Course Name: Canning Technology and Value Addition in Seafood
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Canning Technology and Value Addition - Thermal process calculations - Part 1

Hello everyone, welcome to the sixth session of Seafood Canning Technology. Through the previous sessions, we have already discussed the historical perspective of this technology, the basic concept of this technology, the container part- what are the different containers, then the process. The basic CCPs we discussed. In this session, we will be dealing with the thermal process calculations. Since the canning is a thermodynamic process, different kinds of thermal calculations or mathematical calculations are required to flawlessly plan as well as to execute the thermal processing, preservation process.

We also discussed that the success of any thermal processes or any canning technology is basically it is a time-temperature combination. Depending upon the variety of the product, the type of the container that we are going to use, the type of the retort that we are going to use, then the severity of our processes. Depending on all these parameters, the type of the ingredients that we are going to pack within the containers. So, depending on all these parameters, the time-temperature combination is going to vary.

Every process should be meticulously planned and calculated without any fault. If you over-calculate or under-calculate, these are the two possibilities. If you over-calculate, the process becomes more severe than necessary, resulting in an overcooked product that may lose consumer acceptability and nutritional properties. On the other hand, if you under-calculate, the process may not be sufficient to eliminate reference microorganisms or target microorganisms, such as *Clostridium botulinum*. This is the issue. The calculation must be perfect or as accurate as possible.

There are different calculation methods and thermodynamic concepts developed over the years by various scientists. These calculation processes can be perfected over time. Taking a bacterial population and how it grows in a system, the bacterial growth curve can be classified into different phases. Initially, there is a lag phase, and another crucial phase is the exponential growth phase. There is a stationary phase and then a death phase, forming a standard growth curve for a microbial population. It has been proven that the increase or decrease in the number of microorganisms in a standard environment follows a logarithmic scale, either in multiplication or reduction. This growth curve of microorganisms exhibits phases such as lag, exponential, stationary, and death.

In thermal process calculations, the focus is on the death phase. The goal is to bring down the initial microbial population to a predetermined level as quickly as possible within the stipulated time. To develop thermal process calculations, we consider the log scale of bacterial cells against time. From this growth curve, we exclude the lag, exponential, and stationary phases, focusing only on the death phase. By doing so, we can draw the thermal death curve of a microbial population. As the reduction is in a logarithmic scale, one axis represents the log values of the bacterial population reduction, and the other axis represents the time in minutes of heating at a specific temperature. The reduction yields a logarithmic scale or a straight line. Observing the thermal death curve or this logarithmic scale reduction provides various information. Information includes time, the logarithmic curve and the logarithmic scale can be converted into an arithmetic curve. The arithmetic curve is usually not a straight line, and conversion to a log scale data result in a straight line.

From this data, different thermal properties or characteristics of various microbial organisms can be drawn, known as thermal properties of microbial destruction. This logarithmic scale reduction of microorganisms signifies various properties. The thermal death curve or TDT curve itself provides values such as D value (decimal reduction rate value), and another curve, the thermal resistance curve, can be drawn. From the thermal resistance curve, values like Z value, F values, P values at various stages, lethality rate, and cuck value can be derived. These represent various thermal properties or reduction properties of microorganisms obtained from different thermal reduction or resistance curves. The starting point or property to understand is the thermal death time curve. That is the initial curve, or thermal reduction curve, we are going to draw. The thermal death time curve, or TDT curve, is also known as a survival curve. It's not just about death; despite bacterial death, a certain number of bacteria survive during that period. Another term for this curve is the decimal reduction curve or DRT curve. These are three different terminologies for this particular curve.

Essentially, the thermal death time, or TDT, is the minimum time required to kill a microbial population at a specific temperature. It is the minimum time taken to eliminate a given microbial population at a specific temperature. One log reduction signifies a 90 percent reduction in each log reduction. Understanding log reduction is crucial because death curves of three species demonstrate that the rate of reduction varies among different species of microorganisms at a constant temperature. Depending on the species, the D value or the decimal reduction time, i.e., the rate of reduction of a microorganism, varies. The difference arises because, at a specific temperature, each microorganism possesses different heat resistance properties. The rate of reduction varies according to the heat-resistant properties of each microorganism.

