Candies *See* **Sweets and Candies**: Sugar Confectionery

CANNING

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Principles

M R Berry, Cincinnatti, OH, USA
I J Pflug, Minneapolis, MN, USA

Introduction

Canning is the general term applied to the process of packaging a food in a container and subjecting it to a thermal process for the purpose of extending its useful life. An optimal thermal process will destroy pathogenic (disease-causing) bacteria, kill or control spoilage organisms present, and have minimal impact on the nutritional and physical qualities of the food. Although we think of canning in terms of steel or possibly aluminum cans, the principles apply equally well to a variety of food containers such as glass jars, plastic and foil-laminated pouches, semirigid plastic trays or bowls, as well as metal cans of any one of several shapes, including cylindrical, oval, oblong, or rectangular. The concept of aseptic packaging (sterilizing the food and the container prior to filling and sealing) also follows the same principles.

Basic Concepts

In 1810, Nicolas Appert reported the first methods on the thermal treatment of food. His method of preservation was primarily aimed at the elimination of the use of large quantities of sugar, salt, and vinegar as preserving agents because they detracted from the natural flavor and quality of the food. His methods of food preservation developed over the years into procedures that not only prevented the large economic loss associated with microbial spoilage, but also destroyed the food-borne microorganisms that are capable of causing illness, or even death, in humans.

Heat processing coupled with hermetic packaging is used to preserve a wide variety of products. Microbial control processes at temperatures in the 65–95 °C range are often called pasteurization, those from 100 to 150 °C, sterilization. Pasteurization processes are designed to kill pathogenic microorganisms and extend product life under refrigerated storage; sterilization processes make possible indefinite product life at ambient temperatures. Whereas the principles of thermal process design are the same for all conditions, the concepts for process establishment that will follow are those for the sterilization of foods known as low-acid canned foods (LACFs) packaged in hermetically sealed containers. Low-acid foods have a pH greater than 4.6 and a water activity (a_w) greater than 0.85 – a combination capable of supporting the growth of *Clostridium botulinum*, a spore-forming bacterium that produces an exotoxin which is one of the most deadly neuroparalytic toxins known. *C. botulinum* is ubiquitous; it occurs in both cultivated and forest soils, sediments of streams, lakes, and coastal waters, the intestinal tracts of fish and mammals and gills and viscera of crabs and other shellfish. For many years, canning industry laboratories have devoted much attention to *C. botulinum*. Early in the 20th century, thermal-processing technologists divided high-moisture foods into acid (pH less than 4.6) and low-acid (pH greater than 4.6). The basis for this decision was that, at a pH of less than 4.6, *C. botulinum* will not grow and produce toxin. At a pH above 4.6, in a favorable medium *C. botulinum* will multiply and produce toxin. Examples of

foods with a pH greater than 4.6 are vegetables, fresh meats, and seafood. Tomatoes normally have a pH that is less than 4.6 and require a less severe heat treatment (pasteurization) to achieve preservation.

a_w is a measure of the amount of available water in the food. The a_w of fresh fruits, vegetables, and meats is normally greater than 0.85. Dried fruits, honey, and salami have insufficient water content to support the growth of most hazardous microorganisms and thus do not require a sterilization process to produce a shelf-stable product.

Establishment of the Thermal Process

The establishment of the thermal process for sterilization of canned foods results from a successful marriage of microbiological science and physical science, specifically thermobacteriology and heat penetration testing, their validation and iteration, as shown diagrammatically in **Figure 1**.

Thermobacteriology

Thermobacteriology is the science that studies the potential microbiological contaminants in foods, the relationship between temperature and time levels required to destroy them, and the influence of the food itself on the destruction rates.

There are three microbiological parameters which are involved in all process establishment work, namely D_T, z, and F. These variables define the thermal resistance of bacteria and indicate how much of an effect a particular thermal process is likely to have. The D_T value, which is defined graphically in **Figure 2a**, is the time in minutes at constant temperature (T) to inactivate 90% (one log reduction) of the target organisms present in a food. The D_T value is also known as the 'death rate constant' or 'decimal reduction time.'

Thermal resistance, or thermal destruction tests (TDTs), that measure D_T are conducted using small food samples inoculated with known levels of microorganisms. The samples, contained in specially designed, low-profile TDT cans or glass tubes, are heated in chambers capable of rapidly heating the sample to a precise temperature, holding for a precise time period, and rapidly cooling to sublethal temperatures. Common heating devices are the TDT retort and the thermoresistometer.

