CHAPTER 5
PROCESSING AND SAFETY

Notes

5.1 INTRODUCTION

Acidified foods have an excellent safety record. The acid added to these products, along with the pasteurization treatments (thermal processes) that are used to assure preservation of many acidified foods, kill most spoilage and pathogenic (disease-causing) microorganisms. Thermal processes for acidified foods are designed to kill vegetative cells of microorganisms. It is important to note that the thermal treatments for these foods are *not* the same as sterilization because spores of bacteria, including spores of the deadly pathogen *Clostridium botulinum*, can easily survive such heat treatments. The germination and growth of *C. botulinum* and production of botulinum toxin is prevented in acidified foods by keeping the pH at or below 4.6.

Some pathogenic bacteria, including *Escherichia coli*, *Listeria monocytogenes*, and *Salmonella* species are resistant to acid and low pH. Outbreaks of these pathogens have occurred in acid foods that were not thermally processed with pH values below 4.6, such as apple cider and orange juice. While these pathogens do not usually grow in acidified food products with pH values below 4.6, they may be able to survive for extended periods in some acidified vegetable products. Therefore, appropriate steps must be taken to be sure that these pathogenic bacteria, which do not produce spores, are killed in acidified foods.

5.2 HEAT- AND ACID-KILLING OF MICROORGANISMS

Both heat and organic acids (such as acetic acid) can be used to ensure the safety of acidified vegetable products. Based upon our current knowledge, acidified vegetable products that have a pH value above 3.3 must receive a heat treatment to ensure safety. For products acidified with acetic acid that have a final pH at or below 3.3, the acetic acid present can ensure the death of pathogens, given a sufficient holding time. Details for these procedures are presented later in this chapter, but first it is important to understand the effects of heating and acid on microorganisms.

5.2.1 Bacterial Cells

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Bacterial cells vary widely in their ability to survive heat treatments. Some very sensitive species die rapidly at a temperature of 120°F (49°C), while some thermophilic bacteria grow well at this temperature. There are even some bacteria which grow in deep ocean volcanic vents that can only live and grow at very high pressures and boiling (212^{o}F or 100^{o}C or greater) temperatures. The vegetative cells of most bacteria, including food pathogens, spoilage bacteria, and the lactic acid bacteria used in vegetable fermentations, are readily destroyed by heating to 160°F (71°C), especially when the pH is low.

Acid and low pH are also toxic to most bacteria. This is why vegetable fermentations are useful for food preservation. The lactic and acetic acids produced by lactic acid bacteria during fermentation, as well as other metabolic end-products, preserve vegetables by preventing the growth of other microorganisms, including human pathogens. In acidified foods, acid (typically acetic acid or vinegar) is added for the same reason. As we will see below, if enough acetic acid is added, foods can be preserved without heat treatment, but most acidified foods rely on a combination of acid and thermal processing to ensure shelf stability and safety.

5.2.2 Bacterial Endospores

The spores of bacteria, including the spores of *C. botulinum*, are extremely heat-resistant compared to vegetative cells. It would be necessary to use a retort with high pressure steam to destroy these spores. The spores of *C. botulinum* are widespread in the environment and present in many foods we eat, but pose no danger since only the vegetative or growing cells of *C. botulinum* can produce botulism toxin and cause disease. In most foods, the oxygen present in air and competing microorganisms will keep *C. botulinum* from growing. The germination of spores of anaerobic microorganisms in sealed jars or containers of acidified foods is prevented by keeping the pH at or below 4.6. It is important to remember that heat treatments designed for acidified foods will not kill most spores, so keeping the pH of acidified foods at or below 4.6 is required to prevent botulism. Fortunately, *E. coli*, *Listeria*, and *Salmonella* do not form spores. The sensitivity to heat of vegetative cells makes thermal processing a very useful process for ridding acidified foods of these pathogens and other microorganisms which could cause disease or spoilage.

