, since it would be another 50 years before Louis Pasteur (1822–1895), a French chemist and microbiologist proved, by demonstration, that fermentation is caused by the growth of micro-organisms, and not due to spontaneous generation or by exposure to air.

Fig. 1.2 Nicolas Appert, drawing on Commemorative Stamp issued by Monaco in 2010.

1.2 FOOD MICROBIOLOGY AS A SCIENCE

In 1859, Louis Pasteur demonstrated the role of micro-organisms in food spoilage. In his experiment, he heated broth in long swan necked jars to sterilize them. The jars either had filters on them, or very long necks that allowed only air, but not dust and other particles through. Nothing grew in the broths unless the flasks were broken open. He therefore correctly concluded that the living organisms that grew came from outside, as spores on dust, rather than spontaneously generated within the broth or from the air. He showed that the growth of micro-organisms was responsible for spoiling products like beer, wine, and milk.

He invented a process in which milk was heated to kill most bacteria and moulds already present. This process was soon afterwards known as pasteurization (http://www.wikipedia.org). A little known fact about Pasteur is that he, because of his status as a respected scientist, served on the board of Public Hygiene and Sanitation, in France. One of his responsibilities was food laws.

As a result of his discoveries regarding the cause of food spoilage, various methods of preserving foods were researched by many others. Some of these involved adding chemicals to the food. In 1870, Pasteur advocated that the public had 'the right to know' what was being put into the food and stated that all ingredients and additives must be declared on the label (Goldblith 1971a) (Fig. 1.3).

Microbiology was in its infancy in the nineteenth century. Many people contributed to developing it into the science it is today. A few of these scientists who made significant contributions to the understanding of the science of canning are mentioned below (Goldblith 1972).

Joseph Lister (1827–1912) was an English surgeon who made the important development of antiseptic surgical practice for medicine and microbiology (Fig. 1.4). Lister searched for a way to keep bacteria out of wounds and incisions made by surgeons, as death from sepsis was frequent at the time. He read a paper by Louis Pasteur that described the growth of anaerobic bacteria and suggested killing them by heat, filtering, or with chemicals. Carbolic acid (phenol) was known to deodorize sewage, so Lister soaked surgical dressings, and sprayed carbolic acid into the air of

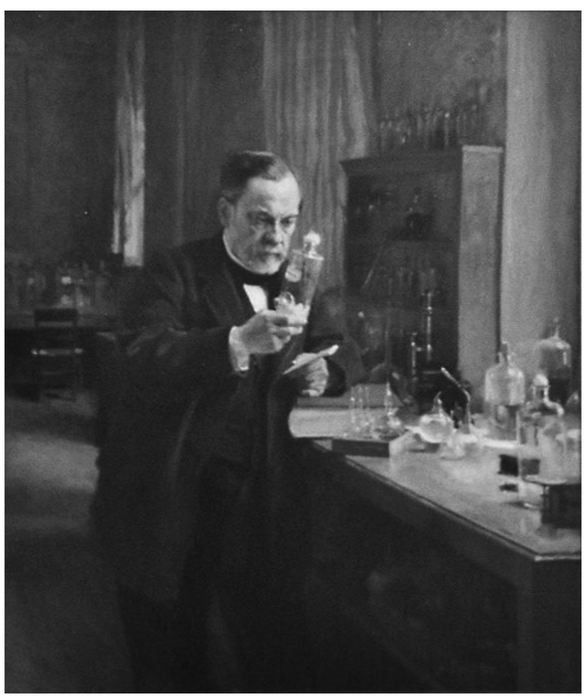

Fig. 1.3 Louis Pasteur, painting by A. Edelfeldt (1885).

Fig. 1.4 Joseph Lister, painting by *unknown*.

operating theatres. The protected wounds did not become infected, and the patients recovered quickly. The success of this technique was so remarkable that aseptic surgical practice was soon established worldwide.

Robert Koch (1843–1910) isolated the *Bacillus* bacteria responsible for tuberculosis and the one for anthrax. He also isolated the bacteria responsible for cholera, *Vibrio cholera*. In his work with anthrax, he noticed that when the bacteria were exposed to unfavourable conditions, they went into a dormant state, forming internal spores that could survive for extended periods in the soil, causing outbreaks of the disease at opportune times. More of Koch's contributions to microbiology were in the areas of culturing bacteria and examining them. He developed solid culture media by adding gelatine and other solidifying agents to liquid media in order to obtain isolated growths of micro-organisms. These isolated growths were called 'colonies' and were found to contain millions of individual micro-organisms packed tightly together. He noted that the colonies were visible to the naked eye, whereas the individual cells were not. Koch also found that, by adding dyes to micro-organisms smeared onto a glass slide, individual cells could be seen more clearly with a microscope.

