

WHITEPAPER

Thermal Processing of Food

CONTENTS

- 1. Introduction**
- 2. Blanching**
 - 2.1 Blanching and enzyme inactivation
 - 2.2 Methods of blanching
 - 2.3 Testing of the effectiveness of blanching
- 3. Pasteurization**
 - 3.1 Purpose of pasteurization
 - 3.2 Method for pasteurizing
- 4. Sterilization**
 - 4.1 Canned foods
 - 4.2 Conditions affecting the growth of micro-organisms
 - 4.3 Micro-organisms in retorted foods
 - 4.4 Microbial spoilage of canned foods
 - 4.5 Sterilisation process and equipment
 - 4.6 Containers for thermally treated products
 - 4.7 Cleaning of containers prior to filling
 - 4.8 Seaming of cans
 - 4.9 Death rate curve [D value]
 - 4.10 Thermal death time [TDT] curve
 - 4.11 Some factors affecting heat resistance
 - 4.12 Design of heat sterilization processes
 - 4.13 The “F₀ value”
 - 4.14 The lethality factor “I”

SUMMARY



The use of high temperatures to preserve and ensure the safety of food is based on the effect of microbial destruction. Thermal processing is one of the most widely used unit operations employed in the food industry and is frequently determined as a Critical Control Point [CCP]. This whitepaper covers the main science behind the unit operation and should be used to underpin the development and design of thermal processing steps.

1. Introduction

There are two main temperature categories employed in thermal processing: Pasteurization and Sterilisation. The basic purpose for the thermal processing of foods is to reduce or destroy microbial activity, reduce or destroy enzyme activity and to produce physical or chemical changes to make the food meet a certain quality standard. e.g. gelatinization of starch & denaturation of proteins to produce edible food. There are a number of types of heat processing employed by the food industry.

Mild processes	Blanching Pasteurisation
More severe processes	Canning Baking Roasting Frying

2. Blanching

The primary purpose of blanching is to destroy enzyme activity in fruit and vegetables. It is not intended as a sole method of preservation, but as a pre-treatment prior to freezing, drying and canning. Other functions of blanching include:

- Reducing surface microbial contamination
- Softening vegetable tissues to facilitate filling into containers
- Removing air from intercellular spaces prior to canning

2.1 Blanching and enzyme inactivation

Freezing and dehydration are insufficient to inactivate enzymes and therefore blanching can be employed. Canning conditions may allow sufficient time for enzyme activity. Enzymes are proteins which are denatured at high temperatures and lose their activity. Enzymes which cause loss of quality include Lipoxygenase, Polyphenoloxidase, Polygalacturonase and Chlorophyllase. Heat resistant enzymes include Catalase and Peroxidase

2.2 Methods of Blanching

Blanching is carried out at up to 100°C using hot water or steam at or near atmospheric pressure.

Some use of fluidised bed blanchers, utilising a mixture of air and steam, has been reported. Advantages include faster, more uniform heating, good mixing of the product, reduction in effluent, shorter processing time and hence reduced loss of soluble and heat sensitive components.

There is also some use of microwaves for blanching. Advantages include rapid heating and less loss of water soluble components. Disadvantages include high capital costs and potential difficulties in uniformity of heating.

Steam Blanchers

This is the preferred method for foods with large cut surface areas as lower leaching losses. Normally food material carried on a mesh belt or rotatory cylinder through a steam atmosphere, residence time controlled by speed of the conveyor or rotation. Often poor uniformity of heating in the multiple layers of food, so attaining the required time-temperature at the centre results in overheating of outside layers.

Individual Quick Blanching (IQB) involves a first stage in which a single layer of the food is heated to sufficient temperature to inactivate enzymes and a second stage in which a deep bed of the product is held for sufficient time to allow the temperature at the centre of each piece to increase to that needed for inactivation.

The reduced heating time (e.g. for 10 mm diced carrot, 25 s heating and 50 s holding compared with 3 minutes conventional blanching) results in higher energy efficiency. For small products (e.g. peas, sliced or diced carrots), mass of produce blanched per kg steam increases from 0.5kg for conventional steam blanchers to 6-7kg for IQB.

Hot Water Blanchers

Includes various designs which hold the food in hot water (70 to 100°C) for a specified time, then moves it to a dewatering/cooling section. In blanchers of this type the food enters a slowly rotating

drum, partially submerged in the hot water. It is carried along by internal flights, residence time being controlled by the speed of rotation.

Pipe blanchers consist of insulated tubes through which hot water is circulated. Food is metered into the stream, residence time being controlled by the length of the pipe and velocity of the water.

The blancher-cooker has three sections, a preheating stage, a blanching stage, and a cooling stage. As the food remains on a single belt throughout the process, it is less likely to be physically damaged. With the heat recovery incorporated in the system, 16 to 20 kg of product can be blanched for every kg of steam, compared with 0.25 to 0.5kg per kg steam in the conventional hot water blanchers.

2.3 Testing of the Effectiveness of Blanching

Over blanching causes quality loss due to overheating while under blanching causes quality loss due to increased enzyme activity because enzymes activated and substrates released by heat. The Peroxidase test in vegetables is used to detect enzyme inactivation. This enzyme is not in itself implicated in degradation, but is relatively heat resistant and easily detected. It consists of adding guaiacol solution and hydrogen peroxide solution and observing the development of a brown colour indicating peroxidase activity.

Complete inactivation is not always essential – green beans, peas and carrots with some residual peroxidase activity have shown adequate storage quality at -20°C through with other vegetable (e.g. Brussels sprouts) zero peroxidase activity is essential.

3. Pasteurization

3.1 Purpose of Pasteurization

Pasteurization is a relatively mild heat treatment in which food is heated to <100°C. It is widely used throughout the food industry and is frequently employed as a CCP in various HACCP plans. As a unit operation in food processing it can be used to destroy enzymes and relatively heat sensitive micro-organisms (e.g. non spore forming bacteria, yeast and moulds). In this regard is it used to extend shelf life by several days e.g. milk or months e.g. bottled fruit.