5.2.3 Yeasts and Molds

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Most yeasts and molds are heat-sensitive and destroyed by heat treatments at temperatures of 140-160°F (60-71°C). Some molds make heat-resistant spores, however, and can survive heat treatments in pickled vegetable products. These molds, however, require oxygen to grow. When jars or containers of thermally processed acidified vegetables are improperly sealed or cracked, oxygen may get in. Under these conditions, spores that survived heat treatment may germinate and grow on the surface of the liquid inside the container where air is present. These molds can consume the acid present in these products, causing the pH to rise above 4.6, which in turn can lead to the growth of *C. botulinum* and potentially the production of deadly botulinum toxin. Therefore, it is very important to make sure that containers of acidified foods are properly sealed.

There are relatively few spore-forming microorganisms which can grow without oxygen and at pH values below 4.6 (see Chapter 10, Table 10.1). One such organism is a mold named *Byssochlamys fulva*. This organism has been responsible for the spoilage of thermally processed canned fruits. It is quite heat-resistant, requiring about 1 minute at boiling temperature to kill cells of the organism, and may survive the heat treatment. Fortunately, this mold has not been reported to be a problem in acidified vegetable foods. When spoilage of thermally processed acidified food products does occur, it is usually because some jars or containers were not heated for the required time at the correct temperature.

5.3 FACTORS INFLUENCING THE SURVIVAL OF MICROBES

Not only do different species of microorganisms vary widely in resistance to heat and acid, but sensitivity within a single species is also variable. Many factors, including the time and temperature of exposure and the amount of acid present, can affect the heat and acid resistance of microorganisms. A particularly important factor is the conditions the microorganisms have been exposed to prior to exposure to acid or heating. For example, some bacteria can become more heat-resistant than normal by exposure to low levels of heat that do not kill but only stress the bacteria. When thermal processes are developed for acidified foods, all these factors must be taken into account to assure that the final products produced are safe and will not spoil. The more important variables are as follows.

5.3.1 Number of Cells Present

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Individual cells of microorganisms in a population are not all killed at the same time. With most bacteria, only a percentage of the cells present are killed in a given time increment. For example, the death of *E. coli*, at 140^{o}F (60^{o}C) and pH 4.1 in acetic acid solution can be determined by measuring the surviving cells at time intervals as shown in Figure 5.1. If a straight line results when the log of the number of viable cells is plotted versus time, as occurred with these data, the time needed for a 10-fold reduction (90%, or 1 log number reduction) in cell numbers is constant.

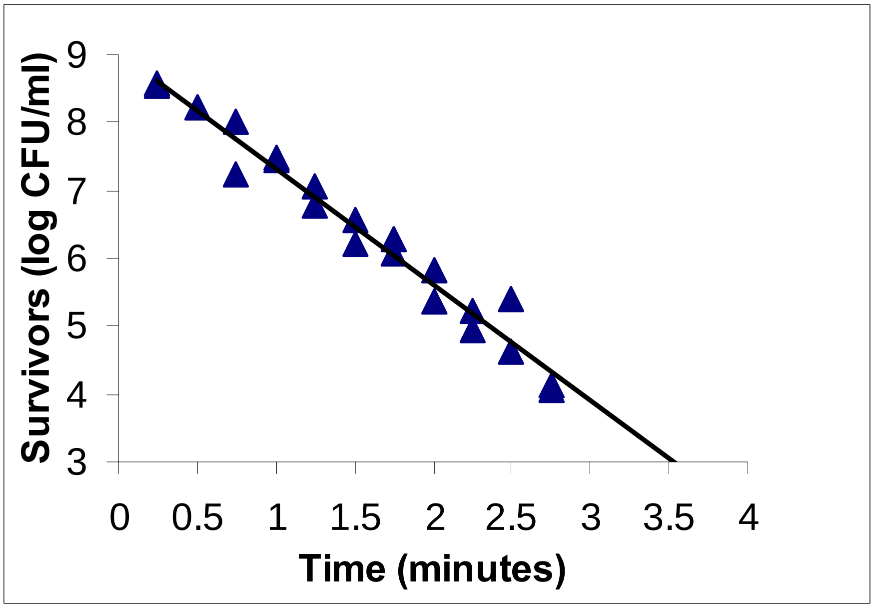

Fig. 5.1. Killing of *E. coli* at 140^{o}F (60^{o}C) in a pH 4.1 solution of acetic acid.

