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The Technology of
Food Preservation

THIRD EDITION

by NORMAN W. DESROSIER, Ph.D.

Director of Research,
National Biscuit Company Research Center,
Fair Lawn, New Jersey

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Preface

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NORMAN W. DESROSIER
West Lafayette, Indiana

Contents

CHAPTER 6

Principles of Food Preservation by Canning

The Art of "Appertizing"

Man is unable to solve problems he does not know exist. Inventions are combination products of observations and items of memory. An invention is usually composed of several parts which are known but unorganized, plus one or more parts, which, when added to previously known information, create a concept unrealized prior to the invention. Canning as known today is the product of such a process.

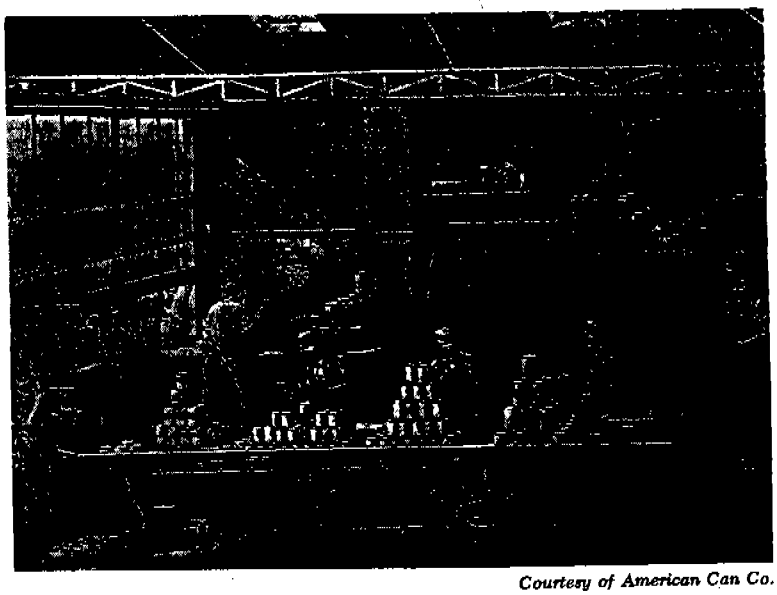
France in the late 1790's was at war and having difficulty feeding its people. Napoleon's fighting forces had a diet of putrid meat and other items of poor quality. The foods available couldn't be stored or transported except in a dry state. Recognizing an important problem, a prize was announced offering 12,000 francs and fame to anyone inventing a useful method of food preservation.

Nicolas Appert, a French confectioner, working in a simple kitchen, observed that food heated in sealed containers was preserved if the container was not reopened or the seal did not leak. He modestly called the process "the art of Appertizing." Appert received the award from Napoleon after spending ten years proving his discovery.

It should be appreciated that the cause of spoilage of food was unknown. The great scientists of the day were summoned to evaluate Appert's process and offer explanations for its apparent success. The conclusion reached was that the process was successful because in some mysterious and magical fashion air combined with food in a sealed container, preventing putrefaction. This was quite incorrect. Nevertheless, the canning process was discovered and practiced for the next 50 years with some success, but in the darkness of ignorance.

Canning from 1800–1850.—Appert began work on his process in 1795. Peter Durand received patents in England in 1810 for glass and metal containers for packaging foods to be canned. The tin-plated metal containers were called "canisters" from which the term "can" is assumed to be derived. Early metal containers (Fig. 44) were bulky, crude, and difficult to seal. By 1823 a can with a hole in the top was invented, allowing the food to be heated in boiling water baths with the hole covered with a loose lid. The lid was soldered into place after the heat treatment. Hole-in-top cans are in use presently for canned evaporated milk, although the cans are sealed prior to heating.

By 1824, Appert had developed schedules for processing some 50 different canned foods. Meats and stews processed by Appert were carried by Sir Edward Perry in 1824 in his search for a northwest passage to India. Several cans of food from this voyage were obtained from the National Maritime Museum in London in 1938 and opened. The food was found non-toxic for animals. Interestingly there were isolated from these canned products bacteria which had been dormant for at least 114 years. Given proper environment and substrate, they grew!



Courtesy of American Can Co.

FIG. 44. CAN MAKING IN THE EARLY 1800's IN EUROPE

In the 1820's canning plants appeared in the United States in Boston and New York. By 1830 sweet corn was being processed in Maine. By 1840 canneries began appearing throughout the United States.

Temperature *vs.* Pressure of Boiling Water

Canning from 1850–1900.—In 1851 Chevalier-Appert invented an autoclave which lessened the danger involved in the operation of steam pressure vessels. It was recognized that some foods could be processed for shorter times if higher temperatures were available. It was learned that the temperature of boiling water could be increased by adding salt. Demands for greater production in factories could be met if the cooking times for foods could be reduced. For instance, the boiling water bath

cooking of canned meats could be reduced from six hours to perhaps a half hour by cooking the cans in a water-calcium chloride solution. Production could be increased thereby from some 2,000 cans per day to 20,000 cans per day. Losses due to failure of containers were large. No pressure was applied to the cooking vessels. Commercial cans were unable to withstand the internal pressures developed by heating to 240°F.

The temperature at which water will boil is dependent upon the pressure. Using a pressure vessel, it was possible to achieve temperatures in the vicinity of 240°F. However, these retorts were still dangerous to operate.

Spoilage of Food Caused by Micro-organisms

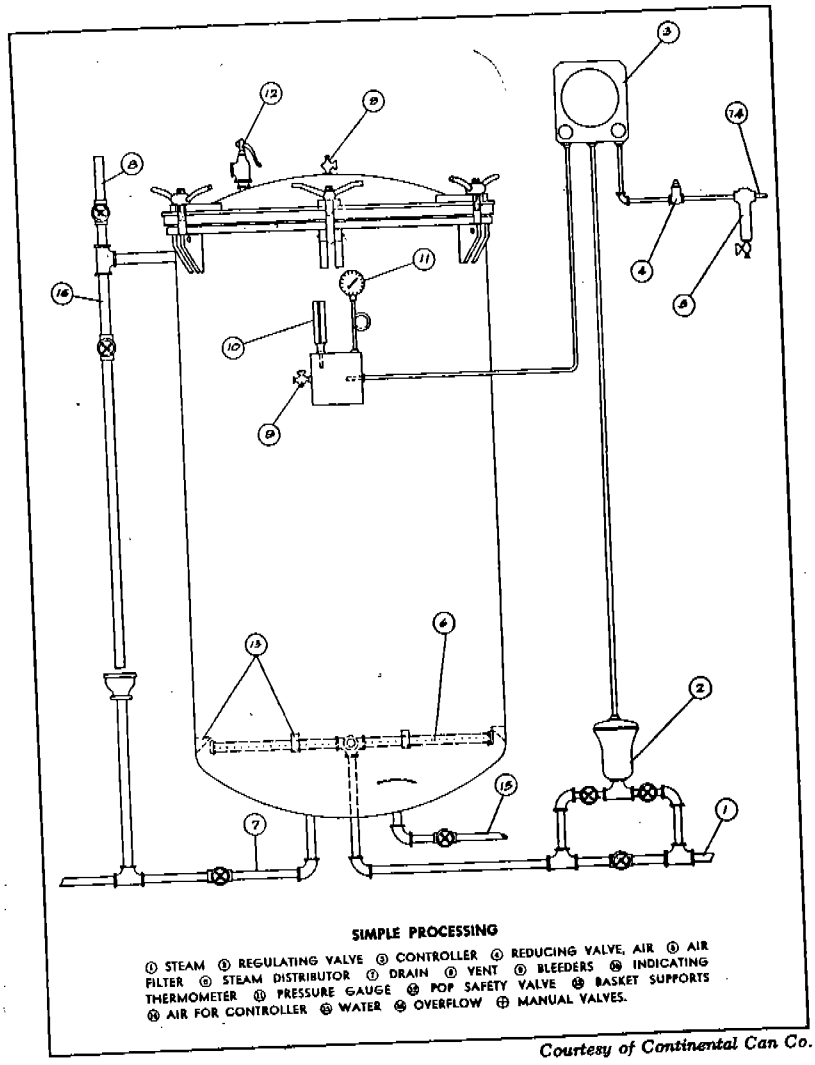
In 1862 President Lincoln signed the Morrill Act, creating the land grant colleges (Purdue, Michigan, Massachusetts, Illinois, etc.). The great scientific debate in universities at that time was "spontaneous generation" of life. At this time, too, Louis Pasteur, son of a well-decorated officer in Napoleon's army, became interested in the problems of the great wine and beer industries of France which were threatened with ruin; their products were diseased and souring from "spontaneous generation" of life in bottles and kegs.

