5 Thermal Processing

5.1 Introduction

The purpose of thermal processing foods is to destroy pathogenic and spoilage micro-organisms and their spores as well as to inactivate enzymes and metabolic reactions resulting in senescence. However, high temperatures can also degrade product appearance, texture, and nutrient quality. The advantages of thermal processing in terms of food safety and increased shelf life must be balanced with the disadvantages of loss of nutrient and sensory attributes.

A number of thermal processing methods are commercially used each using a different temperature and treatment time strategy:

Blanching:
This is a mild heat treatment, usually applied to fruits and vegetables to denature enzymes and is often used before freezing. It uses either hot water above 80°C or live steam.

Pasteurisation:
Pasteurisation destroys pathogenic micro-organisms and extends the shelf life of a food. Pasteurised products may still contain many viable organisms capable of growing and causing spoilage defects. An example is milk in which pasteurisation is usually combined with another means of preservation such as refrigeration. The levels of pasteurisation used to thermally process milk are:

- Low Temperature Long Time (LTLT): 63°C for 30 minutes
- High Temperature Short Time (HTST): 72°C for 15 seconds
- Ultra High Temperature (UHT): 135°C (or above) for 2 seconds

Commercial Sterilisation:
Commercial sterilisation refers to the destruction of all pathogenic and toxin-forming organisms, as well as other types of organisms which, if present, could result in food spoilage under normal handling and storage conditions. These foods may contain a small number of heat resistant bacterial spores, but under normal handling and storage conditions will not multiply. Types of commercially sterile processes include canning, bottling, and aseptic processing. Most commercially sterile food products have a shelf life exceeding two years.

Sterilisation
Sterilisation refers to the complete destruction of all micro-organisms, including both vegetative cells and spores.

Called the logarithmic order of death, bacteria are destroyed by heat at a rate that is proportional to the number present in the food being heated. Expressed as the "D-value," or decimal reduction time this is the time in minutes at a specific temperature required to destroy 90% (or one log cycle) of the organisms in a population. The time (or number of D-values) required depends on the processing temperature, type of micro-organism(s) that are in the food and the physical and chemical characteristics of the food product.

Example:

Consider a food containing 1,000,000 viable, pathogenic micro-organisms. The D-value for killing this pathogen is one minute at 121°C. Determine the time taken to reduce the population to 1 viable cell.

Solution:

The reduction of pathogenic micro-organisms in a food that is thermally processed at 121°C is given by

Cell count	Elapsed time at 121°C
1,000,000 to 100,000	1 min
100,000 to 10,000	1 min
10,000 to 1,000	1 min
1,000 to 100	1 min
100 to 10	1 min
10 to 1	1 min
Total elapsed time	= 6 mins

This is referred to as a "6D process," in which only 1 in 1 million bacteria survive the thermal processing. In a 12D process 1 in 1 million million cells survive. This is commonly used in commercial canning.

The important factors for assuring adequate thermal processing include size and shape of the can, ingredients and pH of the food product and viscosity of the food product. The mechanisms of heat transfer are radiation, conduction and convection. In radiation, infrared energy is absorbed by food surface while conduction is the transfer of heat through the solid body and convection is through convection currents in liquids and gases.

Not all packaging materials conduct heat at the same rate. The cold point in a can or food mass is the location that is last to reach the final heating temperature. A thermocouple can be used to determine location of the cold point. Higher temperatures facilitate shorter processing times for microbial destruction, and shorter time favours retention of desirable quality attributes.

5.2 Thermal Death

As with all living things, micro-organisms are sensitive to heat. To destroy a micro-organism requires thermal energy that must be sufficient to be lethal. This energy must be held for a sufficient period of time to ensure death. For each type of micro-organism it is necessary to identify the temperature and exposure time that is required.

Temperature is a measure of the vibrational energy of molecules. There is a certain probability that the organism will die after a given time above some threshold temperature. The cause of thermal death is thought to be due to the irreversible denaturation of certain enzymes critical for DNA or RNA replication.

Empirical observations have shown that at constant temperature, many micro-organisms will die at a rate that is first order with respect to time. The time rate of change of organisms that have survived the heat treatment, can be described mathematically as

$$\frac{dN}{dt} = -kN$$

By considering isothermal conditions the assumption that k is a constant is valid. The equation holds true for a wide range of organisms even when more than one species of organism may be present. The number of surviving micro-organisms is therefore found from

$$\int_{N(t_o)}^{N(t)} \frac{dN}{N} = -k \int_{o} dt$$

Integrating and rearranging

$$N(t) = N(t_o)e^{-k(t-t_o)}$$

where $N(t_o)$ is the number of organisms initially present at time t_o. Note that the number of remaining viable organisms will approach zero only as the treatment time approaches infinity. In other words, sterility can not be achieved according to this model. The model is, however, widely used. This is because the model is based on probability. This is due to the fact that this is a mathematically continuous model used to describe the behaviour of a collection of discrete organisms, each of which will react to the application of heat in a slightly different way.