It is obvious from these data that the number of cells killed depends on both the heating time and the initial cell count. It is very important that manufacturers of acidified foods understand this and keep the microbial population of foods prior to final processing to a minimum. Equipment should be cleaned on a regular schedule and the food moved through the manufacturing operation rapidly. This is one important reason why good sanitation is so important in food processing plants.

5.3.2 Relationship of Time and Temperature

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The time required to kill microorganisms with heat changes dramatically with temperature. The times needed in minutes to give a 10-fold reduction (90% reduction) in the numbers of surviving *E. coli* strains over a range of temperatures in a solution of acetic acid at pH 4.1 are given in Figure 5.2.

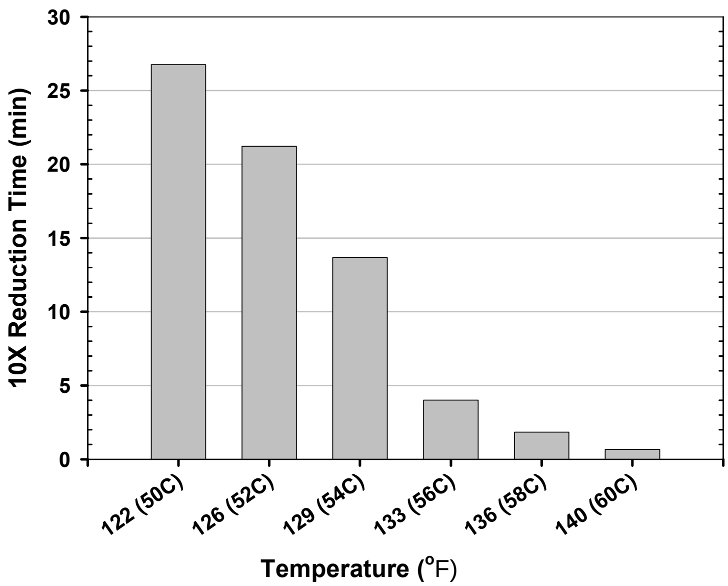

Fig. 5.2. Time needed for a 10-fold (90%) reduction in *E. coli* cell counts in a pH 4.1 solution of acetic acid with a variety of temperatures.

As can be seen in the figure, increasing the temperature dramatically decreases the time needed to kill 90% of the bacteria. These data are typical of heat killing for vegetative cells of most bacteria.

5.3.3 Physiological Condition of the Microbe

The conditions under which microorganisms have been living can greatly influence the ability of an organism to be killed by acid conditions or heating. Important factors include: (a) the culture medium or food in which the organism has grown, (b) the temperature of growth, and (c) the phase of growth or age of the culture. In addition, when bacteria are subjected to one kind of stress, such as chemical sanitizer treatments, surviving bacteria can become more resistant than usual to heating or other environmental insults.

Therefore, when thermal processes are developed in laboratory settings for acidified foods, it is necessary to prepare test microorganisms so they are as heat- and acid-resistant as possible to ensure that all the vegetative cells are killed.

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5.3.4 pH and Acidity

Most bacteria are rapidly killed at pH and acid concentrations typical of acidified foods, but the type and concentration of acid present can play a significant role. Not all acids are equally effective in killing bacteria. The killing effects of a given type of acid can be differentiated from pH effects. As shown in Figure 5.3, acetic acid significantly reduces the time needed for a 10-fold reduction (90%) in cell numbers of *E. coli*, compared to HCl treatments where killing is due to pH alone.