A plot of the thermal resistance (or survival) data must approximate a straight line on semilogarithmic graph paper (as in **Figure 2a**) for the D_T value to be meaningful. Each TDT curve is unique for the microorganism, food medium, and exposure temperature. The D_T value describes the time effect of heat on a population of microorganisms exposed at constant temperature for a precise time period, without influence of a heating (come-up) or cooling period effect.

The $D_{121.1°c}$ value for *C. botulinum* is normally taken as 0.2 min. This is based on thermal resistance studies conducted in the early 1920s on spores harvested from the most heat-resistant strains known. These studies demonstrated that, by extrapolation from the semilogarithmic survival curve, it was necessary to heat a spore suspension in phosphate buffer for 2.78 min at 121.1°C to reduce the survival population from about 10^{11} spores per unit to less than one spore per unit (12-log reduction). Later, correcting the data for come-up time resulted in a reduction of the heating time to 2.45 min to achieve the same lethal effect, hence, a $D_{121.1°c}$ value of 0.2 min.

The time–temperature data in **Figure 3** (see Thermal Process Calculations, below) are typical of the way in which cans of food heat, and illustrates that food in containers does not heat (or cool) instantly. To be efficient in the thermal process design, we must take advantage of the microbial kill at each step along the thermal process path. The thermal resistance curve shown in **Figure 2b** is the vehicle that makes this possible. A series of TDT tests are conducted to determine the effect of different temperatures (D_T values) on the thermal resistance of an organism. By plotting the measured D_T values on a logarithmic scale against temperature on a linear scale (**Figure 2b**), a thermal resistance curve is constructed. The thermal resistance curve relates time for a one log kill with the kill temperature. From this plot, the z value can be obtained; it is the inverse slope of the curve and represents the number of degrees of temperature required for the curve to traverse one log cycle. In other words, the z value denotes the number of degrees of temperature required to effect a 10-fold change in the time to achieve the same lethal effect. A higher z value means that a greater change in process temperature is required for the same change in the destruction rate of an organism. The z value makes it possible to quantify the microbial kill at the product temperature that exists at all times during a thermal process.

A range of z values from 7 °C to 12 °C have been measured over the years for *C. botulinum*. These differences are attributed to the spore type (strain), heating system, test substrate, and method of calculation. Much effort has been expended on determining the appropriate z value for LACF process establishment. Consensus led to the conclusion that the use of a single z value of 10 °C – which has been in general use for 80+ years – is still the best recommendation for calculating LACF sterilization processes that are to be safe from a public health standpoint. It is