All canners had losses due to sporadic swelling and spoilage, but the actual causes for it were unknown, and the canners did not know what they should do to overcome this problem.

In about 1860, Isaac Solomon, a canner in Baltimore in the USA, added calcium chloride to the cooking water enabling it to 'boil' at 116 °C instead of 100 °C and thus drastically reducing the cooking times that had been in use.

In 1895, Dr Harry L. Russell published a paper describing swelling spoilage in canned peas. He did experiments where he processed peas at higher temperatures and longer times and showed that the percent spoilage was significantly reduced.

Two important advances in food science and canning were the invention of the steam pressure retort by A.K. Shriver in 1875 and publication of the time and temperature requirements of canned foods by Underwood and Prescott. William Lyman Underwood was a canner who wanted to understand what caused canned food spoilage (Fig. 1.5). Together with Samuel Cate Prescott, they studied many cases of food spoilage over many years. They demonstrated that spoilage could be caused by inoculation and that the proper time and temperature combinations could prevent spoilage. They showed that bacteria were the causative agents of canned food spoilage, the importance of heat penetration in processing canned foods, the importance of proper cooling of canned foods, and they were also the first to recommend incubation

Fig. 1.5 Underwood and Prescott. Courtesy of the MIT Museum.

testing of canned foods. The significance of their work cannot be over-emphasized; canning passed from an individual skill to a scientific discipline.

There are many excellent scientists who have contributed invaluable insight into the field of thermal processing, but most of the foundation work was done by those mentioned above.

The early bacteriological studies on spore death kinetics were done by different researchers at various temperatures. This work was done between 1921 and 1948. As could be expected, the lower the temperature, the slower the rate of kill. Stumbo took this information and calculated the *z*-value of 18 °F (10 °C) and an *F*-value of 2.78 minutes for *Clostridium botulinum* spores on a thermal death time curve that passed through 250 °F (121.1 °C) at 2.78 minutes (Tucker 2008). This temperature was appropriate for practical cooking times as well as being safely achievable in the processing vessels of the day. This was the basis of the Fo3, at 250 °F concept which is still applicable today.

The General Method for calculating scheduled process times was originally described by Bigelow et al in 1920, but contributions by Ball in 1928 and O.T Schulz and F. C. W. Olson in 1940 resulted in a much improved General Method. M. Patashnik published his improvements which are the most widely used today in 1953 (Patashnik 1953; Park 1996).

The invention of a standardized reliable thermocouple probe for measurement of real time heat penetration temperatures was an important contribution made by Ecklund (1949).

J.R. Manson, A.A. Teixeira, and K. Purohit were three of Stumbo's graduate students who also contributed significantly to the field of thermal processing. They were engineers, and the first to apply engineering mathematics to simulate the coupling of heat transfer with thermal inactivation kinetics in thermal processing of canned foods. Teixeira used this approach to find optimum retort the time and temperature combinations that would maximize quality retention while delivering specified target lethality. Manson carried Teixeira's work further by improving the mathematical model to simulate convection as well as conduction heat transfer. Working together, Teixeira and Manson demonstrated how such models could be employed in real time online control of batch retorts by automatically extending process time to precisely compensate for unexpected process deviations (Teixeira et al. 1969). The research mentioned above took place largely in the USA.

In the United Kingdom, T.G. Gillespy and his team did valuable work on processing times and temperatures of a large range of foods at Campden Experimental Factory (now Campden BRI) (Tucker 2008). In France, H. Cheftel at Carnaud Research did extensive work on canned foods and published *Principles and methods for establishing thermal processes for canned foods* in French. In South Africa, G.G. Knock did much to increase the understanding and hence reduce the incidence of thermophilic ‘flat sour’ spoilage in canned peas (Knock 1954). These researchers and others collaborated from all over the world to improve the understanding of the mechanism of canned food spoilage and the requirements necessary to ensure that safe canned food is produced. Improvements in product safety, quality, and energy usage are still continuously being made. G.S. Tucker at Campden BRI further developed numerical techniques for thermal process calculations and a computer program to recalculate process deviations in real time.