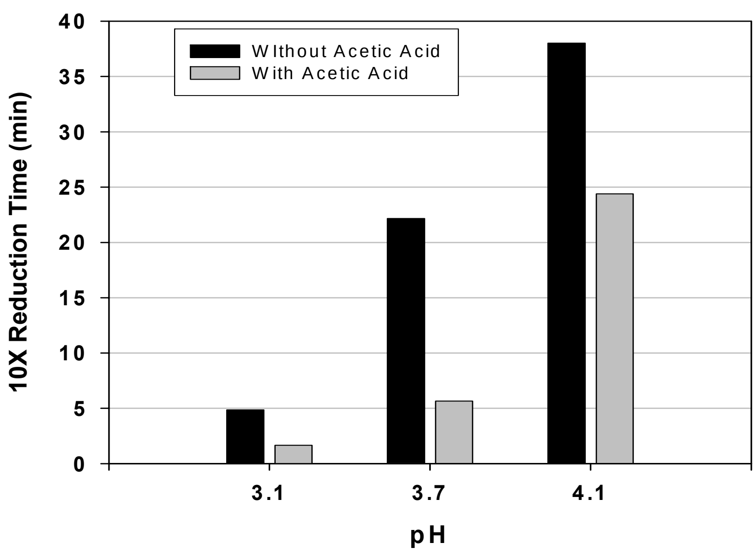

Fig. 5.3. The time needed for a 10-fold (90%) reduction in *E. coli* cell numbers at 20^{o}C at three different pH values, using acetic acid (gray bars) or without acetic acid (black bars).

The data in Figure 5.3 show that acetic acid is more effective at killing *E. coli* than pH alone. It is also clear from these data that, as the pH is lowered, the time needed for a 10-fold reduction in cell numbers is decreased. For the conditions shown in Figure 5.3, the *E. coli* cells were killed most rapidly when acetic acid was used to lower the pH to 3.1.

Thermal processes for acidified foods are routinely less severe than processes for high pH foods (low-acid foods). This is because

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acid and pH enhance the killing effect of heat. It is important to remember that the killing effects of heat and acid combined on vegetative cells of bacteria are more effective than either alone.

Bacterial endospores are also killed more rapidly as pH is lowered, but the effects are not significant because most spores are very resistant to acid and heat. As mentioned above, spores usually survive heat treatments applied to acidified foods.

5.3.5 Sugar and Salt

As with acid and pH, sugar and salt concentration can affect the ability of bacteria to survive in acidified foods. This is because of the reduction in water activity (a_w), as described in Chapter 2, Table 2.2. However, at concentrations typically used in acidified vegetable products, evidence suggests that sugar and salt have relatively little effect on the survival of bacteria. Some yeasts, however, which grow best in high concentrations of sugar become more heat-resistant as sugar concentration is increased.

5.3.6 Other Food Ingredients

Food constituents, such as oils and fats, may protect microorganisms from heat to varying degrees because moist heat is much more effective than dry heat in killing microbes. Cells killed almost instantly in boiling water may survive for hours on dry surfaces in an oven at the same or higher temperatures. Cells suspended in oil respond very much like cells on dry surfaces. This is an important consideration in developing thermal processes for acidified foods marinated in oil. These foods may require longer heating times or higher temperatures than other acidified foods. It is also important to acidify oil-marinated foods prior to adding oil because oil may impede the penetration of acid into the food product.

5.4 THERMAL PROCESSING

The benefit of applying heat to food to increase the shelf-life was first used by Louis Pasteur to preserve beer. Later, the term pasteurization was applied to the process used to destroy pathogenic (disease-producing) organisms in milk. As applied to acid or acidified foods (pH at or below 4.6), the thermal process can be defined as one that is sufficient to destroy the microorganisms that cause disease or spoilage if the product is held under normal conditions of storage. Remember that *C. botulinum* spores will not be destroyed by these heat processes, but germination, growth, and toxin production by this organism is prevented by keeping the pH at or below 4.6.