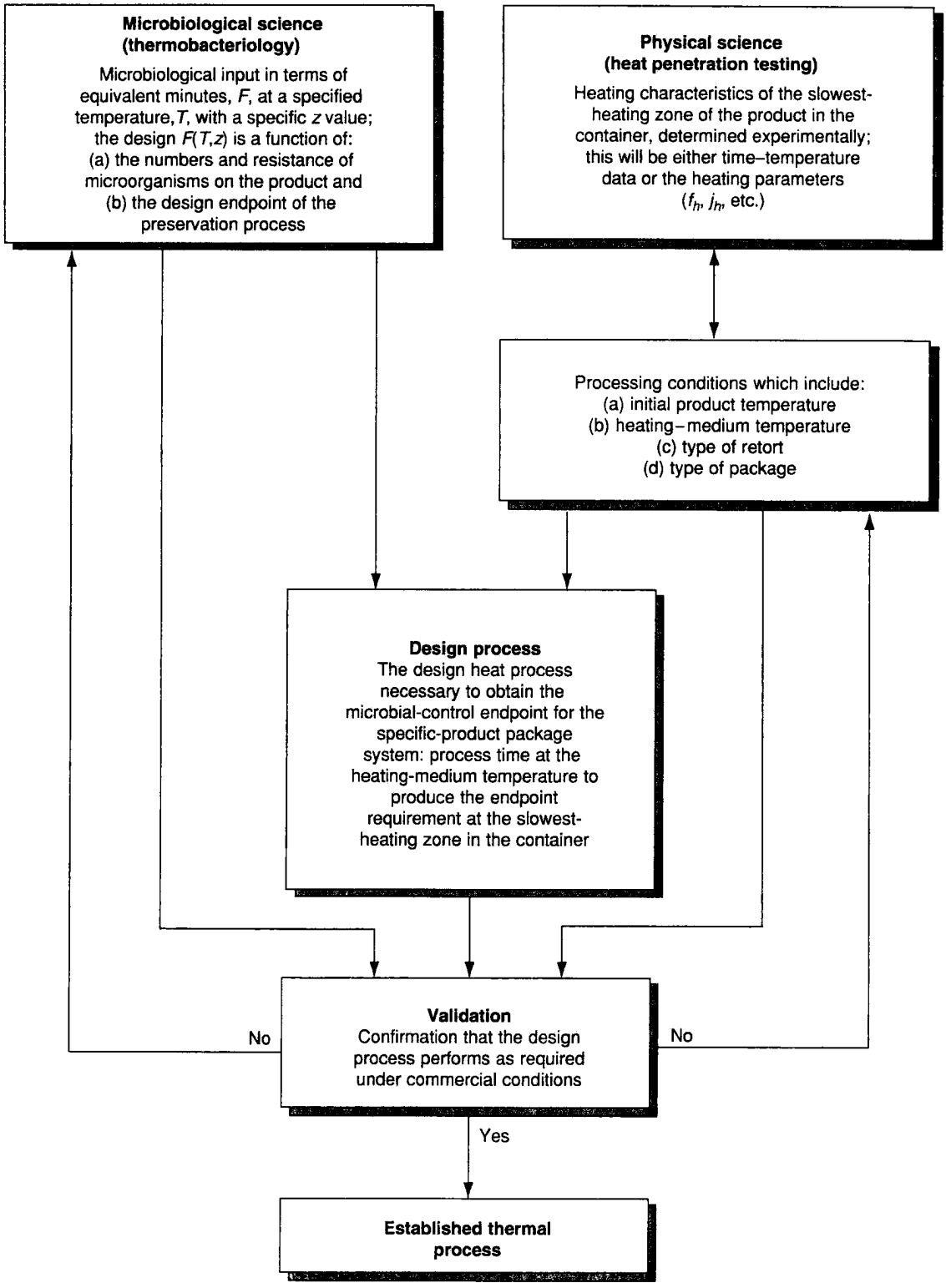

Figure 1 Establishment of the thermal process.

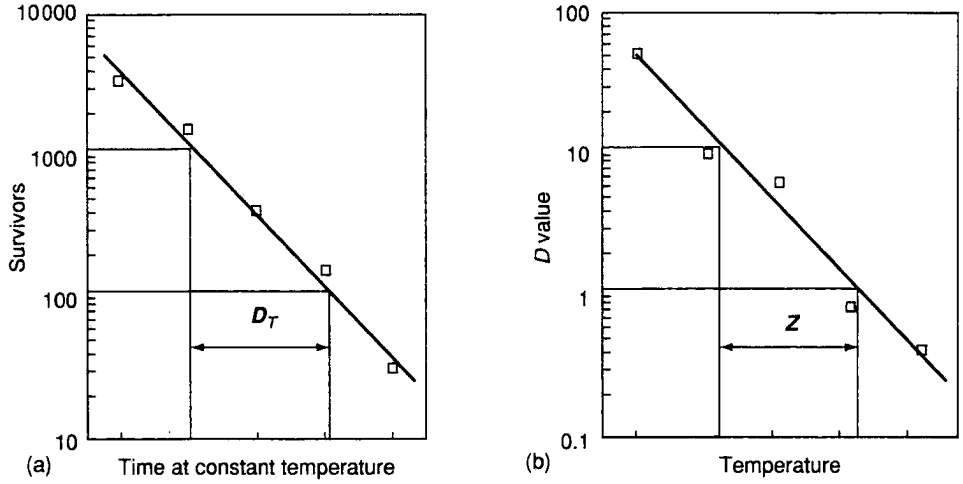

Figure 2 Graphical representations of D and z values. (a) D value; time required at temperature to reduce survivors by 90%; (b) z value; temperature change required for a 10-fold change in destruction rate.