To the Academy of Sciences in France in 1864, Pasteur reported that he had found the cause of the disease of wine and beer to be a microscopic vegetation. When given favorable conditions, this vegetation grew and spoiled the products. However, boiled wine sealed from contamination in jars with even cotton plugs would not sour. In fact, it was possible to isolate this microscopic vegetation from the cotton plugs! It was this microscopic growth which spoiled foods, and it was necessary for such organisms to gain entrance to heated foods if they were to spoil! Here was an explanation for the success of Appert more than half a century before. The concept of heat treating foods to inactivate pathogenic organisms is termed appropriately "pasteurization" today.

It is interesting to note that magnifying lenses were used by Bacon in the late 1200's, but had never been focused on a drop of water until the 1600's by Leeuwenhoek. He had noted microscopic growth which he named "animalcules," but they were only a curiosity in water to him. Two more centuries elapsed before this information was organized and synthesized into an explanation for "spontaneous generation" of life.

Appert had established that containers of food must be carefully sealed and heated. Cleanliness was important to his process, although he did not know that micro-organisms were the agents of spoilage. Pasteur established several important principles. Most changes in wine de-

pended on the development in it of micro-organisms which were themselves the spirits of disease. Germs were brought by air, ingredients, machinery, and even by people. Whenever wine contained no living organisms, the material remained unchanged. Some of Pasteur's flasks remain, and are presumably still sterile today.



Courtesy of Continental Can Co.

FIG. 45. SIMPLE STEAM PROCESSING SYSTEM COMMONLY USED

High pressure vessel which permits increased vapor pressure, hence increased temperature.

From Appert's work the term "hermetic" came into use, meaning a seal such that it sealed out spirits and ferments. Foods treated with heat in hermetically sealed containers are called canned foods. The seal is important not only to prevent the reinfection of food but also to prevent the transfer of gases.

By 1874 Shriver invented a pressure steam retort which had control features. It became adopted quickly by the canning industry. A simple steam pressure retort such as is commonly employed is shown in Fig. 45.

To recall the food carried by Perry in 1824 for a moment, the cans opened in 1938 contained viable bacteria. In the 1800's many foods were spoiling after being canned, just as we find many occasional instances of spoilage today. Prior to the turn of the 20th century, it remained to be established that foods heated to nearly 240°F. could be spoiled from under heating. Certain organisms are very heat resistant and capable of spoiling canned foods even after being heated to such a degree. In addition there are heat resistant bacteria which can grow at very high temperatures (170°F.). If cans are not cooled promptly, these heat resistant thermophilic organisms may survive the heating process, then grow and spoil the canned food. Foods to be stored in warm or hot areas require special attention.

Canning from 1900–1950.—In 1906 the Food and Drug Act was signed. This was a milestone of progress in social legislation and has been considered by many to be a landmark of accomplishment in food technology. Together these have given the United States the best food supply in the world. However, the task is by no means completed; new developments create new problems.

With the 20th century came the common "sanitary" tin can of today. It should be recognized that the term "tin" can is a misnomer. Actually the container is a tin coated steel can, having from 0.25 to 2.0 per cent tin. By the time of World War I the sanitary can was in general use, with high speed can making and sealing machines. In 1921 commercial production of cans with enameled inner surfaces was underway.

The 1920's saw a host of researchers actively evaluating the canning process. Information was accumulated on the heat resistance of bacterial spores, on heat penetration through the contents of cans, and even a mathematical solution to the problem of time-temperature processing schedules for canned foods was evolved by C. Olin Ball. Process times and temperatures were put on a sound basis, replacing the trial and error methods of the past.

In the 1930's much research was devoted to the study of nutrients important to man. Vitamins were better understood and new ones were being discovered. These and other information about food and human

nutrition were applied in the food preservation industries, with resulting improvements in the nutritional value of processed foods.

From the nutrient supply standpoint, in World War II the troops of the United States were the best fed in any war. No one would argue that the ultimate had been reached. Cold meat and vegetable stew were nutritious, but left something to be desired when eaten cold from the can. Napoleon said that an army travels on its stomach. It is still true.

During World War II it was possible to evaluate some of the changes in male population characteristics since World War I. The sons were taller than their fathers had been, and generally evidenced some of the promises of the goal of the science of human nutrition. Canned foods no doubt contributed to this improvement, providing a more varied and balanced diet throughout the year, within the reach of most of the population.

Canning from 1950.—The canning industry in recent years has made steady progress in the area of the mechanical efficiency of processing plants. More production is obtained with fewer people. Some factories produce a million or more cans of food a day. Yet the food industry is not apt to be compared with chemical and petroleum industries in plant efficiency and control.

Recent canning developments have been in agitation retorting; contents of cans can be heated at increased rates. In aseptic canning the food and container are sterilized separately, then meet at sterile filling units to be subsequently sealed in sterile chambers. Sterile canning techniques have been found valuable in preserving many heat sensitive foods (banana purée, milks, etc.). There are inherent difficulties maintaining sterility at all points in the system, and holding sterile products during equipment breakdown.

The food preservation practices prior to the discovery of canning were copied from nature. Canning has no counterpart in nature. Canning is a method of controlling natural processes. Canning is a capital invention, which has changed the eating habits of the western world.

The more man is able to understand the world in which he lives, the more uses he finds for his new information for the betterment of mankind. It has been 150 years since the discovery of the "art of Appertizing," 100 years since Pasteur's discoveries, 50 years since thermophilic bacteria were discovered in canned foods. The last word has not been written on the process, and the last discovery has not been made. The mechanism of death to micro-organisms is not understood today. Who amongst us would dare say that opportunities similar to those of Appert are no longer available?

Evolution of Containers for Canning

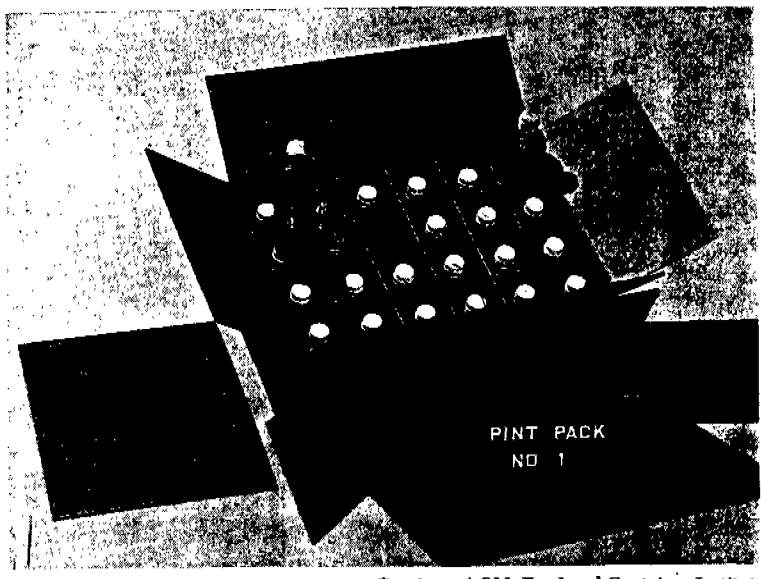
The container is important to success in the canning preservation of foods. While Appert used glass containers in his canning experiments, the tin coated steel can has been used largely during the past hundred years by the commercial canneries. Each container has certain rather exclusive uses. Glass is the traditional container for jams, jellies, preserves, green olives, and various pickled products. In the household the glass jar is used to the practical exclusion of tin for home preservation of fruit, vegetables, meats, preserves, etc. Glass is commonly used for such items as fresh milk, catsup, carbonated beverages, juices, and beer. At present one container is invading the other's field; thus much beer is now packed in cans, and glass containers that will withstand agitation sterilizers are used. Either container is adequate. There is promise for the future of tinless tin cans, and the glass industry has experimented with tin coated glass jars. Tin has protective qualities to food in containers, although it will bleach fruit colors. Glass is an inert container, although damage to food may result from the action of light-instigated reactions. The selection of one container over the other is usually decided on the basis of process and product (Fig. 46).