The time required to reduce the population of a particular contaminating micro-organism by a factor of ten is a commonly mentioned quantity and is calculated as

$$t = \frac{-1}{k \ln\left(\frac{N(t)}{N(t_o)}\right)} = \frac{-1}{k \ln 0.1}$$

The Decimal Reduction Time is the time taken at constant temperature for a ten-fold reduction in surviving micro-organisms. For a food to be sterile will require a number of log cycles. A 12 cycle reduction or 12D cook is required for canned processes. This is called the thermal death time, t_D, and is a term used with thermal processing of foods and is defined as the time required for the complete kill of all organisms in a given suspension. Experimentally, measurements can be made of the number of organisms surviving a particular treatment and then extrapolating to zero. Practically, a commonly used approach to estimate the thermal death time is to determine the thermal death constant, and calculate the time required to reduce the viable count to one organism.

Defining the initial concentration of organisms as 10^B, then

$$\ln\left(\frac{N_{(t)}}{N_{(t_o)}}\right) = \ln\left(\frac{1}{10^B}\right) = kt_D$$

Note that where there is a significant time for heating and cooling of the solution, the heating time and the cooling time also contributes to the killing of organisms, as well as to the denaturation of other heat sensitive materials. It is therefore necessary to integrate the kinetic death model from the time at which the lethal temperature is first reached until the time when the solution is cooled below this temperature.

A widely used term is the F_{121} value. This the thermal death time at 121°C. Another term is the Z parameter which is the temperature rise required to bring about a ten-fold decrease in the thermal death time (see Table 5.1).

Table 5.1 F121 and Z Parameters for Bacteria, Vitamin B1 and Chlorophyll

	Z (°C)	*F (min)*	*E(kJ.mol⁻¹)*	*Temp (°C)*
Clostridium botulinum	5.5-10.0	1.2-3.6	265-340	104+
Bacillus stereothermophilus	7.0-12.0	4.0-5.0	230-400	110+
Vitamin B_1 (Thiamin)	25-27	120-247	90-125	109-149
Folic acid	37	28,000	46	100+
Non-enzymatic browning	17-39	4.8-480	100-250	100+
Peroxidase	26-37	24-36	67-85	100+
Chlorophyll (green leaf)	45-79	13-48	30-90	100-149
Betamin (beetroot)	59	570	46	100+

It is possible to relate thermal death time, t_D, to the F_{121} and Z parameters for which the gradient is

$$\frac{\log_{10} 10F_{121} - \log_{10} F_{121}}{Z} = -\frac{1}{Z}$$

The gradient is also given by

$$\frac{\log_{10} t_D - \log_{10} F_{121}}{121 - T} = -\frac{1}{Z}$$

Rearranging

$$\log_{10}\left(\frac{t_D}{F_{121}}\right) = \frac{121 - T}{Z}$$

or

$$t_D = F_{121} 10^{\frac{121-T}{Z}}$$

The fraction of surviving spores reaching thermal death dS in time dt is therefore

$$dS = \frac{1}{t_D} dt$$

Since the total fraction is unity

$$\int dS = 1.0$$

then

$$\int \frac{10^{\frac{T-121}{Z}}}{F_{121}} = 1.0$$

The integral can be evaluated graphically or by numerical integration.

Example:

The thermal death times of spores of a contaminating micro-organism in a food product are 6 minutes at 120°C and 2 minutes at 125°C. Determine the Z and F_{121} parameters of the product. The food is canned and sterilised in an autoclave with steam at 1.0 barg. Temperature-time data for a test can was obtained as follows:

Time (min)	Temperature (°C)
85	102
90	104
95	106
100	108
105	110
110	111
115	112.5
120	113.5
125	114.5
130	100
135	95

Using the Z and F_{121} values, determine whether the food product is sterilised.

Solution:

The Z and F_{121} parameters are related by

$$\log_{10}\left(\frac{t_D}{F_{121}}\right)=\frac{121-T}{Z}$$

where t_D is 6 mins when T is 120°C and t_D is 2 mins when T is 125°C. Thus

$$Z=\frac{5}{\log_{10}3}=\frac{5}{0.477}=10.5^{o}C$$

and

$$\log_{10}\left(\frac{2}{F_{121}}\right)=\frac{-4}{10.5}$$

Thus

$$F_{121}=5\,\text{min}$$

Using the Z and F_{121} parameters it is necessary to determine t_D and its reciprocal (sterilisation rate). The time interval, Δt, is 5 minutes.