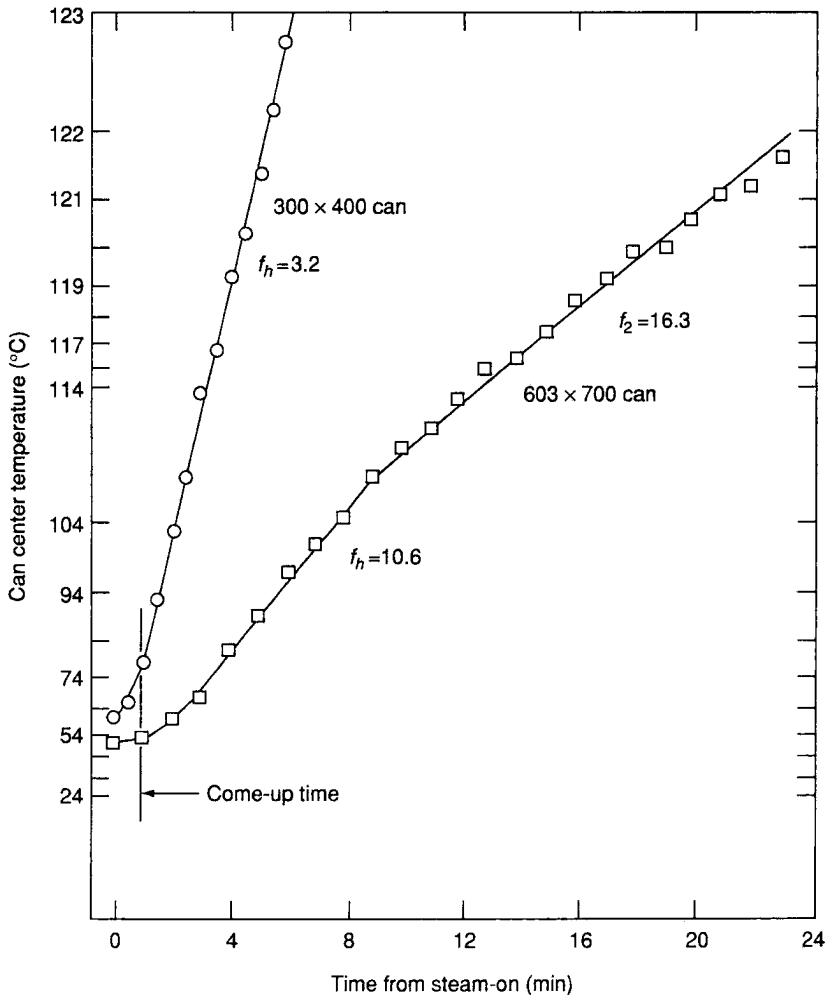

Figure 3 Typical simple and broken heat penetration curves. Tests were for two can sizes of mushrooms in brine, heated simulating the FMC Sterilmatic continuous agitating retort. Can sizes are American designations: 603 × 700 implies an outside diameter of 6 3/16 in (approx. 16 cm) and a height of 7 in (approx. 18 cm). From Berry MR, Bradshaw JG (1982) Heat penetration for sliced mushrooms in brine processed in still and agitating retorts with comparisons to spore count reduction. *Journal of Food Science* 47: 1699, with permission.

possible that this choice was fortuitous; on the other hand, it may have been the purposeful result of research by the canning industry pioneers of the 1920s and 1930s.

Lethality

Containers of food do not heat instantaneously, and since all temperatures (above a minimum value) have a lethal effect and contribute to the destruction of microorganisms, a mechanism to determine the relative effect of a changing temperature while the food is heated and cooled during thermal processing is necessary. The z value is the parameter that allows us to calculate the lethal effect of various temperatures on the destruction of microorganisms. The lethal rate (L) describes, through use of the z value, the relative effect of temperature on microbial destruction with respect to the effect of a certain reference temperature (T_{REF}). In descriptive terms, L is the equivalent minutes at the reference temperature per minute at any temperature T:

$$L = 10^{\frac{T-T_{REF}}{z}} \quad (1)$$

Table 1 shows lethal rates at five temperatures for *C. botulinum* assuming a reference temperature of 121.1 °C and a z value of 10 °C, and times required at each temperature for a 12-log spore reduction. If the initial *C. botulinum* population per container (N_0) is 10^3 and we desire a final probability (N_F) of 10^{-9}, then a 12-log spore reduction is required. The difference in each temperature in Table 1 is one z value (10 °C), which illustrates that changing the exposure or processing temperature by one z value will require a 10-fold change in processing time.