Glass Containers.—Glass is defined as a mutual solution of suitable silicates formed by heat and fusion, with cooling to prevent crystallization. Glass is an amorphous, transparent or translucent, supercooled liquid; investigations have failed to reveal the existence of crystalline components in glass.

Glass was known early in history, at least in 1600 B.C. The first glass was made by mixing sand with the ash of seaweed, covering with clay, and heating in a hot fire. In the period of the Roman Empire glass was melted and blown into bottles and fixtures. The next change in glass jar making involved blowing molten glass into molds to form the object. First wood and later iron molds were used. In 1880 a glass bottle machine was invented which used compressed air instead of human lung power to blow glass.

Glass usually consists of three types of oxides: 1) The glass-forming oxide of silica (high grade sand). Certain phosphates are also glass forming materials. 2) The fluxing oxides. Sodium, potassium, or lithium oxides are used, the first predominating. Fusion of fluxing oxide with the glass forming oxide yields a product soluble in water. 3) To decrease this solubility, a third group of oxides known as stabilizing oxides are used, generally calcia and magnesia. Barium oxide and alumina are used to lesser extents.

Glass food containers consist of the silicates of sodium, calcium, and magnesium. The approximate composition of glass for fruit jars is as fol-



Courtesy of QM. Food and Container Institute

FIG. 46. GLASS CONTAINERS IN OPERATIONAL CARTON

lows: SiO_2 74 per cent; Na_2O 18 per cent, CaO 7 per cent, MgO 1 per cent, and traces of Fe_2O_3 and MnO_2.

In making glass the ingredients are weighed and mixed with cullet (broken glass), in a revolving mixer. The cullet has the same general composition as the glass to be made, and melts at a lower temperature than the other ingredients, assisting in the liquefication of the batch of ingredients. When the cullet and raw materials are thoroughly mixed they are transferred to a melting furnace, where the temperature is maintained near 2600°F. After the fusion of ingredients has occurred and gases are expelled, the batch is allowed to cool until it reaches the desired viscosity. Glass containers are made from the conditioned molten glass. Glass technology is a highly specialized field and outside the scope of this text. Glass jar making equipment is automatic and in the United States either Owens-type or flow-type processes are used. The Owens process has a mold which scoops molten glass from a reservoir by drawing a gob of glass into the blank mold by vacuum. The mold lifts, and a knife edge shears excess glass from the mold. The neck of the bottle is formed by the neck or ring mold. The blank mold opens, a mold containing the desired contour of the bottle rises, closes about the gob of glass, air is applied through a blow head above the neck ring supporting the gob of glass, and it is blown into the shape of the mold. The blow head is removed and the bottle is discharged to a conditioning chamber.

In the flow-type system a gob of molten glass is dropped into a blank mold where the neck is formed by pressure. The mold opens and the partially formed bottle is transferred to the finishing mold which has the desired contour. Air pressure is applied, the gob of glass forms against the mold, the mold opens, and the formed bottle is discharged to the conditioning chamber.

In either system the formed glass container is cooled for an hour or two to control brittleness. Strains in glass are controlled by the temperatures of the conditioning chamber. After this annealing process, the bottles are discharged, inspected and packed.

Ordinary flint glass is decolorized by the addition of small amounts of cobalt or selenium oxides to the batch. Light green glass is prepared by adding small amounts of iron or arsenic oxides. Emerald green bottles are colored by the addition of chromium salts. Amber glass is colored by the addition of carbon or sulfur or a combination of iron and manganese oxides. White or milk glass is made by adding fluorides or alumina.

Glass containers are sealed with caps, made from tinplate or aluminum, and lined with cork or paperboard over which a disc of aluminum, tin, paper, plastic, or resin is placed.

Cork comes from the outer bark of a species of oak tree grown chiefly in Spain, Portugal, Algeria, and California. The bark is removed from the tree, dried, softened in boiling water and steam, flattened, and cleaned of its rough outer surface. At the cap manufacturer's plant, the cork is pulverized, mixed with a binder and formed into rods, or sheets. Rods are sliced into discs. Sheets are laminated and punched. The caps are lined with these discs.

The common crown cap of a bottle of soda is the strongest part of the container. The bottle will break before the cap is blown.

Glass containers are sealed automatically. Vacuum sealing involves passing a filled bottle through a short tunnel which is being swept with steam. This serves to sterilize the top surface of the bottle while at the same time displacing the air in the headspace of the bottle.

The bottle moves through the steam chamber, picks up a cap, which is quickly pressed into place. Cooling causes condensation of the vapor at the top of the bottle, leaving a partial vacuum. By adjusting the flow of steam, a vacuum ranging from 2 to 28 inches of mercury may be attained by this process. Containers may also be vacuum sealed with a mechanically produced vacuum.

Caps for bottles may be placed plain on the bottle, the screw being formed by machining the plain cap to the bottle. A rapidly rotating head follows the contour of the glass container, forming the screw design in the cap.

Courtesy of American Can Co.

FIG. 47. CUTTING MACHINE—A STEP IN THE FABRICATION OF CANS

Sheets of tinned steel plate are cut, notched, and fed to body-forming unit.

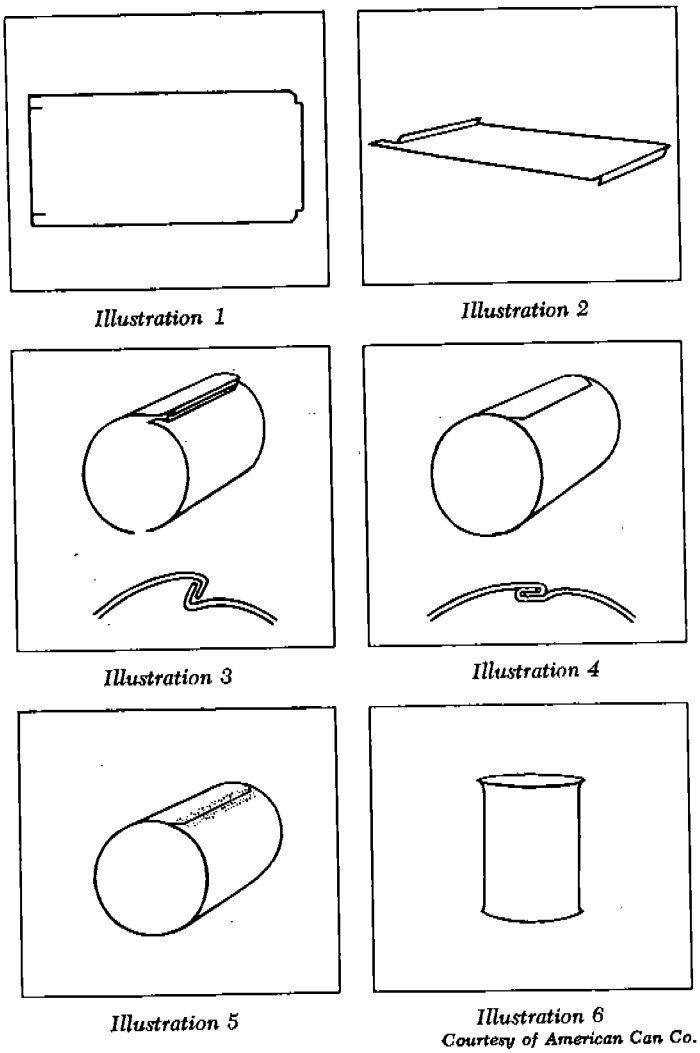
Caps for bottles have a sealing function. Caps enforce a seal either at the top of the neck, at the side of the neck, or at the shoulder of the neck of the bottle.