1.3 PACKAGING FOR HEAT PRESERVED FOODS

Nicolas Appert’s first products were packed in glass. Soon after his discovery was published, Peter Durand, a British merchant patented the idea of preserving food using tin cans. The patent (No 3372) was granted on 25 August 1810 by King George III of England. After receiving the patent, Durand did not make any canned food himself, but in 1812 sold his patent to two other Englishmen, Bryan Donkin, and John Hall, for £1000. Donkin was involved with tinning of iron sheets from 1808 and was keen to expand it to the food industry. Donkin and Hall set up a commercial canning factory and by 1813 were producing their first canned goods for the British army. In 1818, Durand introduced tin cans in the United States by re-patenting his British patent in the United States of America (http://www.wikipedia.org).

The first ‘canisters’ were made from iron plates that were dipped into molten tin to stop it from corroding. The ends were soldered closed with molten lead. The metal was thick and the cans were heavy and strong. The cans often weighed more than the food that was in them. They had to be cut open with a hammer and chisel.

Appert also started using cans. He made them himself in his cannery. They had the capacity of between 4 and 45 pounds and could be reused. He also added handles to some of them so that they could be used as cooking pots once opened. Although he preferred round cans, he made oval and rectangular ones too, at the request of his customers (Goldblith 1971a).

Improvements to the can came when steel was invented, and this allowed for a much thinner metal which had the same strength to be used. In 1888, the hermetic double seam was invented by Max Ams. This paved the way for automated can lines to be made, whereas before about 6 cans per hour were handmade, the first automated can lines could make about 60 cans per hour. Can making lines today can run as fast as of 1500 cans per minute.

Tin is an expensive metal. In the 1930s, hot dipping of tinplate was replaced by electroplating, where much less tin can be used to perform the same job. Improvements in steel making technology have resulted in even lighter weight cans. Single reduced tinplate of 0.19–0.21 mm thickness and double reduced (DR) tinplate as thin as 0.10–0.15 mm are now used to make cans all over the world.

Although improvements in can design (e.g. by beading the body walls) can compensate to some extent for the loss of strength due to the thinner metal, many of the down-gauging improvements are possible only due to improvements in can handling.

1.3.1 Convenience – the can opener is invented

Only when thinner steel cans came into use could the can opener be invented. Before then, canned food used to come with the written instructions: 'Cut round the top near the outer edge with a chisel and hammer'. The first can openers were primitive claw-shaped or 'lever-type' design. Robert Yeates, a cutlery and surgical instrument maker patented the first can opener in Great Britain in 1855. It was a wooden handled leaver-type cutting blade. Three years later, in the USA, Ezra Warner patented another design (Warner et al. 1858). His looked like a bent bayonet. The large curved blade was driven into a can's rim and then forcibly worked around its edge. This first type of can opener was deemed to be too dangerous for ordinary people to use it, and the store assistants opened each can before it was taken away (http://www.wikipedia.org).

Another can opener was invented by William Lyman of the United States in 1870. It had to be pierced into the centre of the end and had a cutting wheel that rolled around the rim of the can end. It was difficult to operate as it had to be adjusted to the size of the end. A breakthrough came in 1925 when a second, serrated wheel was added to hold the cutting wheel on the rim of the can. The basic principle of this opener was the same as is used on the modern can openers. The first electric can opener was introduced in December 1931.

The easy opening end is the ultimate in convenience as far as can openers go. In the 1960s, a pull tab was patented by Ermal C. Fraze owner of the Dayton Reliable Tool Company in Ohio, USA, for aluminium ends for beverage cans. A lot of work then went into the development of an easy opening tinplate end that could withstand the requirements of being retortable and had a good shelf life. By the1980s, these ends were available commercially.

1.3.2 Other forms of packing for 'canned foods'

Other forms of packaging for 'canned foods' have also become popular and practical; including glass, various plastics, and composites. Although glass was not new – being the packaging that Appert used to develop his method, it was difficult to seal adequately and cans soon became the packaging of choice. Developments in the closures for glass, starting with the Mason Jar in 1858, resulted in glass becoming a popular alternate to cans. Improvements in glass making technology have resulted in bottles that don't break easily under the high heat and pressure conditions experienced during thermal processing. Improvements in lids, caps, and closures that form hermetic seals are easy to open and reclose and have tamper evident features such as buttons that 'pop' on first opening have helped to make glass a viable alternate.

Developments in other packaging types are more recent and restricted to the past 40 years or so. Rigid plastics are useful for ready meals, as they are not breakable and can be heated in the microwave oven. Pouches are flexible and during processing the flat dimensions result in faster heat penetration, therefore shorter cooking times and better quality product. Pouches and some rigid containers come with their own challenges for thermal processing as their irregular shapes make it more difficult to measure the cold spot during processing. Tetra Recart's 'square' format saves space when packing and stacking. All of these options have their advantages and disadvantages. None of the plastics and laminates are as good a gas barrier as glass and metal. Light can also cause deterioration in some products, requiring tinted glass or opaque metal or cardboard casing.