The severity of treatment and resulting extension of shelf life is determined mostly by pH of the food. In low acid foods (pH<4.5), the main purpose is destruction of pathogenic bacteria, while below pH 4.5 the destruction of spoilage microorganisms or enzyme deactivation is usually more important. The extent of heat treatment required is determined by the D value (Decimal reduction time or time to reduce numbers by a factor of 10 or 90% of the initial load) of most heat resistant enzyme or micro-organism which may be present. In terms of checking the effectiveness

of the process, alkaline phosphatase is a naturally occurring enzyme in raw milk with a similar D value to heat-resistant pathogens and so is routinely used as an indicator of adequate pasteurisation. If phosphatase activity is found, it is assumed that pasteurisation is inadequate.

Pasteurization is normally used for the destruction of all disease causing organisms (e.g. pasteurization of milk) or the destruction or reduction in the number of spoilage organisms in certain foods e.g. vinegar.

Table: Milk Pasteurizing Temperatures

Temperature	Time
63°C	For 30 min [low temperature long time LTLT]
72°C	For 15 sec [primary high temperature short time, HTST method]
89°C	For 1.0 sec
90°C	For 0.5 sec
94°C	For 0.1 sec
100°C	For 0.01 sec

These temperatures are equivalent and are sufficient to destroy the most heat sensitive of the non-spore-forming pathogenic organisms. Milk pasteurization temperatures are also sufficient to destroy all yeasts, moulds, gram negative bacteria and many gram positive. The two groups of micro-organisms that survive pasteurisation temperatures used in milk are:

Thermoduric: organisms that can survive exposure to relatively high temperatures but do not necessarily grow at these temperatures e.g. *Streptococcus* and *Lactobacillus*.

Thermophilic: organisms that not only survive relatively high temperatures but require high temperatures for their growth.

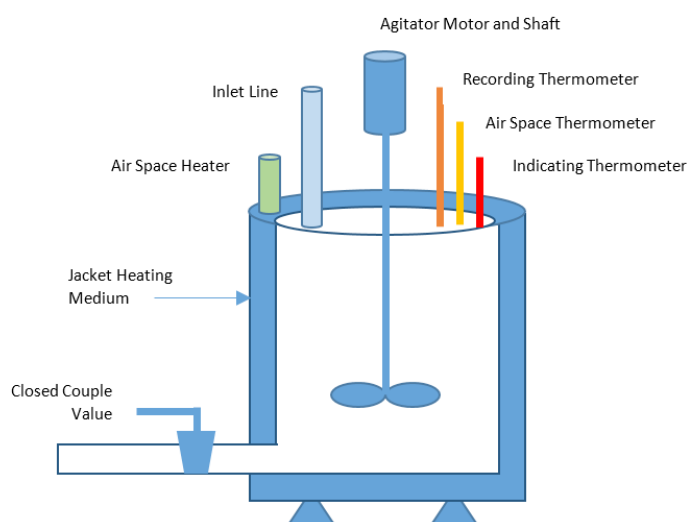
3.2 Method for Pasteurizing

There are number of basic methods of pasteurization widely used in the industry.

Batch (holding) Method

In this method every particle (e.g. milk) must be heated to at least 63°C and held for at least 30 minutes, however this is not used commercially these days.

Fig: Batch Pasteurizer



High-Temperature-Short-Time (HTST)

In this method the heating of every particle of milk to at least 72°C and holding for at least 15 seconds. Carried out as a continuous process. Ultra Heat Treatment (UHT) a sterilisation treatment, can also be performed using higher temperatures and shorter times e.g. 1 s at 135°C

Typical Equipment employed for this method includes:

- Plate heat exchanger (PHE)
- Holding tube – sized to ensure the correct treatment time is achieved
- Holding tanks – for storage of the raw and pasteurised milk
- Balance tank – to assist in maintaining full flow, and to take returned milk if temperature not achieved
- Control and monitoring system – to record temperature and to divert flow back to the balance tank if correct temperature is not achieved.

Pasteurization of packaged foods

Some liquid foods (e.g. beer and fruit juices) are pasteurized after filling into containers. Hot water is normally used if the food is packaged into glass, to reduce the risk of breakage due to thermal shock. Maximum temperature between the container and the liquid are 20°C for heating and 10°C for cooling. Metal

and plastic containers may be pasteurized using steam-air mixtures or hot water. Pasteurisers may be batch or continuous. A simple batch type may be a water bath in which crates of the food are heated to a pre-set temperature, and then cooled by draining and adding cold water. A continuous version may convey containers through a hot water bath followed by a cold water bath. Steam tunnels may also be used with the advantage of faster heating, resulting in shorter residence time and smaller equipment. Temperatures in the heating zones may be controlled depending on the amount of air present. Acid products such as fruit or acidified vegetables like beetroot can be pasteurized in a retort.

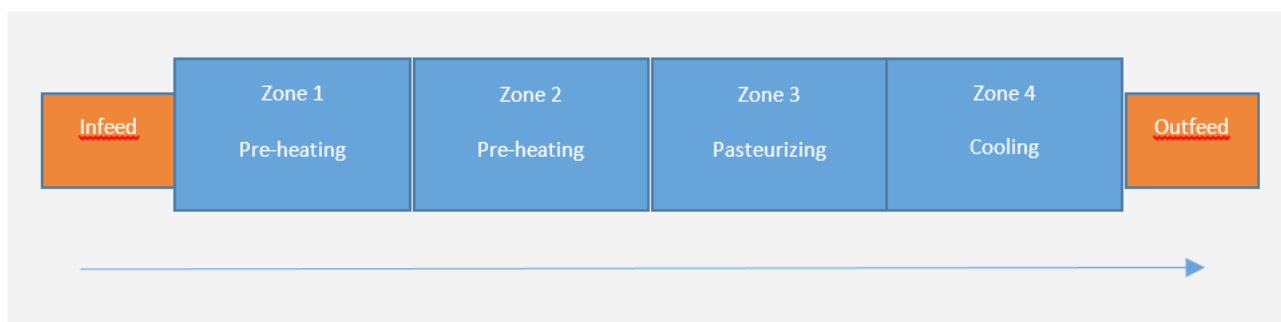
Fig: Tunnel Pasteurizer (bottom of page)

4. Sterilisation

Unlike pasteurized products where the survival of heat resistant microorganisms is accepted, the aim of sterilization is the destruction of all bacteria including their spores. Heat treatment of such products must be severe enough to inactivate/kill the most heat resistant bacterial microorganisms, which are the spores of Bacillus and Clostridium. Food products filled in sealed containers are

exposed to temperatures above 100°C in pressure cookers. Temperatures above 100°C, usually ranging from 110-121°C depending on the type of product, must be reached inside the product. Products are kept for a defined period of time at temperature levels required for the sterilization depending on type of product and size of container.