The D value, or decimal reduction time, has certain characteristics. One definition is the time required for one log cycle reduction. Another definition is the heating time in

minutes at a constant temperature that results in reducing the number of microorganisms by a factor of 10. Additionally, it can be defined as the time for the survivor or the TDT curve to traverse one log cycle. Another definition involves the heating time at a constant temperature required to kill 90% of a given number of microorganisms. Although the definitions differ, they all indicate a particular property. From all these definitions, one common aspect is evident: the temperature is constant, and all the definitions highlight the change in time. Considering the D value, it possesses certain properties that aid in a better understanding of the D value. The first property is that the D value remains constant for each log cycle, regardless of the log cycle reduction time being calculated. It does not depend on the initial number of microorganisms; the rate at which the microorganism is killed remains the same. Another property is that the D value is expressed in time units, specifically minutes. It represents a 90% reduction in one log cycle, where one log reduction is equivalent to a 90% reduction in the given number of microorganisms. The D value is typically denoted as D_T with the reference temperature represented as a subscript. For example, the D value at 100 degrees Celsius is written as D_{100}, with 100 as a subscript. In the context of the thermal death time curve, one log reduction, such as from 10,000 to 1,000, signifies a 90% reduction or a multiple of 10. Examining this one log reduction on an axis reveals a corresponding increase in time required. If you magnify this area, you can observe a one log reduction, specifically from 10^5 to 10^4, representing the reduction of microorganisms. If you take the initial number of microorganisms as log A, the final number as log B, and the change in time as ΔT.

Delta (Δ) signifies a range of data. If the change in or increase in temperature to 5 minutes to 10 minutes. Within 5 to 10 minutes that is time in minutes around one log reduction has happened that the change of time is taken as ΔT. From this logarithmic reduction graph, we can derive an equation. So, we can write it as the D value or

$$DT=\Delta t/ (\log A - \log B)$$

Where,

Δt is the change in temperature in minutes and log A is the initial number of survivors and log B is the final number of survivors.

From this equation you can cross multiply it and we can also find out the time required for if the d value is already known we can find out the Δt value or the time required for that particular d value then $\Delta t= DT (\log A- \log B)$. Using this equation, we can find two values the change in time the time required for bring down a logarithmic scale reduction or the D value of the microorganism if it is heated for that particular time. All this happens in a constant temperature that is what we need to keep in mind. So ΔT as already we explained that it is the total exposure time, log A is initial population , log B is a population signs after the thermal treatment.

Considering the D value, it possesses certain properties that aid in a better understanding. The first property is that the D value remains constant for each log cycle, regardless of the log cycle reduction time being calculated. It does not depend on the initial number of microorganisms; the rate at which the microorganism is killed remains the same. The D value decreases as temperature increases, indicating a reciprocal relationship. Higher temperatures result in lower D values, while lower temperatures lead to higher D values. The time required to achieve a 1 log reduction is less at higher temperatures. This difference in time for a 1 log reduction is evident when comparing lower and higher temperatures. Examining a graph with three temperatures for the same microorganism reveals distinct times required for one log reduction across the three species. For the same bacteria at three different temperatures, such as 120 degrees, the higher the temperature, the shorter the time required. This observation demonstrates that the D value is temperature-dependent. Additionally, the D value is an index for sensitivity to thermal killing.

For example, let's determine which microorganism is more sensitive to heat death at 100 degrees Celsius. Two microorganisms, Bacillus subtilis and E. coli, are considered. At 100 degrees Celsius, this serves as an index for the heat sensitivity of a microorganism. At this temperature, E. coli requires less time to reduce its population compared to Bacillus. This implies that Bacillus is more heat-resistant than E. coli. Decimal reduction time is calculated to determine the sensitivity of different bacteria at a reference temperature. The D values for some microorganisms at 121.1 degrees Celsius are provided. *Geobacillus stearothermophilus* D values range from 4 to 5 minutes, while *Clostridium thermosaccharolyticum* requires 3 to 4 minutes. *Clostridium nigrificans* has a range of 2 to 3 minutes, and Clostridium botulinum (type A and B) require 0.1 to 0.2 minutes. *Clostridium sporogenes* with P.A. 3679 strain requires 0.1 to 1.5 minutes, and *Bacillus coagulans* needs 0.01 to 0.07 minutes.