Sterilization Value

The parameter that accumulates the lethal effect as a function of time (t) during the thermal process is the sterilization value, defined as

Table 1 Lethal rates and times required for a 12-log reduction, applicable to the destruction of *Clostridium botulinum* spores (reference temperature 121.1 °C; z 10 °C)

Temperature, T (°C)	*Lethal rate (min at 121.1 °C/min at T)*	*Time (F_T)[a] required for a 12-log spore reduction*
101.1	0.01	4 h
111.1	0.1	24 min
121.1	1	2.4 min
131.1	10	15 s
141.1	100	1.5 s

[a] $F_T = D_T Y_n$ where $D_{121.1} = 0.2$ and Y_n is the spore log reduction ($\log N_0 - \log N_F$) where N_0 and N_F are 10^3 and 10^{-9}, respectively.

$$F^z_{T_{REF}} = \int_0^t 10^{\frac{T-T_{REF}}{z}} dt \quad (2)$$

Or, in terms of lethal rate, L (eqn 1),

$$F^z_{T_{REF}} = \sum L\Delta t \quad (3)$$

When temperature (T) characterizes the slowest-heating zone in the container of food and when the reference temperature and z value are 121.1 °C and 10 °C, respectively, then the sterilization value is known as the F_0 value for the thermal process. The F_0 value is specific for the food, container, processing conditions, processing system, and thermal process (processing time, temperature, and other physical factors affecting the process). The F_0 value is the equivalent value of the process in terms of minutes at 121.1 °C, as if no time is involved in heating to 121.1 °C and cooling to sublethal temperatures. An F_0 value of 3.0 min ($z = 10$ °C) is generally accepted as a realistic, minimum botulinum thermal process that will produce LACFs that are safe from a public health standpoint.

Commercial Sterility

Commercial sterility of food means the condition achieved by application of heat which renders such food free of viable forms of microorganisms having public health significance, as well as any microorganisms of nonhealth significance capable of reproducing in the food under normal nonrefrigerated conditions of storage and distribution.

Several additional considerations go into the decision as to the design F_0 for commercial sterility which may be as much as 20 F_0 units higher than the minimum *C. botulinum* public health thermal process. By convention in North America, the F_0 used in calculating a thermal process includes the processing equipment heat transfer safety factor along with the requirement for killing the microbial contaminations. These considerations include: initial bacterial level of the food product, physical parameters of the food itself (style, consistency, particle size, liquid-to-solid ratio, etc.); food container; processing system (still, hydrostatic, continuous agitating retorts, etc.); conditions of storage and distribution; natural or added ingredients that prevent spoilage; economics and the general experience of the food processor. As examples, foods that will be distributed to a high-temperature geographical area may require an F_0 of 15–20 min to afford the same protection from economic loss due to spoilage as an F_0 of 5–7 would afford for a moderate temperature area. An F_0 of 8–12 min is recommended for products heated with induced agitation.

The initial bacterial level of the food has a direct effect on the outcome of a specific process; the same thermal process (F_0) does not guarantee the same process endpoint. The F_0 value is a measure of processing conditions necessary to affect a specific process condition, for example, the level of *C. botulinum* spores by a certain number of log reductions, such as 12 $D_{121.1°C}$ values. The higher the initial spore concentration, the higher the spore concentration after processing for a process delivering the same F_0 value.

There is a potential hazard in expressing process requirements as '12*D*,' in that only the spore-log reduction is specified. A spore-log reduction of 12 will yield a probability of a spore surviving of 10^{-9} (one spore per 10^9 containers) only when the initial spore contamination level is 10^3. To provide all consumers of canned food with equal protection, regardless of the initial numbers of *C. botulinum* spores, the heat process F_0 value should always satisfy a constant, agreed endpoint value of probability of a surviving spore.

Heat Penetration Testing

The purpose of the heat penetration (HP) test is to determine, accurately, the temperature of the slowest-heating zone in the food container during thermal processing. The results of the HP test are experimentally determined time–temperature relationships describing the heating and cooling of the product. These data are derived from tests which duplicate commercial processes with a high degree of reliability. The HP data are normally collected in the laboratory because of difficulty in making accurate measurements and having close temperature control in plant equipment. This is especially true for products that heat by natural or forced convection by conduction (i.e., no product movement). The HP test provides the temperature history of the product during the process which, when combined with the thermal resistance information for the organism of concern (the required F_0 value), allows us to calculate the length (process time) of the thermal process at the specified processing temperature.