If spores are not completely inactivated, vegetative microorganisms will grow from the spores as soon as conditions are favourable again. Favourable conditions will exist when the heat treatment is completed and the products are stored under ambient temperatures. The surviving microorganisms can either spoil preserved food or produce toxins which cause food poisoning. Amongst the two groups of spore producing microorganisms Clostridium is more heat resistant than Bacillus. Temperatures of 110°C will kill most Bacillus spores within a short time. In the case of Clostridium temperatures of up to 121°C are needed to kill the spores within a relatively short time. These sterilization temperatures are needed for short-term inactivation (within a few seconds) of spores of Bacillus or Clostridium. These spores can also be killed at slightly lower temperatures, but longer heat treatment periods must be applied.



From the microbial point of view, it would be ideal to employ very intensive heat treatment which would eliminate the risk of any surviving microorganisms. However, most food products cannot be submitted to such intensive heat stress without suffering degradation of their sensory quality or loss of nutritional value (destruction of vitamins and protein components). In order to comply with above aspects, a compromise has to be reached in order to keep the heat sterilization intensive enough for the microbiological safety of the products and as moderate as possible for product quality reasons.

“Commercial sterility” implies less than absolute destruction of all micro-organisms and spores, but any remaining would be incapable of growth in the food under existing conditions. Time-temperature combination required to inactivate most heat resistant pathogens and spoilage organisms. Most heat resistant pathogen is *Clostridium botulinum*. Most heat-resistant (non-pathogenic) spoilage microorganisms are *Bacillus stearothermophilis* and *Clostridium thermosaccharolytom*. Severity of treatment can result in substantial changes to nutritive and sensory characteristics. Two typical forms of sterilised product are:

- In package sterilised, in which product is packed into containers and the container of product is then sterilised e.g. canning, some bottled products, retort pouches
- UHT or Aseptically processed

products in which the product and the package is sterilised separately then the package is filled with the sterile product and sealed under specific conditions e.g. long life milk, tetrapack or combibloc fruit juices and soups etc.

4.1 Canned Foods

Canned foods are processed so that they are shelf stable. They should be ‘commercially sterile’. That means if any microbes survive the processing, they should not be capable of growing (and therefore spoiling the contents) under the normal storage conditions of the can. Most canned foods are sterile (i.e. there are no living organisms present) but some may contain viable organisms which cannot grow because of unsuitable conditions e.g.

- Water
- Temperature
- pH
- water activity
- preservatives

If a canned food is spoilt by microbial spoilage, examination of the microbial types that caused it can pinpoint the offending errors in processing or handling.

4.2 Conditions Affecting the Growth of Microorganisms

Water

Water content and the availability of water A_w can affect the growth of microbes in food. (See Whitepaper on Water)

Temperature

Temperature influences the rate of growth of microbes as well as determining which microbes will grow. Microbes grow fastest at their optimum temperature. For convenience microbes can be divided into groups which have similar optimum temperature for growth.

Table: Growth Temperatures (°C) for Microbial Growth

Group	Min.	Opt.	Max.
Thermophiles	40	55	75
Mesophiles	5	37	45
Psychotrophs	-3	20	30

Oxygen Requirements

Micro-organisms can be classified into three general groups regarding their oxygen requirements.

- Aerobes – can only grow in the presence of oxygen
- Anaerobes – Can only grow in the absence of oxygen
- Facultative Anaerobes – adaptable. Grows best aerobically but can grow anaerobically

pH

In regard to pH, microbes have ideal pH ranges within which they grow as follows:

Table: pH ranges for Microbial Growth

Group	pH
Low acid	>5.0
Medium acid	4.5 - 5.0
Acid	3.7 - 4.5
High acid	< 3.7

4.3 Types of Microorganisms Important in Retorted Foods

A number of organisms are important when it comes to the safe processing of canned foods.

Table: Microorganisms Important for Retorted Foods

Type	Species	Description
Thermophilic Spore Formers	Flat Sours - <i>B.sterotherophilus</i>	High heat resistance, product acid, don't produce gas, found in sugar, salt and spices
	Thermophilic Anaerobes - <i>C.thermosaccharolyticum</i>	High heat resistance, product acid and gas [CO ₂]
	Sulphide types - <i>Desulfotomaculum nigrificans</i>	High heat resistance, produce H ₂ S
Mesophilic Spore Formers [The process should be designed to kill these microbes]	<i>C.sporogenes, C.botulinium</i>	Produce gas [CO ₂ and sometimes H ₂ , moderate heat resistance
	Bacillus spp - <i>B.polymyxa, B.macerans</i> etc	Moderate to low heat resistance, some may grow in acid foods
Non Spore Forming Microbes	Various	<p>Occur only in grossly under processed or leaking caps</p> <p>Can be almost any microbe depending on acidity of the product</p> <p>May or may not produce gas</p> <p>Usually in mixed populations</p>

4.4 Microbial Spoilage of Canned Foods

There are a number of important factors which can cause spoilage of canned foods.