It must be assumed that microorganisms are distributed uniformly in a can or jar of food. Therefore, every part of the food must receive an adequate amount of heat to ensure that the vegetative cells of spoilage or pathogenic organisms are killed. Thermal processes must be based on temperatures achieved at that point in the container which heats more slowly. While this point is usually near the center of the container, its actual position depends on the type of food and the modes of heat penetration.

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5.4.1 Modes of Heat Penetration

The three general modes of heat penetration into cans of food are illustrated in Figure 5.4. Heat moves through a solid or semi-solid substance by a "bucket brigade" (i.e., it is passed on from molecule to molecule). Different substances conduct heat more rapidly than others. In general, metals conduct heat more rapidly than glass, which conducts more rapidly than plastics. Solid or semi-solid foods will also vary in the rate of heat conduction. With solid or semi-solid foods, the slowest heating point in the container is the geometric center.

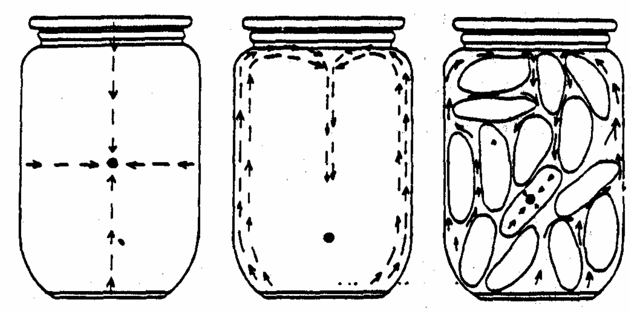

Fig. 5.4. Modes of heat penetration into jars containing different types of foods. Arrows indicate directions of heat penetration. The black dot (●) represents the location of the slowest heating point in each container.

In liquids, heat is rapidly distributed by movement of the liquid. The density of a liquid decreases as the temperature increases. Therefore, as liquid adjacent to the surface of a container is heated, it moves toward the top, creating a convection current. Jars or containers containing liquid foods heat more rapidly than those with any other type of food because of convection currents. The slowest heating point in containers with heating by convection is about 3/4 inch from the bottom in the center of the container (Fig. 5.4).

Foods, such as pickles, with solids suspended in liquid, heat by a combination of convection and conduction. The coldest point in the container is typically the center of a large solid particle located somewhere below the center of the container.

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5.4.2 Factors Influencing Time Required to Raise Temperature to Effective Lethal Levels

The container used for a product affects heating rates. Metal cans conduct heat more rapidly than glass. The coldest point in small containers will reach a given temperature more quickly than in large containers, and a long cylindrical container will heat through quicker than one with a diameter about equal to its height when both contain the same volume of food. As noted above, the type of food strongly influences heating rates. Watery liquids heat faster than heavy syrups. Foods with high water content will conduct heat more rapidly than starchy foods. The smaller the particles of a food suspended in liquid, the more rapidly heat will be conducted to the center of the particles. However, this may be negated by packing small particles more tightly than large particles. This results in reducing or eliminating convection in the liquid phase. For example, pickle relish heats almost entirely by conduction heating because it has small, tightly packed particles. The tightness of packing of solid particles (solid to liquid ratio) has pronounced effects on required heating time.

The higher the initial temperature of the food, the quicker it will arrive at a temperature which will kill microorganisms. Also, the higher the temperature in the thermal processing equipment, the quicker this temperature will be attained. While thermal processes for acidified foods are designed to ensure safety, quality factors also need to be considered. For most acidified foods, safe heat treatments do not require heat so high that the food is damaged by overcooking.

Containers packed closely together in the thermal processing equipment will not receive as much heat as widely spaced containers. Heat penetration rates should be checked in containers packed as tightly as possible in the processing equipment. Some processing equipment has been designed to rotate and agitate containers during the thermal process. This provides some mechanical movement of foods with a liquid phase and increases the rate of heat transfer.