The factors which affect the HP results are numerous and tend to be more complex as the food product, package, and processing systems (retorts or autoclaves) become more complex. The following factors must be considered by the HP technician during the conduct of a HP test because they may influence the resulting heating and cooling temperature profiles:

- Processing (retort) temperature
- Processing time
- Processing medium (steam, water, etc.)
- Initial temperature and temperature distribution within the container
- Size and shape of container
- Container orientation and distribution within retort
- Agitation of containers during processing*
- Container fill and head space*
- Product formulation and preparation procedures*
- Proportion of solids to liquid*
- Size, shape, arrangement, and composition of food particles
- Consistency of product*
- Product drained weight after processing
- Style of container (plastic or metal; rigid, semirigid, or flexible)
- Vacuum or air remaining in container
- Temperature distribution (uniformity) in processing vessel
- Operating conditions during processing (come-up time, sequence of events, controller function, rotational speed, etc.)*
- Location and type of temperature sensor in container
- Ability of test retort to duplicate commercial conditions*

Items marked with an asterisk are particularly significant when processing with agitation.

Every thermal process will have factors that are critical for delivery of the design F_0. For example, the critical factors of retorting systems that are designed to agitate the contents of the container during processing, to increase the rate of heat penetration, will differ from those of a still retorting system for the same product. It is the responsibility of the person establishing a thermal process to understand all the factors that may influence the way the product heats and cools. It has been repeatedly observed that the HP testing program must continue until all parameters are fully understood. Only accurate and applicable HP factors are meaningful for thermal process establishment.

The instrument of choice for measuring food temperature during HP testing has historically been the thermocouple (TC) with recording potentiometer. Normally nonprojecting style TC receptacles are attached to the container and hard-wired to the potentiometer. The TCs are placed to measure the temperature at the slowest-heating zone within the container; this is determined *a priori* by ancillary testing. Since the objective of the HP test is accurate time–temperature data, care must be exercised in the selection and use of the TC. For products that have considerable natural or induced convection, such as whole-kernel corn in brine, a TC of small diameter is

used in order to avoid interfering with product movement. For conduction-heating foods that remain motionless during processing, such as a viscous stew, the TC support material is selected to have thermal properties similar to the food to minimize the conducting of heat to or from the TC junction. If the TC and/or container are not adequately grounded, especially in water processes, stray voltages may cause large temperature errors.

Temperature measuring systems in use today usually use personal computers as the output device and include resistance temperature devices (RTDs) and miniature telemetry or data logger systems. These systems have allowed HP testing in systems that were previously not possible since they have removed the requirement of direct wiring to the container.

The accuracy of the measuring instrument is extremely important. A 0.5 °C difference in the temperature of the thermal process results in more than a 10% difference in F_0. For minimally processed foods, this could result in severe underprocessing and survival of numerous pathogenic or spoilage organisms.

Thermal Process Calculations

The methods for calculating the sterilization value (F_0) from the HP and TDT data can be classified as either a general or formula method. The two methods use similar principles but the procedures are distinctly different.

The general method is essentially a graphical or numerical integration of eqn 2, using the time–temperature data obtained during the HP test. It is the most accurate and simplest method of determining the F_0 delivered by the thermal process. The disadvantage is that the method affords little or no ability first, to change the process time, heating parameters, or initial product temperature and predict their influence on F_0, or second, to use F_0 as an input to predict required process time. An example of calculating F_0 using the general method is given in **Table 2**. In this example, eqn 3 is numerically integrated using typical time–temperature data at 2-min intervals from a HP test. The resulting F_0 for the 30-min combined heating and cooling phases (**Table 2**) is 9.8 min at 121.1 °C. In the general method, improved accuracy may be achieved by reducing the HP data measurement time interval.

The various formula methods are mostly iterations and improvements of the formula method first proposed by C.O. Ball in 1923. The HP data are first plotted on semilogarithmic paper as either simple- or broken-heating curves, as shown in **Figure 3**. The shapes of the respective heating curves are defined in terms of parameters, commonly known as HP factors: a heating lag factor (j), a temperature response parameter that is a function of the slope of the heating curve (f_h), and the second slope and time of the break point (f_2 and X_{bh}) when the heating curve has a change of slope and can be better represented by two straight-line segments.

