Course Name: Canning Technology and Value Addition in Seafood
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Canning Technology and Value Addition - Thermal process calculations - Part 2

Hello everyone, welcome to the sixth session of Seafood Canning Technology. Through the previous sessions, we have discussed the historical perspective, the basic concept, container types, and the process, including the basic Critical Control Points (CCPs). In this session, we will focus on thermal process calculations, specifically commercial sterility, also known as the 12D process or botulinum cook.

Commercial sterility denotes the absence of microorganisms capable of growing in food under normal non-refrigerated conditions during manufacturing, distribution, and storage. That is the CODEX Alimentarius definition of commercial sterility. This is the crucial criterion for ensuring food safety throughout the production chain in simpler terms, commercial sterility is a careful balance ensuring both consumer safety and acceptability. To define commercial sterility, we refer to the absence of microorganisms (the Reference pathogenic organism *Clostridium botulinum* and reference spoilage organism *Geobacillus stearothermophilus*) that could proliferate in the food at the expected non-refrigerated conditions.

Commercial sterility is the minimum heating time needed to eliminate the survival chance of a viable spore of *Clostridium botulinum*, posing a health risk to consumers at a specific temperature. This is also referred to as the Thermal Death Time (TDT) or F0 value. What are the thermal resistance parameters of *Clostridium botulinum*, and how do they relate to commercial sterility? Explaining this involves understanding the D_{121} value of *Clostridium botulinum*, known to be 0.21 minutes, with a Z value of 10 degrees Celsius.

The relationship between the thermal death time value and F0 value is significant. Twelve log reductions are necessary to eliminate the risk of *Clostridium botulinum*. This implies that 12 log reductions equate to 12D, where D represents the decimal reduction time. To clarify, 1 log reduction is equivalent to 1D, so achieving 12 log reductions necessitates 12D, denoting the 12 decimal reduction times. 1D is only 0.21 minutes; hence, 12D equals 12 times 0.21 minutes, which amounts to 2.52 minutes. Commercial sterility, thermal death time, or F0 value is equivalent to 2.52 minutes. This value defines commercial sterility.

Now, what does the term "5D process" signify? We have previously covered the 12D process, but what about the 5D process? Essentially, the 5D process entails a 5 log reduction. For eliminating the risk of *Geobacillus stearothermophilus*, 5 log reductions are sufficient. Recall that 1 log reduction corresponds to a 1D process. In the case of *Geobacillus stearothermophilus*, the D value is 4 minutes. Therefore, 5D translates to approximately 20 minutes.

So, 12D process is basically applied for *Clostridium botulinum* and 5D process is basically applied for *Geobacillus stearothermophilus*. Why 5D process for *Geobacillus stearothermophilus* means? It is heating resistance or D value of *Geobacillus stearothermophilus* is significantly higher than that of *Clostridium botulinum*. That is, *Clostridium botulinum* is only 0.21 minutes. In the case of *Geobacillus stearothermophilus*, it is around 4 to 5 minutes. If we pursue a 12-log reduction when targeting Geobacillus species, the consequence is the destruction of the product, leading to a loss of sensory acceptability and nutritional properties. However, it's important to note that Geobacillus is a spoilage microorganism, not a health hazard for consumers. On the contrary, *Clostridium botulinum*, being a toxin-producing microorganism, poses the primary health hazard we aim to address. The D value for Clostridium botulinum is only 0.21 minutes. Research indicates that achieving 12 log reductions through the standard thermal death time is adequate to eliminate the microorganism and mitigate the associated risk. This is why both the 12D process and 5D process are implemented.

Another key concept in thermal bacteriology or thermal process calculations is the spoilage probability. This concept is grounded in the idea that the logarithmic survival curve that never reaches zero population or absolute sterility. Different forms of sterility exist, each playing a role in the overall understanding of thermal processes. Commercial sterility, absolute sterility, and other forms are considered in thermal bacteriology. Absolute sterility, however, is unattainable because it implies the absence of bacterial spores or populations, leading to the destruction of nutritional and sensory qualities in food. Given that food products are meant for consumers, achieving absolute sterility or zero population is impractical. Therefore, the focus shifts to commercial sterility. Commercial sterility does not require the complete elimination of bacteria or the nullification of all populations. It ensures that the bacterial population has been reduced to a level where it poses no risk to consumers upon consumption. This defines the concept of commercial sterility, which is closely tied to spoilage probability.