Table: Factors Affecting Spoilage of Canned Foods

Type	Description
Pre-process spoilage	Delays between filling and retorting can allow microbes to grow and produce gas or spoil food. Retorting kills microbes but the can will be swollen and food spoilage.
Not processed	Filled cans missing retort
Under processed	<p>Caused by:</p> <ul style="list-style-type: none"> • Incorrect calculations • Faulty retort operation • Operator error e.g. inadequate venting • Poor retort design e.g. cold spots • Higher spore load – poor or different raw ingredients. <p>Under processing usually still kills vegetative cells. Survivors are usually mesophilic spore formers or moderate heat resistance</p>
Thermophilic Spoilage	Canning operations are sometimes not designed to kill thermophiles of high heat resistance [e.g. <i>B.stearothermophilus</i> of D 121.1 = 5 min] as they do not grow below 40oC. If they survive they will grow if there is either slow cooling or storage at high temperatures. Thermophilic spore formers will be found in pure cultures.
Leaker Spoilage	<p>If can seams are inadequately formed, microbes may enter can after processing, particularly when the can is moist e.g. during cooling. Usual contamination is a mixed of a variety of non-heat resistant microbes</p> <p>Cans may leak food or if leakage point is blocked with food, they can swell.</p>

4.5 Sterilisation Process and Equipment

The sterilization process in the canned product can be subdivided into three phases. By means of a heating medium (water or steam) the product temperature is increased from ambient to the required sterilization temperature (phase 1 = heating phase). This temperature is maintained for a defined time (phase 2 = holding phase). In (phase 3 = cooling phase) the temperature in the can is decreased by introduction of cold water into the autoclave.

Autoclaves or retorts

In order to reach temperatures above 100°C (“sterilization”), the thermal treatment has to be performed under pressure in pressure cookers, also called autoclaves or retorts.

In autoclaves or retorts, high temperatures are generated either by direct steam injection, by heating water up to temperatures over 100°C or by combined steam and water heating. The autoclave must be fitted with a thermometer, pressure gauge, pressure relief valve, vent to manually release pressure, safety relief valve where steam is released when reaching a certain pressure, water supply valve and a steam supply valve. The steam supply valve is applicable when the autoclave is run with steam as the sterilization medium or when steam is used for heating up the sterilization medium water.

Simple small autoclaves

These are usually vertical autoclaves with the lid on top. Through the opened lid the goods to be sterilized are loaded into the autoclave. The cans are normally placed in metal baskets. The baskets are placed in the autoclave, either singly or several stapled on top of each other. Before starting the sterilization, the lid must be firmly locked onto the body of the autoclave. The autoclave and lid are designed to withstand pressures up to 5.0 bar. These types of autoclaves are best suited for smaller operations as they do not require complicated supply lines and should be available at affordable prices.

Larger autoclaves

These are usually horizontal and loaded through a front lid. Horizontal autoclaves can be built as single or double vessel system. The double vessel systems have the advantage that the water is heated up in the upper vessel to the sterilization temperature and released into the lower (processing) vessel, when it is loaded and hermetically closed. Using the two-vessel system, the heat treatment can begin immediately without lengthy heating up of the processing vessel and the hot water can be recycled afterwards for immediate use in the following sterilization cycle.

If steam is used instead of water as the sterilization medium, the injection of steam into a single vessel autoclave will instantly build up the autoclave temperature desired for the process.

Rotary Autoclaves

Another technology employed is rotary autoclaves in which the basket containing the cans rotates during sterilization. This technique is useful for cans with liquid or semi-liquid content as it achieves a mixing effect of the liquid/semi-liquid goods resulting in accelerated heat penetration. The sterilization process can be kept shorter and better sensory quality of the goods is ensured.

At the final stage of the sterilization process the products must be cooled down as quickly as possible. This operation is done in the autoclave by introducing cold water. The contact of cold water with steam causes the latter to condense with a rapid pressure drop in the retort. However, the overpressure built up during thermal treatment within the cans, jars or pouches remains for a certain period.

During this phase, when the outside pressure is low but the pressure inside the containers is still high due to high temperatures there, the pressure difference may induce permanent deformation of the containers.

Fig (bottom of page): Pressure inside autoclave (blue) and inside cans (red) during heating and cooling phase

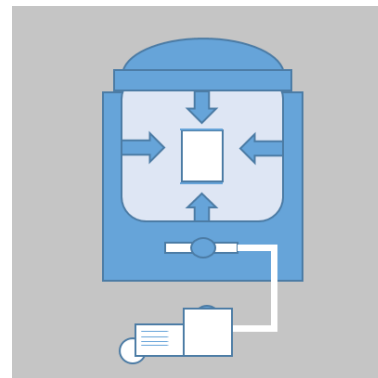
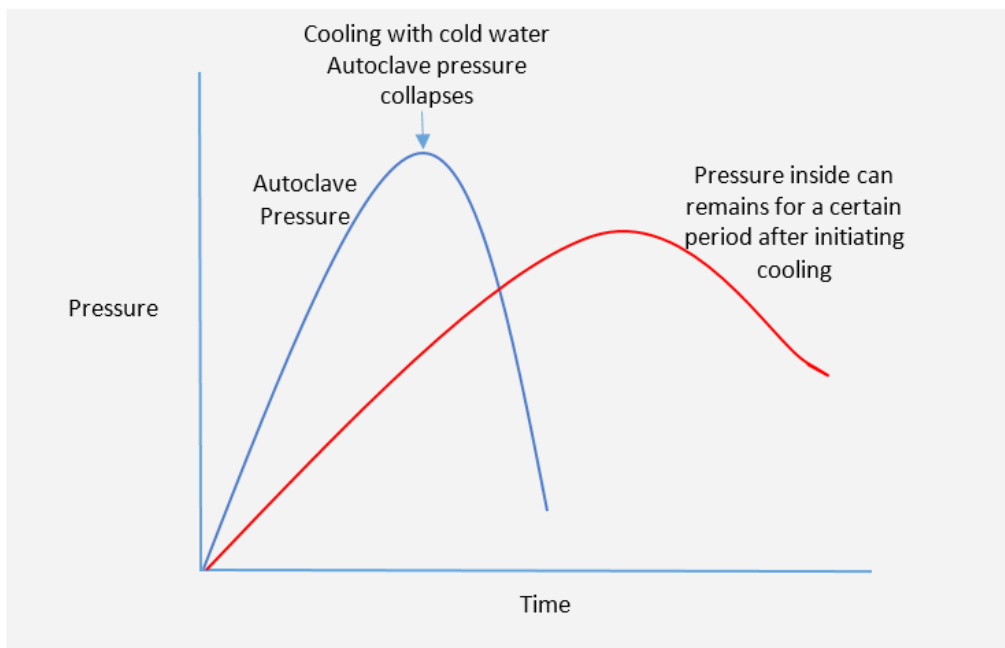