Tin Containers.—Although tin vessels have been used since ancient times, the process of tin plating was invented in the 1200's and was a closely guarded secret until the 1600's. In 1730 there was commercial tin plating in Great Britain. In 1873 commercial production was underway in the United States.

At first iron bars were hammered into thin sheets by hand. An iron oxide film forms on such sheets which must be removed by scouring and soaking in acid. Originally the acid used was the product of fermentation. The term "pickling" iron plate no doubt derives from this process, which means treating with dilute acid.

The cleaned iron plates then were passed through a bath of molten tin. After being tinned, the plates were cleaned and polished with sawdust and moss. Tinning pots were stratified with oil, to prevent oxidation of the tinned surface.

Hammering of iron bars into plates was replaced by rolling the bars through high pressure mills, which flattened the bars into plates.



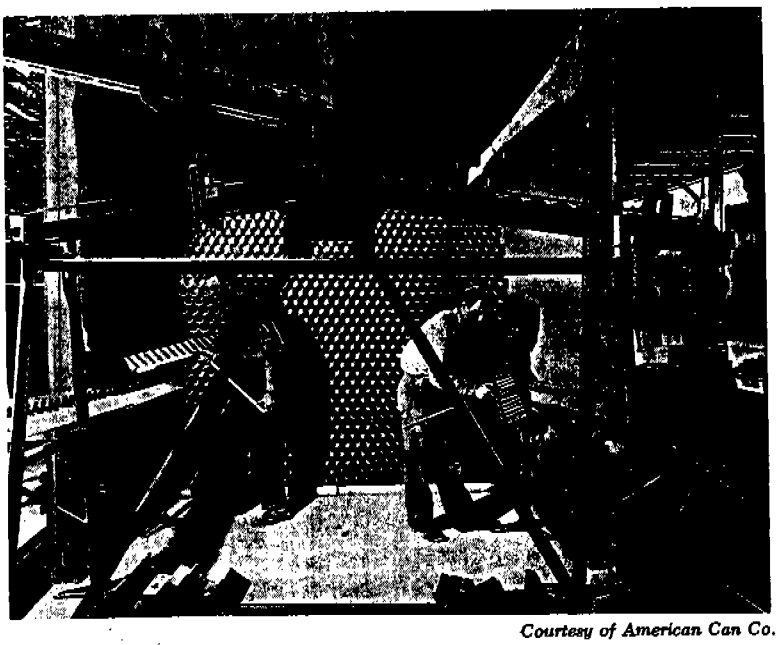
Courtesy of American Can Co.

FIG. 48. FABRICATION OF SANITARY CAN

Steps in the forming of cans. One end of can is sealed into place by can manufacturer, the other end by the food processor.

(1) Body blanks are notched; (2) hooked; (3) hooked blanks formed around bodymaker; (4) hooked blank is flattened to form side seam; (5) side seam solder applied to outer surface; and (6) ends of body are curled outwardly by special form to make the "flange."

In the 1800's sulfuric acid replaced the fermented liquids for pickling black iron plate. Bessemer steel replaced iron. A zinc chloride flux came into use which aided the union of tin to the prepared steel plate surface.

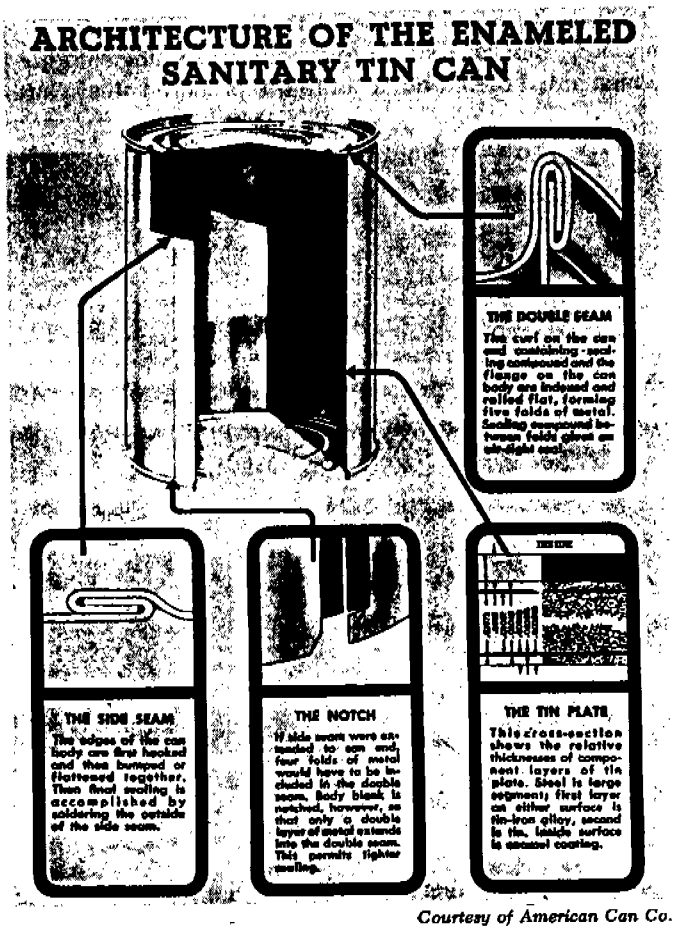


Courtesy of American Can Co.

FIG. 49. SANITARY CANS BEING LOADED INTO BOXCAR FOR SHIPMENT TO FOOD PROCESSOR

In the present century there have been a number of advances in tin container production. The invention of the sanitary can led to nearly automatic production of cans (see Figs. 47, 48, 49 and 50).

In early can manufacturing, sheets of tinned plate were marked and cut by tinsmiths. The sheets were bent into shape on a roller, the edges of the body blank overlapping, and solder was applied. End discs were cut larger than the body of the can. The edges were turned to form a flange, into which the body blank fit snugly, and was soldered into place. Under favorable conditions it was possible for a tinsmith to make a hundred cans a day. Modern equipment manufactures this number in 20 seconds or less. In present production sheets of tin plate are fed into a machine, which slits and trims the sheets into the length and width of the body. The trimmed sheets are notched at the corners, the edges are hooked, the blank bent into a cylinder, the hooks engaged, flattened and the locked seam soldered. The ends of the body are flanged to receive



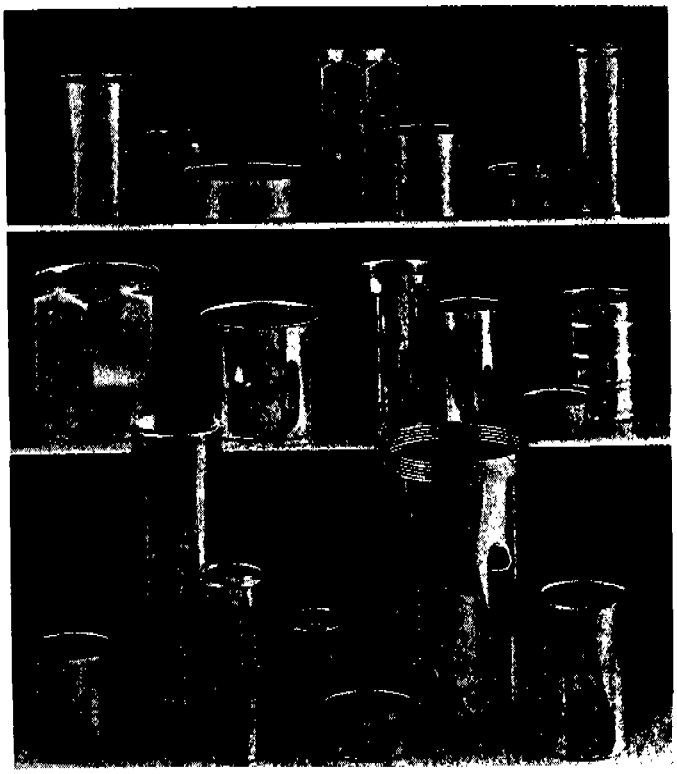
Courtesy of American Can Co.