5.4.3 Measurements

Detailed procedures for measurements of heat penetration into food containers are beyond the scope of this manual. These should be done in each type of food in all different sizes and types of containers used and at a variety of positions in the thermal processing equipment. Thermocouples are positioned at the pre-determined coldest point in each container and the temperature recorded during both the heating and cooling operation. A data recording device containing a computer memory chip can be placed inside of jars or containers to be thermally processed and an entire heating curve established. Regularly scheduled heat penetration checks can be conducted by removing containers from the thermal processing equipment at different periods during the process and inserting a dial thermometer to the coldest point in the container. The container contents must not be mixed before measuring temperature by this method. Processing equipment must be checked frequently to ensure that safe heating requirements are met.

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5.4.4 Establishment of a Heat Process

All acidified foods require filing a process with FDA which will assure the safety of the product that is delivered to consumers. Many, but not all, acidified foods require a thermal process to assure the removal of vegetative bacterial pathogens. Products that do not require a thermal process are defined in section 5.5.2. To determine an adequate thermal process to assure product safety, it is necessary to know two things: (1) the time at the selected process temperature required to achieve a 100,000-fold killing of the most heat-resistant microorganism present which could cause disease, and (2) the time required to reach the target process temperature at the slowest heating point in the container that is used. The thermal process delivered to a product may exceed the filed time and temperature, but neither the time nor the temperature can be less than the filed process. Thermal processes, along with other factors required to assure a safe product, are typically determined by a competent process authority. They must be tailored to a particular product. Most commercial thermal processes for acidified foods greatly exceed what is required to assure safety.

5.5 ENSURING SAFETY

All food manufacturers want to produce safe products. For acidified foods, this means ensuring that the pH is kept at or below 4.6 and that all vegetative cells of food pathogens which may contaminate a product are killed. Acidified foods are divided into two categories, those requiring a heat process to ensure safety and those that do not require a heat process. Acidified foods with an equilibrium pH above 3.3 require a heat process to assure killing of pathogenic bacteria. Acidified foods with an equilibrium pH at or below pH 3.3 do not require heat treatment, but do require a holding time of 48 hours at 77^{o}F (25^{o}C) or higher prior to distribution of the product.

Notes

5.5.1 Products Requiring Heat Treatments

For most acidified foods, the acid or acid ingredients added are not sufficient to ensure the rapid death of vegetative cells of food pathogens. This is true if the final equilibrated pH value of the product is above pH 3.3. For these products, a heat treatment is necessary to ensure that the vegetative cells of pathogenic bacteria are killed. Of primary concern are acid-resistant pathogens, such as *E. coli*, *Listeria*, or *Salmonella* strains. Heat treatments delivered to the slowest heating point in containers of acidified foods with acetic acid as the primary acidulant sufficient to kill these pathogenic bacteria are presented in Table 5.1 (Breidt et al., submitted for publication). The values listed in the table are the minimum times and temperatures required to assure a 100,000-fold (5-log reduction) reduction in viable cells for acidified foods.

Table 5.1. Minimum 5-log reduction times and temperatures for pathogenic bacteria in acidified foods with a pH above 3.3*.

Temp (°F)	Time (min)	Temp (°F)	Time (min)
140	12.6	161	0.98
141	11.2	162	0.87
142	9.9	163	0.77
143	8.8	164	0.68
144	7.8	165	0.60
145	6.9	166	0.53
146	6.1	167	0.47
147	5.4	168	0.42
148	4.8	169	0.37
149	4.2	170	0.33
150	3.7	171	0.29
151	3.3	172	0.26
152	2.9	173	0.23
153	2.6	174	0.20
154	2.3	175	0.18
155	2.0	176	0.16
156	1.8	177	0.14
157	1.6	178	0.12
158	1.4	179	0.11
159	1.2	180	0.10
160	1.1	181	0.09

***Note: The time and temperature conditions are for the slowest heating point in the container.**

The times and temperatures shown in Table 5.1 are based on heat-killing data with *E. coli*, *Listeria*, and *Salmonella* strains in conditions typical of acidified vegetable products. As can be seen in Table 5.1, the time needed to ensure safety is reduced as the temperature of heating is increased. It is important to note that the recommended temperatures and times shown are the minimum required for safety. A graphic representation of these data is shown in Figure 5.5.