Fig: Producing counter pressure on cans (see arrows) inside the autoclave with compressed air



Therefore, high pressure difference between the autoclave and the thermal pressure in the containers must be avoided. This is generally achieved by a blast of compressed air into the autoclave at the initial phase of the coolings. Sufficient hydrostatic pressure of the introduced cooling water can also build up counter pressure so that in specific cases, in particular where strong resistant metallic cans are used, the water pressure can be sufficient and compressed air may not be needed. For the stabilization of metallic cans, stabilization rims can be moulded in lids, bottom and bodies.

4.6 Types of Containers for Thermally Treated Products

Containers for heat-preserved food must be hermetically sealed and airtight to avoid recontamination from environmental microflora. Most of the thermally preserved products are in metal containers (cans). Others are packed in glass jars or plastic or aluminium/plastic laminated pouches.

Type	Description
<p>Metal containers are cans or “tins”</p>	<p>Produced from tinplate. They are usually cylindrical. However, other shapes such as rectangular or pear-shaped cans also exist. Tinplate consists of steel plate which is electrolytically coated with tin on both sides. The steel body is usually 0.22 to 0.28mm in thickness. The tin layer is very thin (from 0.38 to 3.08 μm). In addition, the interior of the cans is lined with a synthetic compound to prevent any chemical reaction of the tinplate with the enclosed food.</p> <p>Tin cans consist of two or three elements. In the case of three-piece steel cans, they are composed of the body and two ends (bottom and lid). The body is made of a thin steel strip, the smaller ends of which are soldered together to a cylindrical shape. Modern cans are induction-soldered and the soldering area is covered inside with a side-strip coating for protection and coverage of the seam. The use of lead soldered food cans was stopped decades ago. Hence the risk of poisonous lead entering canned food no longer exists.</p> <p>Two-piece steel cans have a lid similar to the three-piece cans but the bottom and body consist of one piece, which is moulded from a circular flat piece of metal into a cup. These cup-shaped parts may be shallow-drawn (with short side wall) or deep-drawn (with longer side walls). However, the length of the side walls is limited through the low moulding ability of steel (example: tuna tins 42/85mm, i.e. side wall: diameter =1:2)</p> <p>Aluminium is frequently used for smaller and easy-to-open cans. Aluminium cans are usually deep-drawn two-piece cans, i.e. the body and the bottom end are formed out of one piece and only the top end is seamed on after the filling operation. The advantages of aluminium cans compared to tin cans are their better deep-drawing capability, low weight, resistance to corrosion, good thermal conductivity and easy recyclability. They are less rigid but more expensive than steel plate cans.</p>

Type	Description
Glass jars	Glass jars are sometimes used for meat products but are not common due to their fragility. They consist of a glass body and a metal lid. The seaming panel of the metal lid has a lining of synthetic material. Glass lids on jars are fitted by means of a rubber ring.
Retortable pouches	<p>Retortable pouches, which are containers made either of laminates of synthetic materials only or laminates of aluminium foil with synthetic materials, are of growing importance in thermal food preservation. Thermo-stabilized laminated food pouches, have a seal layer which is usually PP (polypropylene) or PP-PE (polyethylene) polymer, and the outside layers are usually made of polyester (PETP) or nylon. They can be used for frankfurters in brine, ready-to-eat meat dishes etc. From certain laminated films, for instance, polyester / polyethylene (PETP/PE) or polyamide/polyethylene (PA/PE), relatively rigid container can be made, usually by deep drawing.</p> <p>They are used for pieces of cured ham or other kinds of processed meat. Small can-shaped round containers are made from aluminium foil and polyethylene (PE) or polypropylene (PP) laminate and are widely used for small portions, particularly of sausage mix. PE or PP permits the heat-sealing of the lid made of the same laminate onto these containers, which can then be subjected to intensive heat treatment of 125°C or above.</p> <p>One advantage of the retortable pouches/laminated containers is their good thermal conductivity which can considerably reduce the required heat treatment time and hence is beneficial for the sensory product quality.</p>

4.7 Cleaning of containers prior to filling

Rigid containers (cans, glass jars) are delivered open to meat processing plants, i.e. with the lids separate. During transport and storage, dust can settle inside the cans, which must be removed prior to filling the cans. This can be done at the small-scale level by manually washing the cans with hot water. Industrial production canning lines are equipped with steam cleaning facilities, where steam is blown into the cans prior to filling.

4.8 Seaming of Cans

After the can is filled with the product mix the can is sealed with a tight mechanical structure - the so-called double seam. The double seam, in its final form and shape, consists of three layers of lid (D, black colour) and two layers of body material (D, striated). The layers must overlap significantly and all curves must be of rounded shape to avoid small cracks. Each double seam is achieved in two unit operations referred to as “first operation” (A, B) and “second operation” (C, D).

The can covered with the lid is placed on the base plate of the can seaming machine. The can is moved upwards while the seaming chuck keeps the lid fixed in position. The pressure applied to the can from the base plate can be regulated and must be strong enough to ensure simultaneous movement of the lid and the can to avoid scratching-off of the sealing compound.