Time (min)	Temperature (°C)	t_D (min)	$1/t_D$ (min^{-1})	$1/t_D\Delta t$
85	102	320	0.0031	0.0155
90	104	206	0.0048	0.0240
95	106	132	0.0076	0.0380
100	108	86	0.0116	0.0580
105	110	55	0.0182	0.0910
110	111	44	0.0227	0.1135
115	112.5	32	0.0314	0.1570
120	113.5	25	0.0400	0.2000
125	114.5	20	0.0500	0.2500
130	100	500	0.0020	0.0100
135	95	1500	0.0001	0.0005
			Total	0.9575

A plot of *1/tD* versus time results in an area under the graph corresponding to a value less than 1.0 concluding that the food is just short of being sterilised.

Example:

The food product is canned and sterilised in an autoclave. The heating rate is constant at 1°C per minute. If the Z and F_{121} values are 9.19°C and 5.45 minutes, respectively, determine the time to sterilise the food product and the final temperature of the food if the starting temperature is 20°C. Ignore any cooling that would subsequently be used.

Solution:

A iterative approach can be taken to satisfy the criteria that

$$\int_0 \frac{10^{\frac{T-121}{Z}}}{F_{121}} dt = 1.0$$

Using increments of 1 minute (and therefore 1°C), the criteria is satisfied after 102 minutes, corresponding to a temperature of 122°C.

Alternatively, the ramped temperature increase can be substituted where

$$T = 20 + bt$$

So the integral becomes

$$\int_0^t \frac{10^{\frac{bt-101}{Z}}}{F_{121}} dt = 1.0$$

Integrating

$$\frac{10^{\frac{-101}{Z}}}{F_{121}} \left[\frac{10^{\frac{bt}{Z}}}{\frac{b}{Z}\ln 10} \right]_0^t = 1.0$$

gives

$$t = \frac{Z}{b}\log_{10}\left(\frac{F_{121}\frac{b}{Z}\ln 10}{10^{\frac{-101}{Z}}} \right) = \frac{9.19}{1}\log_{10}\left(\frac{5.45 \times \frac{1}{9.19}\ln 10}{10^{\frac{-101}{9.19}}} \right) = 102\,\text{min}$$

As above, the final temperature is therefore

$$T = 20 + bt = 20 + 1 \times 102 = 122^o C$$

5.3 Canning

Canning is used as a long term storage method for many food products. When meat, fish or fruit products are hermetically sealed in a container, any accompanying micro-organisms, if not otherwise destroyed, will multiply if conditions are favourable. Microbial destruction is therefore the core to the process of canning. High temperatures are required the completely destroy bacterial spores although high temperatures may also influence the organoleptic properties of the contents of the cans. It is therefore necessary to determine the time and temperature required to sterilise the food and still produce a desirable product.

In the canning of meat, meat is delivered to the canning factory in the form of carcasses, quarters, or smaller pieces. After it has been checked for quality, it is freed from bone, tendons and fat, sorted, trimmed and then cut into small pieces which helps filling. The meat is partially cooked meat is filled into cans. More meat is overfilled to compensate for moisture loss during sterilisation. Meat jelly is prepared and added which acts as a binder and improves the appearance and palatability of the canned meat. A lid is then placed and sealed, and the cans then placed in a steam autoclave to be heated for a specified time.

5.4 Milk Processing

The dairy industry which has been established on practical experience over centuries is today a highly complex organisation responsible for producing and distributing processed milk and its associated products. Production of milk begins on the farm. The milk that is of interest comes from cows, goats and, to a certain extent, sheep. Breeds and characteristics of dairy animals influence the milk quality. From the farms, the milk is sent to milk processing plants where it is subdivided into heat-treated milks (pasteurised or sterilised) and homogenised, soft curd, irradiated and fermented milks. The treatment of milk is focussed on the destruction of the Mycobacterium tuberculosis bacilli that is responsible for causing tuberculosis, which is a disease of the lungs.

The composition of milk varies with the age and breed of animal, the way the animal is fed and the elapsed calving time. Raw milk is blended so as to annul any variations. When milk is heated extra care is taken to ensure that milk composition remains unaltered.

Named after the 19th centaury scientist Louis Pasteur who first discovered that spoilage organisms in wine could be inactivated by applying heat at temperatures below its boiling point, the pasteurisation of milk depends on the total count of heat resisting organisms present. To produce a pasteurised product of satisfactory quality, it is essential that the raw milk supply is also of good hygienic quality. Pasteurisation methods are usually standardized and controlled by national food safety agencies. In the UK, a temperature of not less than 71.7°C for at least 15 seconds is used (see Figure 5.1)

The conditions of pasteurisation are similar worldwide albeit with minor variations in time–temperature combinations, cooling temperatures and testing procedures. The pasteurisation process, which is a mild form of heat treatment in which the milk has no appreciably cooked flavour and a low whey protein denaturation of between 5% and 15%, is either carried out as a batch or continuous process.