FIG. 50. ARCHITECTURE OF THE ENAMELED SANITARY TIN CAN

Enamels are useful in protecting food and container.

the top and bottom of the can. Can ends are punched from sheets. The edges of the lids are curled, then a rubber-like sealing compound is flowed into the curl, automatically. The can bottom is then attached. After pressure testing to insure absence of leaking, the cans are shipped to canneries where food is packed into the cans and the top is sealed into position. Cans are expected to have less than one defective per ten thousand.

Highly colored foods bleach in tin containers, but retain their color in lacquered cans. The lacquer is applied and baked to one side of tin plate, then the plate is formed into containers (Fig. 50).

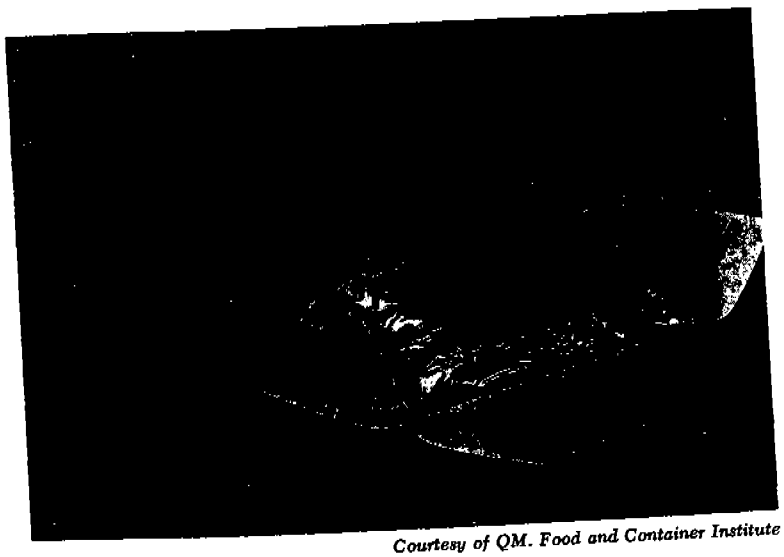


Courtesy of Food Processing

FIG. 51. FUNCTIONAL ALUMINUM CONTAINERS ARE BEING MANUFACTURED IN MANY SHAPES AND SIZES

Tin cans are made in a great variety of sizes and shapes, developed by trade customs rather than by the needs of consumers. The canner refers to the size of a can by symbols, i.e., 211 by 400. This means that the can is $2\text{-}^{11}/_{16}$ inches in diameter and four and no 16th inches high. The first number denotes the diameter and the latter the height of the can. The first digit is in inches, the last two digits denote the number of 16th. A 307 by 409 can is $3\text{-}^{7}/_{16}$ inches in diameter and $4\text{-}^{9}/_{16}$ inches high. The following are a few examples of common standard cans:

Name	Cans	Capacity in Ounces of Water at 68 °F.
No. 1	211 × 400	10.94
No. 2	307 × 409	20.55
No. $2^1/_2$	401 × 411	29.79
No. 3	404 × 414	35.08
No. 10	603 × 700	109.43



Courtesy of QM. Food and Container Institute

FIG. 52. FLEXIBLE CONTAINERS FOR CANNED FOODS BEING DEVELOPED

Experimental packages.

The trend is towards smaller container sizes. Whereas the No. 2 can was used for many consumer products for generations, it is being displaced by the 303 can which is smaller. No doubt rising prices and costs have played a role in this shift. Can sizes of smaller dimensions have become increasingly popular, too, for small families and apartment house dwellers of the country. The No. 10 can is well established in hotel, restaurant and institution trades.

Aluminum containers have recently become available in the United States (Fig. 51). Flexible containers are now being tested (Fig. 52).

The unit operations in canning are shown generally in Fig. 53.

Important Food Groups

Alkaline Foods.—Foods with pH values in the basic range are few. Old eggs, aged seafood, soda crackers, and lye hominy may have pH values higher than 7.0. Lye hominy is the only food item canned which is normally over 7.0. The degree of alkalinity is dependent upon manufacturing procedures. If all the lye is washed from the treated kernels of corn, it would be expected that its pH would be slightly less than 7.0.

Low Acid Foods.—Meat, fish, poultry, dairy products, and vegetable foods of man generally fall into a pH range of 5.0 to 6.8. This large group is commonly referred to as the low acid group, and in some cases these foods are even referred to as non-acid foods. While they are relatively

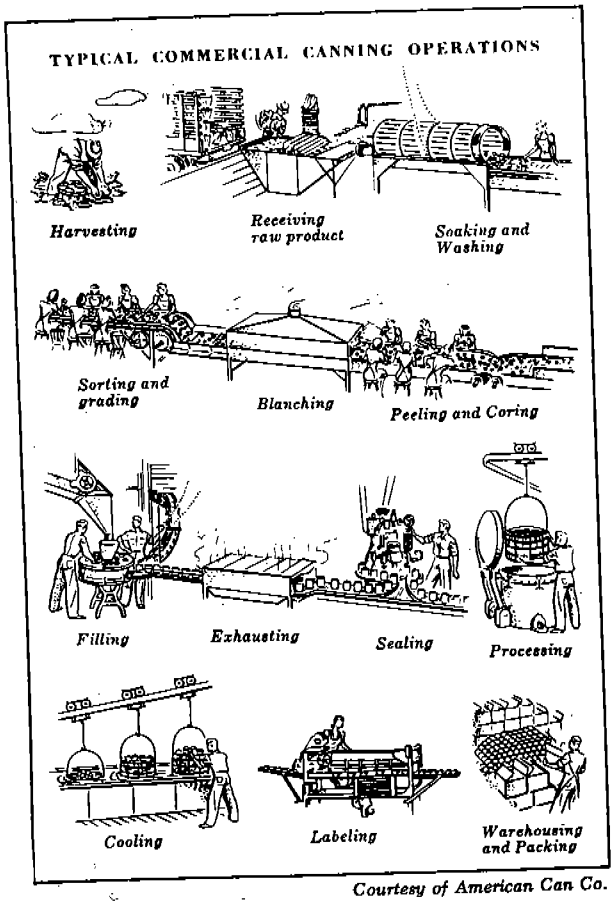


FIG. 53. SKETCH DEMONSTRATING TYPICAL CANNING OPERATION

non-acid, they do fall in the acid range of pH values.

Manufactured food items such as soups and spaghetti products, as well as figs and pimientos fall into what is called the medium acid food group. These foods have pH values between 4.5 and 5.0.

Foods with pH values greater than 4.5 require relatively severe heat treatments. The lower limit of growth of an important food poisoning organism, *Clostridium botulinum*, is at a pH value of 4.5. Inasmuch as a millionth of a gram of the toxin produced by this organism will kill man, certain precautions are indicated. All foods capable of sustaining the growth of this organism are processed on the assumption that the organism is present and must be destroyed. Foods could be classed into two

groups, depending on whether this organism can grow or not.

Acid Foods.—Foods with pH values between 4.5 and 3.7 are called acid foods. Fruits such as peaches, pears, oranges, apricots, and tomatoes fall into this class. Potato salad made with vinegar is also in this group.