In the first operation the lid hook and body hook are interlocked by rolling the two into each other using the seaming roll with the deep and narrow groove. The body hook is now almost parallel to the lid hook and the curl of the lid adjacent to or touching the body wall of the can. In the second operation, the interlocked hooks are pressed together by a seaming roll with a flat and wide groove. Wrinkles are ironed out and the rubber-based material is equally distributed in the seam, filling all existing gaps thus resulting in a hermetically sealed container.

Design of Seaming Rolls

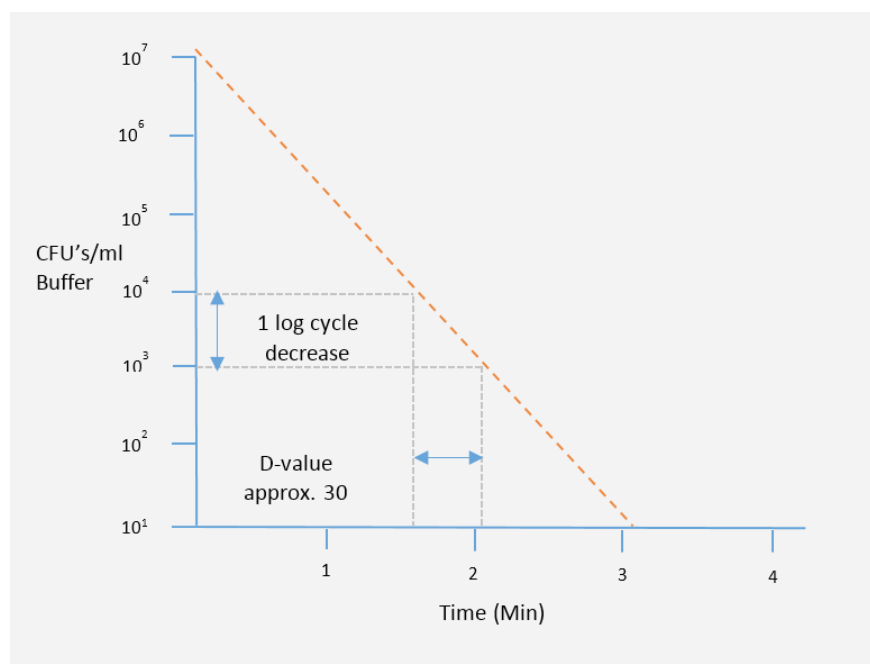
The seaming rolls for the first and second operations are designed differently in order to facilitate the respective operations. The seaming roll for the first operation has a deep but narrow groove to interlock body and lid hook (rolling the hooks into each other) The seaming roll for the second operation has a flat but wide groove to press

the interlocked hooks together (sealing the seam). The first action (first roll) is rolling (interlocking) the hooks, the second action (second roll) is compressing (sealing) the seam.

4.9 Death Rate Curve (D value)

At slightly elevated temperatures most microbes will grow and multiply quickly. At relatively high temperatures, microbes can be destroyed. However, there is a lot of variation within any one population of microbes of the same species – most will be killed relatively quickly, others can survive much longer. If a population of microbes is held at a constant high temperature, the number of surviving spores or cells plotted against time (on a logarithmic scale) will look like the following graph – which is referred to as the ‘death rate curve’.

Fig: Death Rate Curve (D-value)



This graph is a straight line – it is referred to as the Logarithmic order of death.

Logarithms refers to the power to which a base must be raised to produce a given number. For example, if the base is 10, then the logarithm of 1,000 (written $\log 1,000$ or $\log_{10} 1,000$) is 3 because $10^3 = 1,000$. The “death rate curve” is a straight line when plotted using a logarithmic scale – this means that if in some time period the number was reduced from 1000 to 100 (divided by ten, sometimes referred to as “1 log reduction”), then if you had held the microbes at the same temperature for twice that time period, the number would have been reduced to 1 (divided by 100, or “2 log reductions”).

The time period for each “log reduction” is referred to as the decimal reduction time or D value. For example the D-value of *Bacillus stearothermophilus* a common spoilage microorganism at 121°C is about 4 minutes. This means if you had cans of food product each containing 1000 of these spore and you held the product at a constant temperature of 121°C

- After 4 minutes (1 D-value) there would be 100 spores surviving in each can (1 log reduction)
- After 8 minutes (twice D-value) there would be 10 spores surviving in each can (2 log reductions)
- After 12 minutes (3 times D-value) there would be 1 spore surviving in each can (3 log reductions)

If this food product, with an initial count 1000 spores of *Bacillus stearothermophilus*, was held for 16 minutes at 121°C it would result in 4 log reductions, or 0.1 spores surviving in each can. 0.1 spores per can means that on average there would be one spore surviving in each group of ten cans. After holding for 20 minutes there would be one spore per 100 cans and so on.

Based on this:

- The higher the number of microbes initially present the longer it takes to reduce the numbers to an acceptable level. Therefore, good quality raw materials and hygienic pre-processing is essential if the commercial sterility of the processed product is to be assured
- It is theoretically impossible to destroy all cells – therefore we reduce the probability of spoilage to an acceptable small number – perhaps 1 in 1 million. The probability of a pathogen surviving must be even less – perhaps one in one billion or less.
- The above refers to holding the product at a constant temperature. Remember destruction of microbes is temperature dependent – they get killed more quickly at the higher temperatures. Therefore you would expect that if you increase the temperature, decimal reduction time (D-value) would decrease.