In the context of different heating time D values and log reductions, negative values emerge after a certain point. Examples include 10^{-1} ,10^{-2} etc. These negative values signify negative or spoilage probabilities in the particular process. The range extends from 10^{4} to 10^{-1}. Crossing into the negative zone, like 10^{-1}or 10^{-2}, indicates an increase in spoilage probability. That area indicates the probability of the survival. For example, if we conducted an experiment with 1000 cans, then after a 6D process or a 6 log reductions

of heating time, it is 1000 into 10^{-2}. The 6D you can see that the probability is 10^{-2}. So, 1000 cans into 10^{-2} is equal to 1000 divided by 10 is equal to 10. For example, that means 10 samples out of 1000 cans will contain a surviving spore. The spoilage probability in this case is that 10 samples out of 1000 cans may contain a surviving spore. So, the negative power of survivor are interpreted in terms of probability of survivor. The aim of a commercial sterile process is to decrease the survival probability to 10^{-12}. That is $\Delta T*D$, that equation if we are using for minimum bottulinum number. For example, log A is 1 spore per can and log B is 10^{-12}. So, our target is to push the probability to 10^{-12} spores per can. So, if log A is 1 spore per can and log B is 10^{-12} spores per can and the D value is 0.21 minutes. Using that equation, $\Delta T= 0.21*$ (log 1- log $10^{-12)}$. We can find out that we need to calculate this at 2.52 minutes. So, 2.52 minutes of the F0 value or the thermal death time or thermal death reduction time of the *Clostridium botulinum*, which is basically the probability at F naught value at 2.52 minutes is basically 10^{-12} spores per can.

So, you can see that 2.52 minute at 121.1 degree Celsius at the slowest heating point of the container. That is also very important. This condition has to be prevailed at the core of the product or slowest heating point of the container. So, the thermal process calculations are also depend on the thermal conductivity or the transfer of heat from point A to point B throughout the containers. The heating process depends on the container's consistency, whether processing liquid food only, a mixture of liquid and solid food, or solely solid food. For solid food, conduction predominantly governs the heat transfer. In the case of a liquid-solid mixture, heat transfer involves both convection and conduction. For liquid foods, the process is solely based on convection.

When considering conduction and convection, the concept of core temperature, core point, or the slowest heating point within a container varies. In convective heat transfer, the cold point or core point is slightly above the container's bottom. However, in purely conductive heat transfer, the core point or cold point is at the geometrical center of the container.

The core temperature is measured at specific spots for both liquid and solid food. Various gadgets, such as thermocouples, are employed to measure the core temperature in different processes, whether conductive or convective. Thermocouples, specifically, are utilized for this purpose. The placement of the thermocouple depends on the type of container – convective or conductive. In convective container processes, the thermocouple gland is positioned just above the container's bottom. Conversely, in conductive containers, the thermocouple is placed at the geometric center.

A thermocouple is a temperature-measuring sensor composed of two wire legs made from different metals. These legs are welded together at one end, forming a junction where the temperature is measured. When the junction undergoes a temperature change, it generates a voltage. This voltage can be interpreted using thermocouple reference

tables to determine the temperature. Two non-identical metal wires are used to create a junction, resulting in the flow of electricity. Temperature transfer between points leads to the generation of electricity or flow of electrons. The temperature difference is calculated as electricity using specific algorithms, and this is further interpreted as a particular temperature. Various types of thermocouples are employed, with the most common being the type K thermocouple, utilizing a nickel-chromium and nickel-alumel combination for the junction. This type has a temperature range of -270 to 1260 degrees Celsius. Another example is the type J thermocouple, employing iron and constantan, with a temperature range of -210 to 760 degrees Celsius. Type T thermocouple utilizes a copper, copper, and constantan combination with a temperature range of -270 to 370 degrees Celsius. Additionally, there is the type E thermocouple, which uses a nickel, chromium, and constantan combination, featuring a temperature range of -270 to 870 degrees Celsius. Different metal combination wires, specifically non-identical ones, are employed. The variation in thermal conductivity among these wires creates an electric flow. The resulting electricity is measured and, through calculations, converted back into temperature, providing readings for the container's core point.