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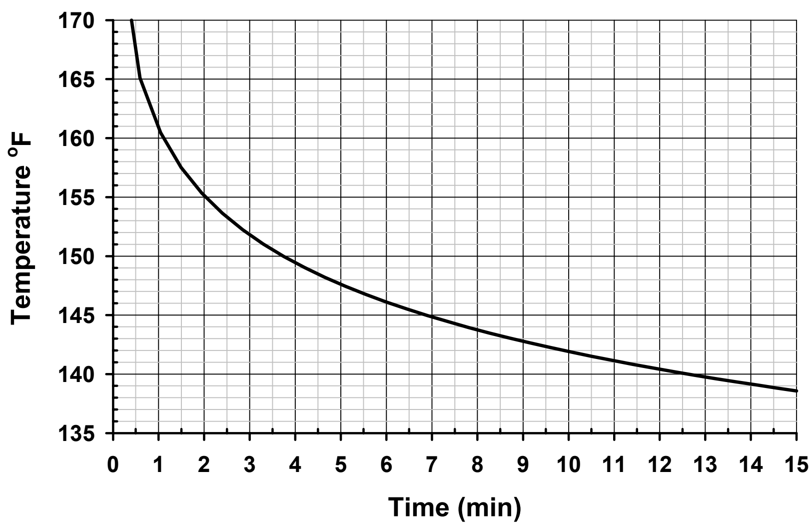

Fig. 5.5. Times and temperatures needed to ensure killing (at or above the curve) of pathogenic bacteria in acidified foods.

Filing and delivering a heat process with times and temperatures shown in Figure 5.5 will assure the safety of acidified food products. Typically products are heated above the minimum times and temperatures to assure quality and prevent economic spoilage (Etchells and Jones, 1942, Fruit Products Journal, 21:330-332; Monroe et al., 1969, Food Technology 23(1):71-77). However, a process without a heat step may be filed provided the product pH is less than or equal to pH 3.3, as described below.

5.5.2 Products Not Requiring Heat Treatments

Acidified foods with pH values above 3.3 must be heated to ensure the destruction of pathogenic bacteria. For products where acetic acid is used as the primary acidulent that have a pH value at or below 3.3, safety can be assured without a heat process. However, to safely produce these products without a heat treatment they must be held at 77°F (25°C) or higher for a minimum of 48 hours prior to distribution. The 48-hour holding time is required to ensure that the acetic acid present has sufficient time to kill the vegetative cells of bacterial pathogens that may be in the product. As described above in section 5.3.5, not all acids have the same killing effects on bacteria, so this method can only be used with products that were acidified with acetic acid as the primary acidulent and that have an equilibrated pH of 3.3 or lower. It is the combination of the specific killing effect of acetic acid and low pH that ensures safety.

Notes

5.6 OPERATION OF THERMAL PROCESSING EQUIPMENT

5.6.1 Scheduled Heat Processes

It is the supervisor's responsibility to ensure that each container of product receives the appropriate heat treatment and that this is properly documented. To do this, the supervisor must make sure that the thermal processing equipment is in good operating condition, the food is properly packed and sealed, containers are at the correct temperature as they enter the retort, steam tunnel, or other processing equipment, and that the correct temperatures and hold times are achieved to satisfy the scheduled heat process. The safety, as well as the quality, of the product depends on the proper operation of the thermal processing equipment.

5.6.2 Scheduled Heat Process Records

It is important to keep accurate records of heating times and temperatures for acidified foods requiring thermal processing. Failure to adequately heat treat or thermally process these products may result in outbreaks of potentially deadly disease and, at the very least, can lead to serious economic losses due to microbial spoilage. Detailed, accurate records of processing temperatures in the thermal processing equipment and, in some cases, the temperature of the food being processed should be made on each coded lot for each batch, or as often as necessary if the thermal process is continuous. Records should also include data on other factors affecting thermal processing, such as headspace, liquid/solid ratios, etc. To ensure that all product containers have achieved their scheduled heat process, the food manufacturing company must have documentation to show:

1. Regular calibration of thermometers, thermocouples, and other temperature measuring devices.
2. Regular calibration of the speed of the belt through continuous thermal processing equipment.
3. Sufficient temperature measurements to ensure that the cold spot of every jar reaches the minimum temperature designated by the scheduled process.