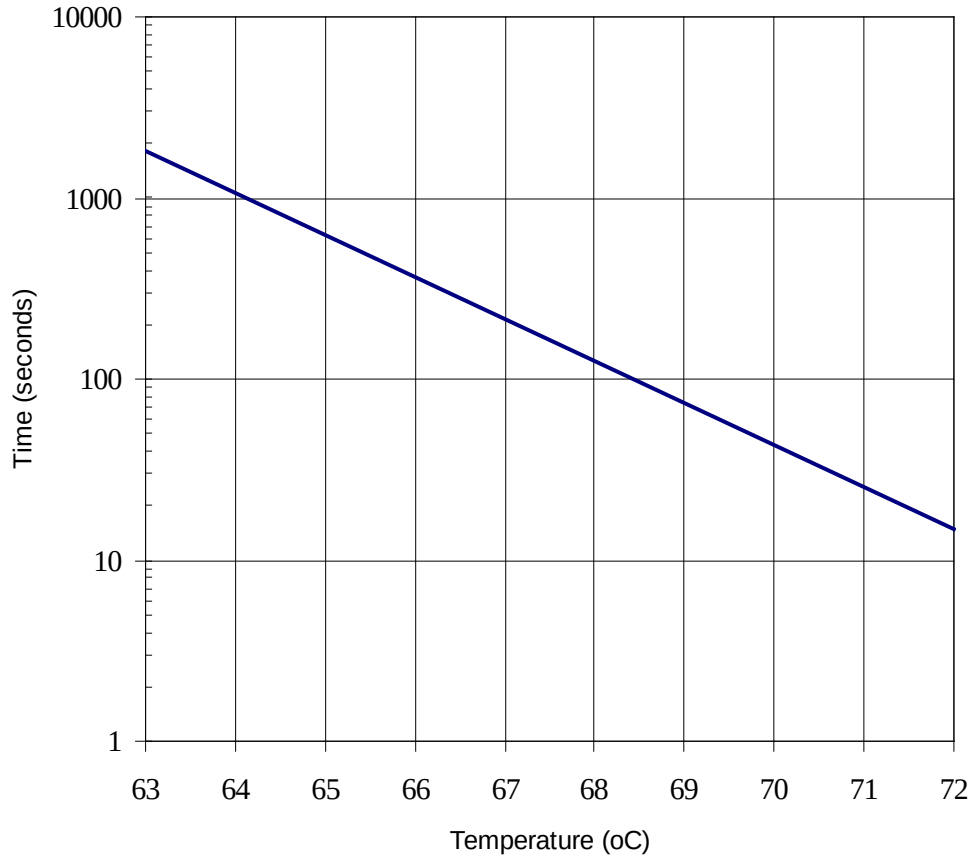

Figure 5.1 UK Pasteurisation Standards

5.4.1 Holder Process

The Holder thermal process requires a temperature of not less 62.8°C not more than 65.6°C for at least 30 minutes, and then immediately cooled to a temperature of not more than 10°C. Regarded as being uneconomic on the large scale, it is used as a batch process for pasteurisation of human breast milk for neonatal purposes due to its low temperature preserving essential growth hormonal components.

5.4.2 High Temperature Short Time HTST

In the HTST process, raw milk at 10°C enters the process through the regeneration section. Raw milk and is heated to 68.6oC by hot milk, which, in turn, cools. The now warm milk enters the final heating section where hot water or electricity is used to heat it to the desired temperature. It then passes through a holding tube and through the regeneration section, and enters the main water and chilled water-cooling sections.

Most HTST pasteurisers use plate heat exchangers, which offer a large surface area for heat transfer within a compact space. The gap between the plates is narrow so as to induce turbulence and to maintain the required pressure drop in the system. Such heat exchangers are suitable for low viscosity fluids, which are sensitive to heat.

5.4.3 Homogenisation

Homogenised milk is produced from raw milk that is first warmed and then forced through a fine aperture. This breaks down fat globules into smaller particles that remain distributed through the milk. The milk is then either pasteurised by bottling, sealing and heat treating at 110°C to 115°C for 20 to 30 minutes and allowing it to cool, or it is UHT processed.

5.4.4 Ultra High Temperature UHT

Invented in the 1960s, UHT is used to kill spores found in milk but is also used for processing fruit other liquid diary products, fruit juices and soups. UHT processing involves short times of one to two seconds at temperatures exceeding 135°C. Continuous UHT process equipment is similar to that used in the HTST pasteurisation process and uses plate heat or tubular heat exchangers.

The of shelf life UHT processed milks is typically nine months. However, due to the high temperatures used in UHT processing, Maillard browning can occur resulting in a change in taste and darkening of colour.