As an example, let's consider a problem: calculating the D value for a bacterial suspension with an initial density of 10^9 CFU per ml, subjected to 85 degrees Celsius for 15 minutes, resulting in a reduced density of 10^6 CFU per ml. Given the mathematical situation, the information provided includes a ΔT of 15 minutes, the initial population of 10^9 CFU per ml, the final population of 10^6 CFU per ml, and a heating time of 85 degrees Celsius. The task is to determine the D value at 85 degrees Celsius using the equation $D = \Delta T / (\log N1 - \log N2)$. By substituting the known values, the calculated D value is 5 minutes. Thus, the D85 value for that microorganism under these conditions is 5 minutes.

In another example, the problem involves finding the D_{90} value for a bacterium with an initial culture of 10^8 CFU per ml. The objective is to determine the duration the suspension should be kept at 90 degrees Celsius to eliminate the entire population. The provided information includes the initial population (N1) of 10^8 CFU per ml, the final population (N2) of 1 CFU per ml, a D value of 2 minutes, and a temperature of 90

degrees Celsius. Calculating delta T using the formula reveals a period of heating of 16 minutes.

Another thermal phenomenon that can be derived through a specific graph is known as the thermal resistance curve. In a thermal resistance curve, one axis represents D value in minutes, and the other axis represents temperature in degrees Celsius. The curve indicates the thermal resistance of a microorganism concerning the temperature to which it is exposed. While similar to the D value, which deals with one log reduction, the thermal resistance curve focuses on the reduction in the D value. It considers one log reduction in the D value and the corresponding temperature change. This connection between temperature and D value is depicted in the thermal resistance curve. In contrast, the thermal death time curve (TDT curve) compares the number of microorganisms and time in minutes.

Similar to the D value, the Z value, also known as the thermal resistance constant, is derived from the thermal resistance curve. The Z value describes the temperature's influence on the decimal reduction time or D value. Specifically, it represents the increase in temperature necessary to cause a 90% reduction or one log reduction in the D value. When drawing a thermal resistance curve, one axis shows a one log reduction of the D value, with a subsequent increase in temperature required to achieve that D value. If you consider this one log reduction on a graph, similarly to the case of the D value, log D_1 represents the initial D value, log D_2 the final D value, and delta capital T signifies the change or increase in temperature. The formula for the Z value is expressed as $Z = \Delta T / (\log D_1 - \log D_2)$, where ΔT signifies the increase in temperature or temperature difference, log D_1 represents the initial D value, and log D_2 signifies the final D value.

An example of the application of the Z value involves a food processing company producing canned meat, where preventing the growth of *Clostridium botulinum* spores is crucial. For botulinum spores, the D121 is 0.2 minutes, and the Z value is 10 degrees Celsius. The company aims to sterilize the canned food at 111 degrees Celsius and wants to determine the length of sterilization to eliminate 10^{12} spores per can content. Considering that every 10-degree Celsius decrease in treatment results in a 10-fold increase in the D value, it is assumed that each change or decrease of 10 degrees Celsius in the processing temperature has an impact. It causes a 10-fold increase in D value. Considering D_{111}, it results in a 10-fold increase in the D value of *Clostridium botulinum*. The known D value of Clostridium botulinum at 121 degrees Celsius is approximately 0.2 minutes. Multiplying 0.2 by 10 yields 2 minutes. Using the given equation, D_{111} can be calculated as $\Delta T / (\log 10^{12} - \log 10^{0})$. Simplifying, log 10^0 is the final log required. Applying this formula reveals that ΔT is approximately 24 minutes. Therefore, treating the product at 111 degrees Celsius for 24 minutes would reduce the population to 10^0, ensuring complete destruction.

This demonstrates the application of these equations and methods. The average values of D and Z for different microorganisms are shown, specifying D_{121} and Z values for *Clostridium botulinum*, the D_{121} is 0.2 and Z value is 10. *Geobacillus Stearothermophilus* D 121 can be 2 to 4 minutes and the Z value is around 6. Like that, different D values and Z values are assigned to different microorganisms. So, you can see that both the thermal death time curve and thermal resistance curve are shown here simultaneously. So, you can see that the TDT curve almost similar but deals with two different values. One is with the D value or decimal reduction time or one is as a Z value which is the thermal resistance constant.