4. Sufficient belt speed and temperature measurements to ensure that the cold spot of every jar reaches the minimum dwell time at temperature as designated by the scheduled process.
5. Monitoring and recordkeeping to ensure that steam, electrical and mechanical failures are detected and scheduled process integrity is maintained.

Notes

5.7 SUMMARY

(1) Thermal processes for acid, acidified and fermented foods are designed to destroy vegetative cells of microorganisms capable of surviving or growing in the product under the conditions of storage. Spores may survive these processes, but botulinum toxin will not be produced at a pH of 4.6 or less.

(2) Bacterial cells, yeasts, and molds are killed quickly at boiling water temperature, but many spores of microorganisms may survive. To reliably kill the spores of *Clostridium botulinum* a high pressure steam treatment in a retort is needed.

(3) A very dangerous situation can occur if air gets into improperly sealed containers of acidified foods because mold spores may germinate and grow, causing the pH to rise above 4.6.

(4) Microbial cells do not all die at the same time during acid and heat treatments. The more cells present initially, the longer it will take to kill them. Therefore, it is important to keep bacterial contamination to a minimum.

(5) Bacteria exposed to one type of stress, such as chemical sanitizers or heat, can become more resistant to other stresses, such as acid and low pH.

(6) All acids are not equally effective at killing bacteria. In general, acids become more effective as the pH is lowered.

(7) Vegetative cells of bacteria are killed by acid more readily as pH is lowered, and heat killing is more effective as pH is lowered. However, many bacterial spores will survive thermal processing at low pH, but typically do not germinate and grow in acidified foods.

(8) Thermal processes for acidified foods must ensure that required times and temperatures for safety are met or exceeded at the slowest heating point in a container.

(9) In solid foods, heat must be conducted to the coldest

spot or geometric center of the container. In liquids, heat can be transferred by convection currents, and the coldest spot is typically somewhere between the center and the bottom of the container.

(10) A combination of convection and conduction heating occurs in foods such as pickles, in which solids are suspended in liquid. The solid to liquid ratio has a pronounced effect on the rate of heat penetration.

(11) The temperature of the food at the time it enters the thermal processing equipment is very important. The higher the initial temperature, the more quickly all of the food reaches a temperature which becomes effective in killing microorganisms.

(12) Acidified foods with an equilibrated pH value above pH 3.3 require a heat process to ensure safety.

(13) The heat process necessary for each product is dependent on: (a) the heat resistance of the most resistant microorganism which might be present and grow in the product and (b) the rate of heat penetration into the coldest point in the container. The actual processes may vary, but must meet safety requirements.

(14) Acidified foods using acetic acid as the primary acidulent and with a pH value at or below 3.3 do not require heat treatment, but must be held at 77^{o}F (25^{o}C) or higher for 48 hours prior to shipping or sale.

(15) Thermal processing equipment must be checked on a regular basis to ensure that they are operating efficiently and heating uniformly.

(16) Heat penetration rates into food products under regular thermal processing equipment operating conditions should be checked frequently.

(17) Thermal processes and the acid present in acidified foods can be relied upon to kill vegetative cells of bacteria, but not bacterial or mold spores.

(18) Careful records of equilibrated pH and the thermal process, or holding times and temperature, for each coded lot of acidified food products must be maintained.

Notes

Breidt, Jr., F., Costilow, R.N. Processing and safety. In Acidified Foods: Principles of Handling and Preservation. Fleming, H. P. and Costilow, R. N. (eds.). Pickle Packers International, Inc., St. Charles, IL. 2004.