The thermocouple allows measurement of various core temperatures, including the retort temperature. Heat penetration data is generated by measuring the product's core temperature. Key parameters such as core temperature, retort temperature, and the F0 value (lethality rate) are crucial for standardizing the thermal process. These values are calculated to ensure the efficiency of the thermal process, with different calculation methods developed over the years. Generally, three types of calculation methods are there, one is the general method proposed by Bigelow et al. (1920) and there is the improved general method proposed by Schultz and Olsen (1940). And the currently which is most popularly used is the Balls process time calculation method which is proposed by Charles Olin Balls in 1923. In general method that is proposed by Bigelow et al. in 1920, it is a process calculation method. It is suggested that if the time required to render the food at the slowest heating region is safe, other regions of the container or the can as well as the old container is rendered as safe.

So, in the general method the temperature at the cold spot is read at equal intervals of time starting from the time steam is allowed into the retort or steam on till can cooling. From heating to cooling process the temperature data is recorded. The TDT of most significant organism in that particular pack has to be determined at various temperatures throughout the heating and cooling period. So, throughout the heating and cooling period the core temperature is measured and that data is used in the case of general method. General method is mostly kind of a graphical method where a graph is drawn in the case of comparing the lethality rate and the time and minutes required.

From the heating to cooling points, the entire time's lethality rate across the temperature

range is considered. A lethality rate curve is developed, and the area under the curve is determined. The lethal rate, equivalent to 1 divided by TDT, represents the unit value of the total thermal death time. These values are plotted against corresponding times to create the lethal rate (LR) curve. LR values are calculated for each temperature, and the total lethality of the process is computed based on the area under the lethal rate curve.

A lethality of 1 indicates complete destruction of spores in that particular process, with the maximum lethality assigned a value of 1. On a graph sheet, a lethality of 1 square is calculated as 0.0025 multiplied by 5, resulting in 0.0125. For instance, if the total area under the curve is 71.35 square centimeters, the total lethality is calculated as 0.0125 multiplied by 71.35, equaling 0.089, which is less than 1. The total lethality of the process, 0.089, is insufficient for complete spore destruction, indicating a need to increase retorting time. This suggests that the process lethality is not close to 1, requiring additional lethality. The graphical method, a general approach, is employed to calculate total process lethality.

An alternative method, the improved general method proposed by Schultz and Olsen in 1940, involves plotting temperature versus time on specially constructed lethal rate paper. This paper has product temperature on a log scale on its left-hand vertical axis and lethal rate on a linear scale on the other vertical axis. Each temperature corresponds to the respective lethal rate. Time is plotted along the horizontal axis using a convenient scale. The area under the graph, representing the product of exposure time at all lethal rates throughout the process, is then divided by the area equivalent to the F0 value or unity. This yields the total sterilizing effect or the F0 value for the process. To summarize, the improved general method considers the entire heating and cooling effects, incorporating changes in heat penetration rates due to product gelation or liquefaction. Knowledge of the product's thermal characteristics is unnecessary, simplifying F naught calculation but limiting the technique's versatility. There are various advantages and limitations for these processes. In the general method, core temperature characteristics are the primary focus. Contrastingly, the improved general method simultaneously considers both heating and cooling time lethality rates, consistently calculating a unit value. The L-R curve reflects the inclusion of two types of information: heat penetration data, core temperature data, and lethality rate data. F0 value is computed by dividing the area under the heat penetration curve by the area corresponding to an F0 or a single unit value. This involves dividing the complete area by the unit value or the F0 or 2.52 minutes that is known as unit value of lethality. The improved general method divides the total sterilizing effect by the unit value of lethality. In the Balls process time calculation method proposed by Charles Olin Balls, both heating and cooling curves, along with core temperature measurements, are considered simultaneously. The formula used is BPT (Balls process time) = fh (log jh*lh- log gc). This method assigns equal importance to both heating and

cooling processes. In the Balls process time calculation, core temperature retort temperature deficits are computed, encompassing both heating and cooling temperature deficits. The heating temperature deficit is the reference temperature of 121.1 degrees Celsius minus the core temperature, while the cooling deficit is the core temperature minus the temperature of the cooling water.