Another concept discussed is process lethality or lethality rate (LR value). The lethality rate is the temperature's lethality concerning the processing temperature (121.1 degrees Celsius in canning). Each temperature has its own lethality rate, denoted as LR at a particular temperature, representing the ratio of the microbial death rate at that temperature to the death rate at the lethal rate reference temperature. The reference temperature indicates the death value or thermal resistance of a specific lethality at a given temperature. The maximum lethality rate is assigned to the reference temperature, which is 121.1 degrees Celsius, with the lethal value set at 1. For temperatures below 121 degrees, the lethality rate is less than 1, defining the concept of lethality rate. The lethality rate formula is defined as $10^{(T - TR) / Z}$, where 10 is the logarithmic scale, T is the calculated temperature of lethality, TR is the lethal rate reference temperature, and Z is the thermal resistance constant (10 degrees Celsius in the case of *Clostridium botulinum*).

For example, to find the lethality rate at 110 degrees Celsius, the equation $LR = 10^{(111 - 121) / 10}$ is used, resulting in 0.1. Therefore, the lethality rate at 110 degrees Celsius is 0.1, with the maximum LR value set at 1, achieved at 121.1 degrees Celsius. This information allows the drawing of a lethality curve, where time in minutes and temperature are plotted against the lethality rate.

Another value to discuss is the F value or integrated lethality. In the food industry, the F value represents the number of minutes required for a specified number of bacteria to be destroyed at a given temperature, akin to the thermal death time (TDT) concept. The unit and concept are similar to the D value. The F value represents the integrated effect, the sum total of all the D values and lethality. It is denoted as F^{Z}_{T}, where Z is the thermal resistance constant, and T, the temperature, serves as a subscript. This notation signifies the time-temperature combination of a process, encapsulating the overall impact of the process.

Another related concept is the F0 value. Also known as F-zero or F0, it measures the sterilization effect on a product instantaneously heated to 121.1 degrees Celsius and held for 1 minute. The F0 value is a hypothetical metric representing the sterilization effect on a product under these specific conditions. To calculate F0, the formula is $\Delta t 10^{(T-Tr/Z)}$.

Here, delta T is the time of heating in minutes, T is the temperature of the product during the specified time interval, and TR is the lethal rate reference temperature. Tr is the reference temperature, set at 121.1 degrees Celsius, and Z value represents the temperature-resistant constant, specifically 10 degrees Celsius for Clostridium botulinum. For instance, if the sterilization time is consistently 15 minutes at 121.1 degrees Celsius, the F0 value for this organism can be calculated using the formula $F0 = \Delta t 10^{(\text{lethality rate equation})}$. Given the specified temperature and time, with Δt being 15 minutes, the calculation simplifies to 15×10 ($^{121 - 121),}$ resulting in 15×1, equating to an F0 value of 15. As another example, consider a sterilization time of 15 minutes at a constant temperature of 111 degrees Celsius. Applying the same formula with a temperature of 111 degrees Celsius, the calculation becomes $15 \times 10^{(-1),}$ leading to 15×0.1 when converted from the log value, resulting in an F0 value of 1.5 minutes. For Clostridium botulinum, the representation of the F value is F^{Z}_{T}, with Z as the superscript and T as the subscript. Specifically, F^{10} divided by 121.1 is known as the F0 value.

The thermal death time (TDT) of *Clostridium botulinum* is 2.52 minutes at 121.1 degrees Celsius. To find the F0 value, we equate it to the TDT value, resulting in F0 = 2.52 minutes. The F0 value signifies the thermal death time of *Clostridium botulinum* at 121.1 degrees Celsius, specifically 2.52 minutes.

The integrated lethality concept is defined using the lethality rate equation, which is essentially an anti-log: $10^{(T - TR) / Z}$. For F0, the formula is $F0 = \Delta t\ 10^{(T - TR) / Z}$, where ΔT represents the time of heating in minutes. F0 represents the integrated lethality across all temperatures within the heating period, denoted by the subscript "0" indicating the entire process.

For example, when considering F6, the time interval required to maintain the processing temperature at the core of the product for achieving the desired lethality is 6 minutes. This demonstrates the distinction between F0 and other subscripted values, such as F6, each indicating a specific lethality target.