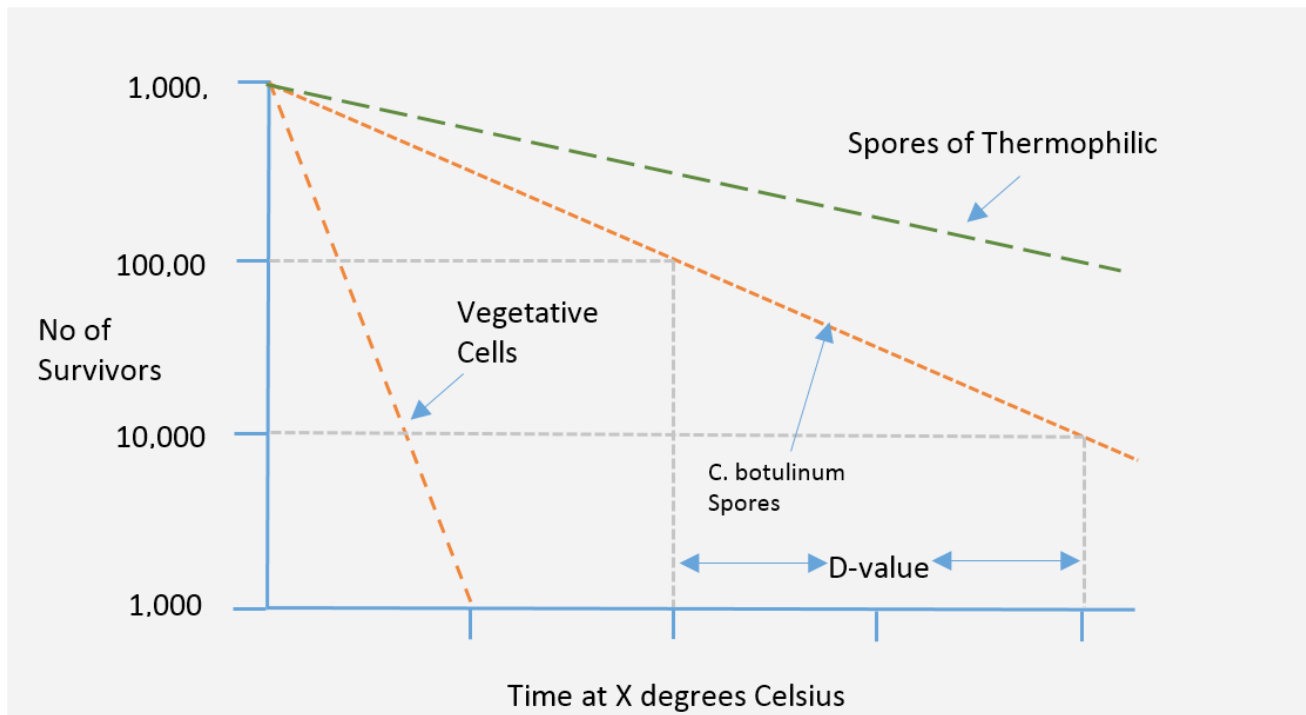
4.10 Thermal death time (TDT) curve

If D-value versus time is plotted – again on a logarithmic scale, the graph looks very similar to the one previously. This one is called the Thermal death time (TDT) curve. This time the straight line graph means that if you change the temperature by a certain amount, the D-value will change by a factor of 10. If you had changed it by twice that amount, D-value will change by a factor of 100. The change in temperature to cause a factor of the ten change in D-value is referred to as that z-value.

Fig : Thermal Death Rate Curves

The z-value for *Bacillus stearothermophilus* is 10°C. Remember the D-value for this microorganism at 121°C is 4 minutes. Therefore if you held the containing this microbe at 111 oC (10 oC, or one z-value, less than 121 oC), D-value would be 400 minutes.

That is, for *Bacillus stearothermophilus*, 4 minutes at 121°C will have the same effect (one log reduction in spores) as 40 minutes at 111oC, which would have the same effect as 400 minutes at 101°C. It is obvious why using high processing temperatures is an advantage. The D-values of different microbes differ greatly – for example, the D-value of *Clostridium botulinum* at 121°C is about 0.21 minutes. However the z-value of microorganisms is close to 10°C.



4.11 Some Factors that Affect the Heat Resistance of Micro-organisms

A range of factors affect the heat resistance of micro-organisms. The most important are:

Type of micro-organism – species and strains differ, spores are more resistant than vegetative cells

Conditions during cell growth or spore formation – e.g. spores produced at higher temperature are more heat resistant, stage of growth and the type of medium in which they grow can also affect heat resistance

Conditions during heat treatment including pH. Pathogenic and spoilage bacteria are less heat resistant at more acid (low) pH, yeasts and fungi are more acid tolerant but less heat resistant than bacterial spores.

Aw – moist heat is more effective than dry heat.

Composition – e.g. protein, fats and high concentration of sucrose increases heat resistance

D and z-values of enzymes are generally in a similar range to those of micro-organisms, but some are very heat resistant.

4.12 Design of Heat Sterilization Processes

The design of heat processes must:

- Take account of the type of microorganism (determined largely by food conduction e.g. acidity) and its heat resistance.
- Result in an acceptably low probability of survival of spores
- Be effective in every part of the food

In low acid foods ($\text{pH} < 4.5$), *Clostridium botulinum*, is the most dangerous, heat resistant spore forming pathogen ($D_{121} = 0.1$ to 0.2 min). It is anaerobic and so can survive and grow in a sealed can. Its destruction is a minimum requirement of heat sterilisation. This is often interpreted as “12D” process – that is, the product must be treated for 12 times the D-value of the microbe. For *Clostridium botulinum* this is a process equivalent to about 2.5 minutes at 121°C – this is commonly known as a “botulinum cook”. Normally a more severe heat treatment is required to destroy other more heat resistant spoilage bacterial. For example *Bacillus stearothermophilus* (thermophile – won’t grow at less than 35°C , so proper can cooling is important) can produce the “flat sour” defect. Its D-value at 121°C is commonly around 4 min, but it is not of health significance.

In high acid foods ($\text{pH} < 4.5$) the anaerobic pathogens cannot grow or produce toxins.

Spoilage microorganisms are quickly killed at temperatures of about 90°C. Therefore the minimum treatment applied to high acid foods often involves ensuring every part of the product reaches a temperature of at least 95°C e.g. pasteurisation. In acid foods where the pH is close to 4.5 (e.g. foods such as tomatoes and pears) *Clostridium butyricum* can cause spoilage. It is a common soil borne micro-organism, and grows easily on surfaces in the food plant. It is not killed by processes commonly used for acid foods and can cause swelling/bursting of the cans in about 2 weeks.