High Acid Foods.—Next in order of increasing acidity are the berries, pickle products, and fermented foods. The pH values range from 3.7 down to 2.3. An example of this high acid group is cranberry juice.

Another important group of foods is one termed high acid-high solids. Jams and jellies are in this classification.

It is possible to classify the foods of man then on the basis of acidity and pH value. Plant tissue (except fruits and berries) and animal tissue (including meat, fish, and dairy products) are classed as low acid foods. Manufactured items with several ingredients may fall into the medium acid group. Fruits are in the acid group. Berries, fermented products, and certain citrus products fall into the high acid group as do jams and jellies. Few foods are basic in reaction if considered in their best quality.

A summary of the acidity classification of foods is presented in Table 54.

Micro-organisms Associated with the Food Groups

Most micro-organisms if actively growing (vegetative state) are readily killed by exposure to temperatures near the boiling point of water. Bacterial spores are more heat resistant than vegetative cells. As mentioned previously, bacteria can be classified according to their temperature requirements for growth. Bacteria of the soil, water, air, and body growing at room temperature or slightly higher are called mesophiles; their range is between 70°F. and 110°F. Some water and soil type bacteria grow best at temperatures ranging from 35°F. to 50°F., and are called psychrophiles. There are bacteria of soil, water, and air which grow best at temperatures from 120°F. to 170°F., and are called thermophiles.

It is important to distinguish between organisms capable of growing at moderately high temperatures (150°F.), the thermophilic group, and those capable of resisting the effect of high temperatures, the thermoduric group. Mesophilic organisms can be thermoduric due to their spores, as can the spores of thermophilic bacteria.

Typical genera of micro-organisms commonly associated with the spoilage of important foods are given in Table 55. The thermophiles of importance to the food industries are presented in Table 56, along with other information pertinent to the canning process.

Foods have associated microfloras; certain organisms are associated

TABLE 54

CLASSIFICATION OF CANNED FOODS ON BASIS OF PROCESSING REQUIREMENTS

Acidity Classification	pH Value	Food Item	Food Groups	Spoilage Agents	Heat and Processing Requirements
	7.0	Lye hominy	Meat	Mesophilic spore-forming anaerobic bacteria	High temperature processing 240°–250°F.
Low acid		Ripe olives, crabmeat, eggs, oysters, milk, corn, duck, chicken, codfish, beef, sardines	Fish Milk Poultry	Thermophiles	
	6.0	Corned beef, lima beans, peas, carrots, beets, asparagus, potatoes	Vegetables	Naturally occurring enzymes in certain processes	
	5.0	Figs, tomato soup	Soup		
Medium acid	4.5	Ravioli, pimientos	Manufactured foods	Lower limit for growth of *Cl. botulinum*	
Acid		Potato salad		Non-spore forming aciduric bacteria	Boiling water processing (212°F.)
		Tomatoes, pears, apricots, peaches, oranges	Fruits	Acidic spore-forming bacteria	
	3.7	Sauerkraut, pineapple, apple, strawberry, grapefruit	Berries	Natural occurring enzymes	
High acid	3.0	Pickles Relish Cranberry juice Lemon juice Lime juice	High acid foods (pickles) High acid-high solids foods (jam-jelly)	Yeasts Molds	
	2.0		Very acid foods		

with particular food groups. These organisms gain entrance to the food during the canning operation either from the soil, from ingredients, or from equipment. On the basis of the acidity classification of foods, it is possible to make general statements relative to the spoilage organisms encountered of importance to the success of the canning process (Table 54).

Micro-organisms of Low Acid Foods.—In foods with a pH value greater than 4.5, mesophilic spore-forming anaerobic bacteria are important, see Table 54. *Clostridium botulinum* is a soil borne mesophilic spore-forming, anaerobic bacterium. Another is one known as Putrefactive Anaerobe (P.A.) No. 3679, a *Clostridium sporogenes* type, common in soil. The latter is more heat resistant than the former, and is used to evaluate many heat processing schedules. If heating is adequate to kill the spores

TABLE 55

COMMON SPOILAGE ORGANISMS OF FOODS

Food	Organisms Commonly Found in Spoiled Food
Milk and milk products	Streptococci, Lactobacilli, Microbacterium, Achromobacter, Pseudomonas and Flavobacterium, Bacilli
Fresh meat	Achromobacter, Pseudomonas and Flavobacterium, Micrococci, Cladosporium, Thamnidium
Poultry	Achromobacter, Pseudomonas and Flavobacterium, Micrococci, Penicillium
Smoked cured meats	Micrococci, Lactobacilli, Streptococci, Debaryomyces, Penicillium
Fish, shrimps	Achromobacter, Pseudomonas and Flavobacterium, Micrococci
Shellfish	Achromobacter, Pseudomonas and Flavobacterium, Micrococci
Eggs	Pseudomonas, Cladosporium, Penicillium, Sporotrichum
Vegetables	Penicillium, Rhizopus, Lactobacilli Bacilli, Achromobacter, Pseudomonas and Flavobacterium
Fruits and juices	Saccharomyces, Torulopis, Botrytis, Penicillium, Rhizopus, Acetobacter, Lactobacilli

of P.A. No. 3679, the process insures the destruction also of *Clostridium botulinum*.

In addition to the mesophilic spore-forming bacteria there are also thermophilic spore-forming organisms, which are very heat resistant. In fact, they may be more heat resistant than the mesophiles. Processes designed to kill all thermophilic spore-forming bacteria may also result in canned foods far overcooked and degraded in nutritional value. These organisms therefore are controlled through sanitation and by strict control of ingredients, which may be highly contaminated. For example, it is nearly impossible to sterilize chocolate with moist heat, due to the high fat content of the chocolate which apparently entraps (thermophilic) organisms, causing death by dry heat conditions rather than by moist heat. Canned products (i.e., chocolate milk) containing such ingredients may be especially difficult to sterilize.

TABLE 56

THERMOPHILES OF IMPORTANCE TO THE FOOD INDUSTRIES

Name	Economic Importance	Heat-Resistant Spores	Growth Temperatures Optimum Degrees F.	Growth Temperatures Range Degrees F.	Oxygen Requirements
Streptococcus thermophilus	Grow during pasteurization of milk. Ripening agent in Swiss cheese.	None	120	77 –140	Facultative
Lactobacillus bulgaricus	Bulgaricus milk. Lactic acid manufacture.	None	120	77 –140	Facultative
Lactobacillus thermophilus	Grow during pasteurization of milk.	None	131	86 –150	Facultative
Lactobacillus delbruckii	Acidification of brewery mash. Lactic acid manufacture.	None	113	70 –140	Facultative
Bacillus calidolactis	Coagulates milk held at high temperatures.	Yes	131–149	113–167	Facultative
Bacillus thermoacidurans	Flat sour spoilage of tomato juice.	Yes	113	80 –140	Facultative
Bacillus stearothermophilus	Flat sour spoilage of canned foods.	Yes	122	113–169	Facultative
Clostridium thermo-saccharolyticum	Hard swells of canned foods.	Yes	131–143	110–160	Anaerobic
Clostridium nigrificans	Sulfide-stinkers of canned foods	Yes	131	80 –158	Anaerobic

Micro-organisms of Acid Foods.—In the acid food grouping, the troublesome organisms are aciduric bacteria of no special heat resistant qualities. Bacteria, yeasts, and molds are capable of spoiling these foods. The lack of growth of *Cl. botulinum* in acid foods is reflected in their low heat processing requirements. A few mesophilic anaerobic spore-forming organisms (i.e., *Cl. pasteurianum*) may cause spoilage, but in acid foods the organism has relatively low heat resistance. *Bacillus thermoacidurans* is an exception worth noting. It is the flat sour spoilage organism of tomato juice. Canned tomatoes generally are not found spoiled by this organism, although it could spoil this product. Thermophilic flat sour spoilage is due to an inoculation of food by equipment or ingredients and is related to the sanitary condition of a plant. Flat sour spoilage of home canned tomato juice is not common because equipment in homes is easily cleaned. In flat sour spoilage, as the name implies, acid is produced without gas. One difficulty then is that containers do not appear to be spoiled until open, either by the canner, buyer, or worse, by a consumer.