The simple (single, straight-line) heating curve normally occurs for food product heating by conduction, or by forced convection induced by mechanical agitation of the container. Broken-heating curves normally occur for product heating by natural convection in still retorts, and for products that undergo a change in their thermophysical properties during processing (such as a rapid increase in viscosity as temperature increases).

In the formula methods, the temperature of the food during the process is described by equations that utilize the HP factors for the heating, cooling, and transitional phases of the processing cycle. When these expressions are substituted into eqn 2, the equivalent minutes at heating medium temperature of the process can be calculated. F_0 values are calculated by either numerical procedures that use high-speed computing equipment or by classical 'cookbook' procedures using supplemental tabulated data. The versatility of the formula method makes it possible to vary the heating time, process temperature, design F_0, and even can size, using the same HP data, and to determine the influence of each of these factors on the thermal process delivered to the product.

Sterilization values calculated using the original Ball formula method are reported to be conservative. Numerous investigators have offered modifications which have improved the method, resulting in F_0 values nearer those calculated by the general method.

Process Validation

The delivered F_0 in the process establishment procedure is a value calculated using experimental data that can be related to the reduction in microorganisms that occurs when the process is used for the commercial production of canned foods.

The final step in the process establishment process is the validation or confirmation of the design process to provide assurance that the design F_0 will be delivered to the product under the commercial processing conditions (**Figure 1**). It is not possible to measure the design level of sterilization processes (microbial survival probability of about 10^{-9} spores for *C. botulinum* or 10^{-6} for nonpathogenic organisms) using the organism for which the process is intended to destroy. Process validation is normally performed

Table 2 Example heat penetration data and calculation of the sterilization value by the general method (reference temperature 121.1 °C; z 10 °C)

Time[a] *t (min)*	*Temperature*[a] *T (°C)*	*Lethal rate L (eqn 1)*	*Lethality* $(L \times \Delta t)$	*Cumulative lethality* F_0 *(eqn 3)*
0[b]	58.0	0.00	0.00	0.00
2	81.0	0.00	0.00	0.00
4	96.0	0.00	0.01	0.01
6	104.0	0.02	0.04	0.05
8	109.0	0.06	0.12	0.17
10	114.0	0.19	0.39	0.56
12	116.0	0.31	0.62	1.18
14	118.5	0.55	1.10	2.28
16	119.8	0.74	1.48	3.76
18	120.7	0.91	1.82	5.58
20	121.6	1.12	2.24	7.83
22[c]	120.1	0.79	1.59	9.42
24	114.0	0.19	0.39	9.81
26	100.0	0.01	0.02	9.82
28	79.0	0.00	0.00	9.82
30	60.0	0.00	0.00	**9.8**

[a]During heat penetration test.
[b]Begin heating.
[c]Begin cooling.

using microbial techniques involving the inoculation of calibrated bacterial spores into the cans before the containers are sealed and processed. After the cans receive the thermal process, they are incubated. At the end of 2 to 4 weeks incubation, all cans are examined, the number of cans that show evidence of microbial growth is determined.

The bacteria used in biovalidation have a heat resistance higher than *C. botulinum* and are typically spore-forming, putrefactive mesophiles or thermophiles. A commonly used organism is PA3679 which is nontoxic and, therefore, safe for use in food plants and not hazardous to microbiologists conducting the validation tests.

Experience in commercial processing indicates that the microbial kill measured by biological methods does not always agree with the measurements of physical parameters (HP and TDT). This is why each process must be validated biologically. If the bacterial spores have been adequately calibrated, they give an indication of the actual killing power of the thermal process as delivered by the commercial processing equipment. A common biological validation is to carry out an inoculated pack where 10 000 resistant PA3679 spores ($D_{121.1°C}$ of between 1.0 and 1.5 in phosphate buffer) are added to each container of product before processing. After processing inoculated containers are incubated. An acceptable process should produce a greater than 5-log reduction of the PA3679. The test must be carried out with good technique and appropriate controls. If the results of the validation tests do not agree with the physical process design, it is an indication that the critical processing parameters were not adequately understood and the differences should be resolved, typically using the iterative process depicted in **Figure 1**.