4.13 The “F₀ value”

The amount of heat treatment applied to a food product can be measured using the F-value-concept. This concept is practiced in canning plants, in particular as part of the HACCP-system. The size and format of cans is of utmost importance for the speed of heat penetration. Temperatures to be achieved at the “cold point” of the can where the heat arrives last, are reached faster in small cans due to the shorter distance to the heat source than in large cans.

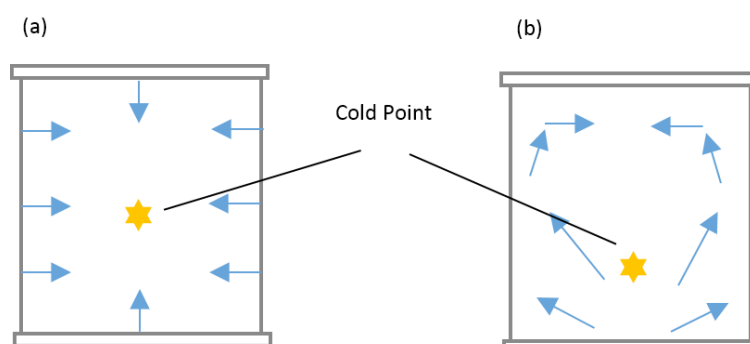
The F₀ value is a measure of the “sterilising value” of a process. It can be thought of as the time required at a temperature of 121°C to reduce microbial numbers by the same amount as the actual process being considered.

Remember processes are not always carried out at 121°C and certainly product temperature is not constant at this temperature throughout the process.

It therefore provides a basis for comparing different heat sterilisation procedures if two processes have the same The F₀ value, they provide the same level of sterilisation.

The temperature of 121°C is simply an arbitrary reference – there is nothing special about this particular temperature. Why choose and off temperature like 121°C? In the past someone decided 250°F which is equal to 121°C was a good reference temperature. More accurately it is 121.1°C.

A similar concept to F₀ often used in determining the heat treatment of beers and other high acid foods is “pasteurising units” (or PU’s) – 1 PU is equivalent to



pasteurising at 60°C for one minute. The minimum treatment for low acid products, the “botulinum cook”, therefore has a F_0 of 2.5 minutes (i.e. $12 \times 0.21 = 2.5$ min)

The required level of heat treatment (F_0 of the process) may vary with factors such as pH and carbohydrate level, and type and expected level of contamination with micro-organisms. Other chemical additives may also assist inhibition of micro-organisms e.g. salt, alcohol, nitrite and misin (these last two are both ‘sporostatic’ and stop spores germinating and so enable the use of lesser processing conditions). Also some products require additional processing to achieve the required level of cook e.g. baked beans must be soft enough.

Table: F-values (per minute) for the temperature range of 100°C to 135°C

°C	F-value	°C	F-value
100	0.0077	118	0.4885
101	0.0097	119	0.6150
102	0.0123	120	0.7746
103	0.0154	121	1
104	0.0194	122	1.2270
105	0.0245	123	1.5446
106	0.0308	124	1.9444
107	0.0489	125	2.4480
108	0.0615	126	3.0817
109	0.0775	127	3.8805
110	0.0975	128	4.8852
111	0.1227	129	6.1501
112	0.1545	130	7.459
113	0.1545	131	9.7466
114	0.1945	132	12.2699
115	0.2449	133	15.4560

4.14 The Lethality Factor “L”

Given that the F_0 is based on a constant reference temperature of 121°C, but the product is mostly at a different temperature, how can the F_0 be calculated? This is the purpose of the Lethality Factor or “L-value”. It is defined as the time at 121.1°C which is equivalent in sterilising value to one minute at some other temperature. One minute at some temperature will contribute “L” minutes worth of F_0 , where “L” is the L_0 value for the temperature concerned. The L-value is dependent on the z-value of the micro-organism being considered, but for most purposes $z=10^\circ\text{C}$. L-value can be calculated from the formula or can be read from a table.

$$L = 10(T-121.1)/z$$

An example – A product is held at a temperature of 118°C for a period of 12 minutes. Ignoring other heating and cooling periods, what is the F_0 value of this process? From the formula, the L-value for 118°C is 0.490. That is each minute at 118°C contributes 0.490 minutes to the F_0 value. Therefore the F_0 value of this process = $12 \times 0.490 = 5.9$ minutes.

Calculating the F_0 value when temperatures vary

In a real retort process the temperature of the product is not constant – it slowly heats up, will stay at a constant temperature for some time, then cool down again. The period when the product is heating and

cooling contribute significantly to the severity of the process. To calculate the F_0 value of such a process, the contribution of the varying temperatures must be converted to an equivalent F_0 value. This is achieved based on the L-value, as indicated previously.

Graphical Method

This involves drawing a graph of the product temperature vs time, then looking up the L-value of each temperature, and plotting L-value against time. The area under this graph is a measure of the L-value.

Trapezoidal Integration or General Method

For this method, determine the L-value for each temperature measurement, add the L-value together then multiply by the time interval in minutes between temperature measurements (if temperatures are measured every minute there is no need to multiply). Obviously as the severity of the process is related to the time spent at high temperatures the faster a product is heated the greater will be the severity of the process (for the same process time)

A number of factors affect the rate at which a product heats inside a container:

- Type of container – for example glass is not a good conductor of heat so you would expect product in a glass jar to heat more slowly than an equivalent size/shape metal can.

- Size and shape of the container – obviously a large container will take longer to heat than a small container
- Retort temperature – a higher retort temperature will result in more rapid heating but also may lead to more over processing of product near the package surface.
- Agitation of the containers will increase the heating rate by mixing the contents of the container, especially with viscous or semi-solid foods. End over end agitation is better than axial agitation)
- Type of product – obviously different products conduct heat more or less easily and have different heat capacities. Some products are more viscous than others which can have a particularly significant effect in agitating retorts. Therefore different products will heat at a different rate.
- Headspace – insufficient headspace can also affect the rate of heating, especially in an agitating retort.

Therefore if any of these factors change, the severity of the process needs to be re-evaluated.

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