It is a general axiom of the canning industry never to taste spoiled low or medium acid foods, due to the threat of spoilage by *Cl. botulinum*. With acid and high acid foods, the spoiled products may be distasteful, but there is reasonably little cause for alarm in their being tasted. It is good practice to give a can of spoiled food due respect, in any case. Fortunately most canned food spoilage is associated with the production of gas, bulging the container. There may be visible signs of decomposition in the canned food itself.

Micro-organisms of High-Acid Foods.—Aciduric bacteria, yeasts, and molds are the troublesome organisms in this group. Their heat resistance is generally low. In this group too, the natural enzymes present in food may be as heat resistant as micro-organisms. Heat processes for pickles must give due consideration to the destruction of the natural enzymes of cucumbers. It is no less difficult to destroy enzymes than bacteria, yeast, or molds in pickles.

Sources of Spoilage Organisms

Spoilage micro-organisms troublesome in canning are organisms of soil, water, air, and animals. Table 55 shows the common groups associated with various foods.

Organisms of Soil.—While all the spoilage types are to be found in the soil, unless there is a transfer of soil (or dust) to the container of food, soil is not an important source of spoilage organisms. There is of course the contamination of raw products taken from the soil, but ordinary processing in a cannery should find soil washed adequately from food. There

is no excuse for food containing soil being canned. The surface of certain foods not peeled or prepared for canning will contain varying numbers of soil borne micro-organisms. Asparagus and green beans could be contaminated with soil unless the washing process is adequate. Carrots, beets, and tomatoes, for example, are peeled. The surface contamination of these products would not directly come from soil. Meats are prepared from butchered animals, and soil contamination would be unlikely. Certain animal products such as pig's feet would be an exception, not different from asparagus relative to soil inoculation. Dust carried through air to cans and products may be a source of contamination.

Equipment.—Spoilage micro-organisms can normally be expected to be present on equipment, particulary that having a steam connection. When undue spoilage occurs from understerilization, attention should be directed to accumulation of spoilage organisms on equipment. Only microbiologically, physically, and chemically clean equipment can give desired results. Contamination of foods by equipment means either poor sanitary practices, poor equipment design, poorly utilized equipment, or a combination of these factors. It is not possible to clean constantly equipment during operating periods, and in spite of a sanitation program, it is possible to have clean equipment contaminated by the flow of raw food products. For example, if tomatoes containing rot are not sorted from processing lines outside the factory, these decomposed tomatoes will deposit mold on equipment and mold could be transferred to sound products. In the case of tomato products, microscopic examination of the finished commodity for mold is used as an index of quality. Mold in tomato products is undesirable. According to our laws one decomposed tomato in a hundred sound fruit is adequate to cause the entire lot to be declared unfit for human consumption.

Equipment is a constant source of contamination of food products in canneries. Careful attention to sanitation practices and the condition of raw products flowing through a plant are essential to successful canning preservation of foods.

Ingredients.—Sugar and starch are common ingredients in foods and have been found to be sources of mesophilic and thermophilic spore-forming bacteria as well as other micro-organisms. Standards have been established for these ingredients by the canning industry. Other ingredients including dry milk solids, syrups, flours, and spices are generally contaminated with micro-organisms. Packing brine for canned sweet corn or peas prepared from sugar having 40 flat sour spores per gram when made into the packing solution could yield 500 or more spores per can! Hence, careful attention is indicated to ingredients which are added to foods during preparation and canning preservation.

Botulism.—Due to the public health significance of *Clostridium botulinum*, it is worthwhile to discuss this organism more thoroughly.

It is possible that at one time or other many people have eaten this bacterium, as it is a common soil organism. There are at least four types, two of which (A and B) are noteworthy here. Type A occurs generally only in virgin soil or newly reclaimed forest areas. Type B is found in cultivated soils.

This organism is a gram positive, anaerobic, spore-forming bacterium. It develops only in the absence of atmospheric oxygen, or in low oxygen tension environments.

The organism exists in both a vegetative form and in the form of a heat-resistant spore. The vegetative form is easily killed by moist heat at temperatures below 212°F. The spores on the other hand may survive 300 minutes of boiling at 212°F. The spores are the important form of the organism from the canner's or food processing viewpoint. Spores are found in dust and soil. The main contamination is from the soil in which food is grown. Most animals become contaminated, too. It is a difficult organism to work with because it loses its toxin producing capacity when manipulated in laboratory media. Spores vary in heat resistance, and it is not simple to obtain a spore suspension of uniform heat resistance to study.

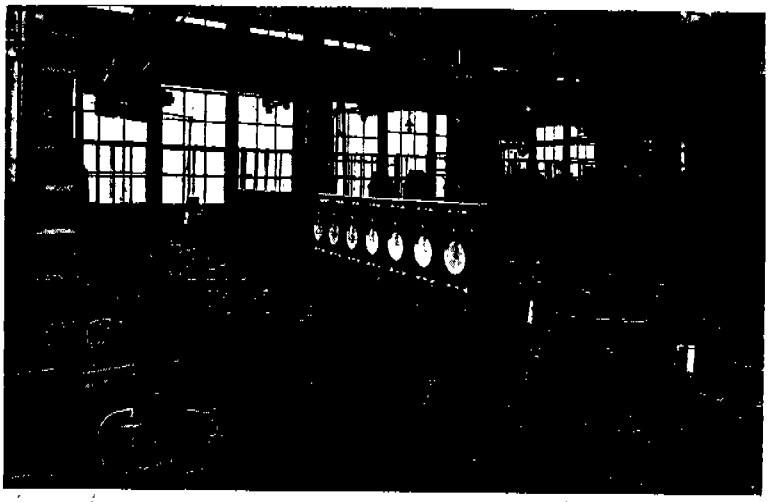
The organism has both proteolytic and saccharolytic powers. The media in which a culture actively is growing has an odor much like decomposed meat mixed with butyric acid. However, it is not unlikely to find the organism present, with its toxin, and still have the material reported as not objectionable to taste or smell. Hence, persons ingesting such food who are not killed may not suspect the food from which they became poisoned. *Cl. botulinum* has a heat resistance at 250°F. of 2.8 minutes for 10,000 spores per ml. in neutral phosphate buffer solution.

From a public health standpoint, foods with pH values greater than 4.5 must be processed such that the sterilization value is equal to that of 2.8 minutes at 250°F. As noted previously, there are other organisms with greater heat resistance which must be destroyed if the food is to keep at ordinary storage temperatures.

The botulina toxin produced is water soluble, and extremely lethal to man. It has been characterized chemically recently by researchers in the United States.

The spores must germinate in order to produce a vegetative cell to produce the toxin. The toxin is destroyed by a ten-minute exposure to moist heat at 212°F.

Type A and type B toxins are important to man, and it is possible to determine which type toxin is present by antigenic reactions.



Courtesy of Foxboro Co.

FIG. 54. STEAM PRESSURE CANNING RETORTS WITH INSTRUMENTATION FOR CONTROLLING AND RECORDING PROCESSES

Instruments which control and record processes shown in background.

A food suspected to contain *Cl. botulinum* spores may be exposed as follows: The sample is inoculated into suitable sterile media (liver broth), given anaerobic conditions (mineral oil layer, agar layer) and incubated at 97°F. At the end of 72 hours, the medium is filtered and one-half ml. units of this filtrate are injected into mice. Antitoxin A or B is administered to a portion of the mice interperitonially. If the toxin is present, some mice will die. If control mice die, those receiving antitoxin A live, and antitoxin B die, then Type A toxin was present. The causative organism was *Clostridium botulinum* Type A.