See also: **Canning**: Quality Changes During Canning; **Consumer Protection Legislation in the UK**; **Heat Treatment**: Ultra-high Temperature (UHT) Treatments; **Microbiology**: Classification of Microorganisms; Detection of Foodborne Pathogens and their Toxins; **Packaging**: Packaging of Liquids; Packaging of Solids; **Pasteurization**: Principles; **Preservation of Food**; **Spoilage**: Chemical and Enzymatic Spoilage; Bacterial Spoilage; **Storage Stability**: Mechanisms of Degradation; **Water Activity**: Principles and Measurement; Effect on Food Stability

Further Reading

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Cans and their Manufacture

M de F Filipe Poças, Escola Superior de Biotecnologia, Universidade Católica Portuguesa, Portugal

Cans

Cans for food and drinks may be manufactured in tin plate, tin-free steel, or aluminum. Depending on the metal to be used and on the type of can, different production methods may also be used to manufacture cans. The characteristics of the metals and the operations to produce and close the cans are described below. Additionally, information is given on the polymeric coatings used to avoid undesirable interactions between the product and the metal surface.

Types of Cans for Foods and Drinks

Metal cans for foods and drinks are usually classified in three-piece cans and two-piece cans. The can components and the terms commonly used to designate different parts of a can are shown in **Figure 1**. Cans in the first group are composed of a welded body and two seamed ends and are usually made in tinplate. The two-piece cans have the body and the bottom end in a single piece and a seamed top end. They are made in tinplate, aluminum, or tin-free steel, and are produced by the Draw–Redraw (DRD) process or by the Draw-Wall-Ironing (DWI) process. The DRD process is used to produce shallow cans, with a low height/diameter ratio, whereas the DWI process is typically used for drink cans, commonly with a high height/diameter ratio. These cans have a very thin wall, thus lacking mechanical resistance. They are used for carbonated drinks where the high pressure from the product (very often around 4 atm) imparts the required resistance. In still drinks, the application of liquid nitrogen in the headspace yields a high internal pressure.

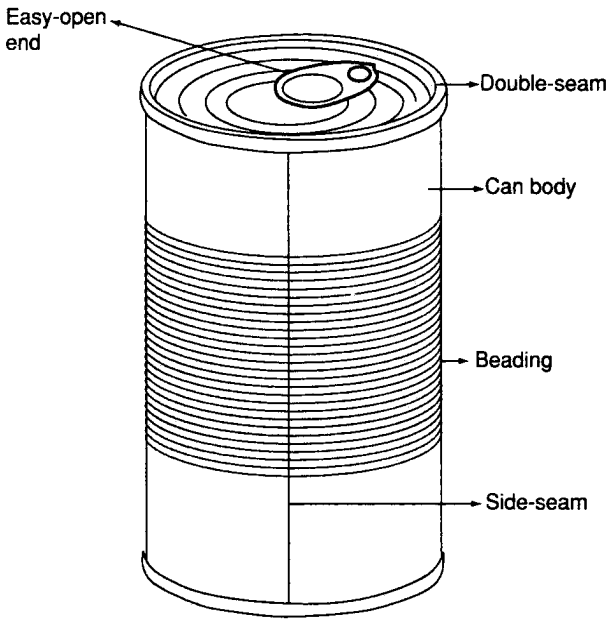

Figure 1 Can terminology.

A wide variety of can shapes are available: round, rectangular, oval, trapezoidal, etc. The circular can is the most popular shape because it is the easiest shape to seam and uses the least metal sheet area for a given volume content. Rectangular shapes are common for processed fish because this format benefits the product presentation when the consumer opens the can.

For a given can capacity, the surface area of metal required for round cans is minimal when the can diameter equals its height. The dimensions of cans are designed taking into consideration this diameter/height ratio so as to maximize the efficiency of metal usage. However, it is easier and less expensive to reset a production line to make a can with a different height than to change its diameter, and thus a standard can diameter system was developed (**Table 1** shows the standard diameters of round cans in both imperial and metric units). Therefore certain can dimensions have been commonly used for certain capacities of cans. The nominal size of round cans is given as diameter × height. The dimensions of rectangular cans are given as three sets of numbers: the first two sets are base dimensions, and the third is the height dimension. The units conventionally used are millimeters for metric units; imperial dimensions are given in three digits: the first digit is in whole inches, and the second two digits indicate 16ths of an inch. For example, a can designated as 307 × 403, is 3-7/16 inches in diameter and 4-3/16 inches in height. **Table 2** shows some of the more widely used cans for foods.