The temperature deficit, the difference in temperature compared to the reference temperature and cooling water temperature, is calculated. This data is plotted on semi-log or three-log graph paper, commonly using a semi-log graph. Time is represented on the x-axis, and temperature deficit values on the y-axis. Additionally, the come-up time, the duration for the retort to reach the reference temperature, is considered in Balls process time calculation. Only 58% of the come-up time is utilized for the retort to reach the processing time in the calculation. The formula used is BPT = fh (log jh*lh- log gc). fh represents the slope value of the heating curve, jh is the lag factor of heating, determined from pseudo-initial deficit and initial deficit. Ih is the pseudo-initial deficit used for the calculation, and gc is calculated from fh by U or using fh/U value tables. Values are obtained from these studies. The total processing time is essentially 58% of the come-up time plus BPT. An operator process time is also determined, calculated as BPT minus 42% of the come-up time. Various scientists have conducted heat resistance evaluation studies over the years, revealing thermal properties such as the D value and Z value of microorganisms like *Clostridium botulinum*.

Notable studies include the single tube method proposed by Bigelow and Esty in 1922, the multiple tube method by Esty and Williams in 1924, Townsend et al.'s method in 1938, and methods proposed by Stumbo in 1973 and Schmidt in 1971. These studies led to conclusions about the heat resistance properties of different microorganisms. In the Bigelow and Esty method, a known number of bacterial spores in suspension are sealed in a glass test tube, heated in an oil bath at a constant temperature, and each tube is removed at specific intervals, rapidly cooled, and cultured to determine the number of organisms. The TDT is calculated between the time of heating the last tube showing growth and the next tube showing no growth. The main disadvantage of the single tube method is known as skips, which occur due to taking only one tube at a time, sometimes resulting in tubes that show no growth. This hinders the calculation's accuracy. To overcome the shortcomings of the single tube method, the double-tube method, or multiple tube method, developed by Esty and Williams in 1924, was proposed. Unlike the single tube method, the multiple tube method uses several tubes at a prescribed time interval. Even if some tubes show skipping characteristics, others reveal the actual survival count, ensuring accurate calculations. Approximately 25 to 30 tubes are used in the multiple tube method to mitigate the skips phenomenon encountered in the single tube method. Townsend et al., in 1938, introduced a method that departed from using only known bacterial suspensions in single and multiple tube methods. Townsend's

innovation involved studying bacterial suspensions in the presence of food, a crucial aspect. For determining thermal death time in raw food products, Townsend used special cans of specific dimensions, sealed under vacuum, containing raw material and a test organism. The cans were heated in small retorts, rapidly cooled, inoculated, and assessed for bulging, considered an indication of growth. Townsend et al. devised a container that simultaneously held food and culture. Given that various food factors influence microorganisms' heat resistance, such as the presence of oil or calcium, Townsend et al. identified the importance of including food in heat resistance calculations. In 1973, Stumbo designed a specialized machine for assessing thermal resistance properties. Stumbo designed a thermo resistometer for heat distribution studies within the range of 115 to 132 degrees Celsius. The thermo resistometer comprises three chambers connected to a steam reservoir, each independently pressurized and exhausted. Samples are placed in small metal cups, 7 mm by 1.5 mm in diameter and 1.5 mm in depth, on aluminum boards and moved through the chambers sequentially. Advantages include increased accuracy in a single operation, complete sample culturing, and reduced contamination risk. This thermo resistometer simulates conditions similar to commercial retorting or production processes, enhancing calculation accuracy. Stumbo invented this device to calculate the thermal resistance properties of various microorganisms.

In 1971, Schmidt introduced the concept of core temperature measurement. He placed a test microorganism in glass tubes fitted with cotton wool plugs, allowing the addition of culture medium directly into the tubes, minimizing contamination risks. The experiment was conducted in a mini-retort with a pressure cooling system and chambers to manage pressure, preventing the blowing of cotton plugs. Temperature measurements were facilitated using thermocouples. Schmidt's innovation involved using glass tubes with cotton plugs and thermocouples to measure core temperature, marking an improvement in the method. The introduction of thermocouple-based measurements was Schmidt's contribution to the field.