The ideal packaging choice depends on the requirements of product type, processing conditions, required shelf life, and target market.

1.4 DEVELOPMENTS IN CANNERY EQUIPMENT

1.4.1 Seaming

The equipment used in canneries also had to develop significantly. Originally, cans were manually soldered closed, and good artisans could do about 6 an hour. Once the hermetic double seam was invented, closing of cans became much faster. Today, there are seamers that can close over 1000 cans per minute.

1.4.2 Processing

Processing (heating) of the sealed cans started off as being an all-day event. Appert processed most of his products in boiling water. He did experiment with pressure processing, but at that time ‘digesters’ were quite dangerous and it was not the norm. Around 1863, processors used ‘chemical baths’, where high concentrations of calcium chloride enabled ‘water’ to boil at temperatures approaching 121 °C. This allowed for significantly shorter cooking times. By 1870, basic steam retorts were being used to temperatures up to 121 °C, but they were still quite dangerous and hand operated.

In 1950, the first reel and spiral continuous cooker was introduced and was something very innovative. It was the first retort that did not process in batches. It was called the Anderson-Barngrover Cooker and was taken over by FMC and is currently John Bean Technology (JBT). These enabled cans to be processed much more efficiently at higher speeds, thus reducing production costs.

Around the same time, aseptic filling was started. In 1961, flame sterilization (using direct gas flame heating of rolling cans) was introduced in France, as was the continuous hydrostatic pressure sterilizer. Today, with computers being able to control equipment we have many more options and more precise control. There are combinations of steam and air, raining hot water, and rotation. All of these developments have the objective to optimize temperature distribution and product heating to improve product quality. Modern retorts can process at temperatures up to 145 °C, yielding faster throughput.

1.5 FOOD SAFETY

The canning process was originally developed to preserve food safely and for long periods of time. Food safety is often taken for granted with thermally processed foods; however, this understates the efforts made by food companies to ensure their products are safe for consumers to eat. Safety of thermally processed foods is closely monitored using a system called Hazard Analysis and Critical Control Point, or HACCP (Bauman 1974). HACCP is a system that identifies areas of potential contamination within the food process and builds checkpoints, or CCPs, to ensure that the product safety is maintained at all times. Validation of a thermal process and the determination of appropriate CCP levels is a challenging exercise that requires in depth product knowledge and accurate temperature measurement tools.

HACCP originated in the 1950s, when the National Aeronautics and Space Administration (NASA), the Pillsbury Company, and the U.S. Army Laboratories (Natick) collaborated to devise a food safety system to ensure that food for upcoming space expeditions was guaranteed to be safe. Critical Control Points (CCPs) were part of NASA's engineering management requirements (used to test weapon and engineering system reliability), and it was decided to use this concept for this food safety initiative to eliminate the potentially 'critical failure areas' in the food processing procedures. The programme was a success and the food produced proved to be safe.

There were many food safety incidents over the years, but in 1971 two incidents are identified as being tipping points for the food processing industry to realize that they needed a more formal food safety programme: The first was when Pillsbury had a recall on a product called Farina, a cereal used in infant food in which glass pieces were found; and the second was a botulism incident from canned vichyssoise soup made by Bon Vivant. Pillsbury was fortunate to have had direct involvement in the HACCP programme developed for the production of the space mission food and so implemented a HACCP programme to convince their customers that a similar incident would not happen again. The National Canners Association and FDA learnt about the HACCP programme while deciding how to ensure better canned food safety as a result of the soup incident and so asked Pillsbury to give some of their inspectors HACCP training and by 1973 HACCP was used as part of the low acid food regulations that were published in the USA and soon used internationally (Dick and Launius 2007).

Today, HACCP is used throughout the food industry and is generally considered to be part of Good Manufacturing Practice. It is published by the Food And Agriculture Organization (FAO) of the United Nations World Health Organization (WHO) as part of the Recommended International Code of Practice General Principles of Food Hygiene (Codex Alimentarius 1997).

HACCP is important because it prioritizes and controls potential hazards in food production. By controlling major food risks, such as microbiological, chemical, and physical contaminants, the industry can better assure consumers that its products are as safe as good science and technology allows (http://www.safefoodalliance.com).

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