A suitable anaerobic condition for this organism to grow would be a sealed can with a vacuum or deep in a liquid or in the center of inoculated meat products, or in oil packed fish, etc. However, it has been reported that aerobic organisms may grow and use up oxygen in a container, creating anaerobic conditions adequate for growth of *Cl. botulinum*. In an acid product when the acid has been utilized by other (mold) organisms, raising the pH, *Cl. botulinum* may grow if present.

The boiling of home canned products for 10–15 minutes prior to eating is a safety practice which should be carefully adhered to. At the present time some ten people are killed annually by botulina toxin poisoning in the United States.

Accurate time-temperature records must be kept by processors (Fig. 54) for just this reason. Any serious outbreak of botulism would cer-

tainly be detrimental to the food canning industry. Until recently hermetically sealed cans have not been used to package low acid foods to be frozen. Research has indicated that there is no more danger with sealed cans than with any other sealed container. Improperly handled frozen foods present a problem of equal significance.

One important rule should be remembered: never taste low acid canned or frozen foods suspected of being spoiled.

Heat Resistance of Micro-organisms Important in Canning

There are two important genera of bacteria which form spores. Both genera are rod forms: one (Bacillus) is aerobic, and the other (Clostridium) is anaerobic. When a rod is about to sporulate, a tiny refractile granule appears in the cell. The granule enlarges, becomes glassy and transparent, and now resists the penetration of various chemical substances. All of the protoplasm of the rod seems to condense into the granule, or young spore, in a hard dehydrated, resistant state. The empty cell membrane of the bacterium may separate off, like the hull of a seed, leaving the spore as a free, round or oval body. Actually a spore is an end product of a series of enzymatic processes. There is no unanimity of opinion either of spore function in nature or of the factors concerned in spore formation.

Since no multiplication takes place as a result of the vegetative cell-spore-vegetative cell cycle, few bacteriologists accept the concept of the spore as a cell set apart for reproduction. Instead, various explanations of the biological nature and function of bacterial spores have been advanced, including the teleological interpretation of the spore as a resistant structure produced to enable the organism to survive an unfavorable environment, the idea that the spore is a normal resting state (a form of hibernation), the notion that spores are stages in a development cycle of certain organisms, or a provision for the rearrangement of nuclear material. It is interesting to note that the protein of the vegetative cell and the protein of the spore are antigenically different.

Spores appear to be formed by healthy cells facing starvation. Certain chemical agents (glutamic acid) may inhibit the development of spores. No doubt sporulation consists of a sequence of integrated biochemical reactions. The sequence can be interrupted at certain susceptible stages.

The literature on the subject of the heat resistance of bacteria contains many contradictions and discrepancies from the records of the earliest workers to those of the present day. This lack of uniformity has been due in part to factors of unknown nature. Until the factors operative in the thermal resistance of bacteria are understood, it will not be possible

to control by other than empirical means the processes which require for their success the destruction of bacteria.

Heat may be applied in two ways for the destruction of bacteria. Oven heat may be considered as dry heat, used in the sterilization of glassware. Other materials are heated when moist, or in the presence of moisture; this is commonly termed moist heat. Dry cells exhibit no life functions; their enzyme systems are not active. Cell protein does not coagulate in the absence of moisture.

The gradual increase in the death rate of bacteria exposed to dry heat is indicative of an oxidation process.

Where death by dry heat is reported as an oxidative process, death by moist heat is thought to be due to the coagulation of the protein in the cell. The order of death by moist heat is logarithmic in nature. The explanation of bacterial death as caused by the inactivation of bacterial enzymes cannot be correct. A suspension containing 99 per cent dead cells has 80 per cent of its catalase active. Since the order of death by moist heat is logarithmic in nature, death must be brought about by the destruction of a single molecule. This change is termed a lethal mutation. To a food technologist, death of a bacterium is described by its inability to reproduce. Heat inactivates or coagulates a single mechanism (gene?) preventing reproduction. The decreasing enzyme content of dead bacteria is the consequence of inhibited growth and probably not the cause. Replacement of the enzyme molecules becomes impossible; the enzyme content slowly decreases.

Regardless of the explanation of death of bacterial spores, the logarithmic order of this death permits the computation of death points, rates, or times, independent of any explanation. The death rates or times permit the comparison of the heat resistance of one species at different temperatures or of different species at the same temperatures. It is also possible to describe in quantitative terms the effect of environmental factors upon the heat resistance of the bacteria.

Originally the standard method of establishing the heat tolerance of different species of bacteria was the thermal death point, i.e., the lowest temperature at which the organism is killed in ten minutes. This method cannot give comparable results unless conditions such as to the age of the culture, the concentration of cells, the pH value of the medium, and the incubation temperature are standardized. Food technologists concerned with processing canned foods have adopted the thermal death time, keeping the temperature constant and varying the times of heating. The thermal death time is the shortest time required at a given temperature to kill all bacteria present.

It is necessary to know the time and temperature required to ade-

quately sterilize canned foods (Fig. 55). This procedure involves not only the destruction of spores by moist heat, but also the rate of heat penetration and heat conductivity of containers and their contents. The heat resistance of an organism is designated by the "F" value, or the number of minutes required to destroy the organism at 250°F., and the "z" value, or the number of degrees (Fahrenheit) required for the thermal death time curve to traverse one logarithmic cycle. These two values establish and describe the thermal death time curve, and are a quantitative measure of the heat resistance of the spores over a range of temperatures (see Fig. 56).

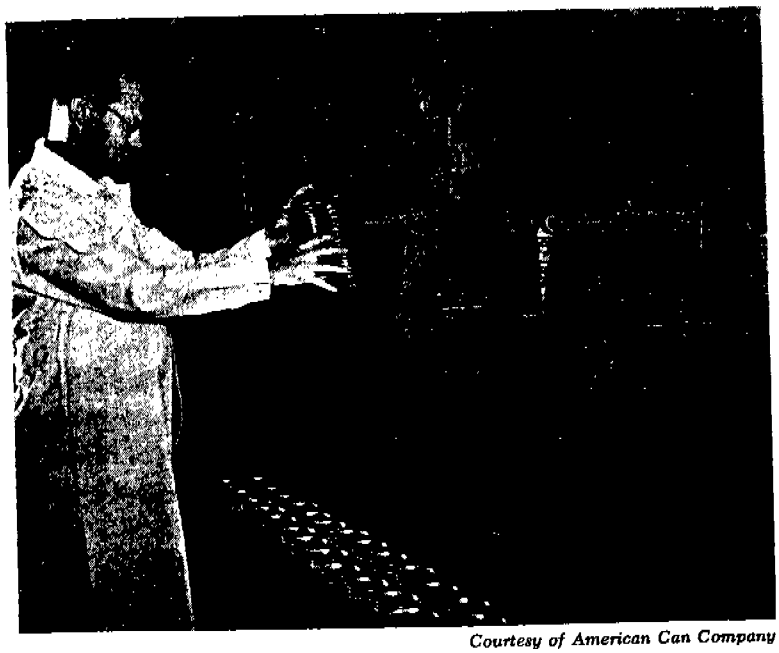
It has been recognized that spores of different species, and of strains of the same species, exhibit marked differences in heat resistance, but little or nothing is known in explanation. Some workers have believed that there might be a difference in heat resistance among the vegetative cells, which was transmitted to the spores. Comparing the heat resistance of vegetative cells and spores of a number of bacteria, considerable differences in the spore resistances are found among organisms. Differences in vegetative cell heat resistance is in some instances associated with high spore resistance. Other cultures of vegetative cells produce spores of low resistance. There is evidently no significant relationship between the heat resistance of the vegetative cell and that of the spore produced therefrom. As noted above, even the proteins of the vegetative cell and spore differ for a species.

Some researchers reason that the spores of a strain are all of the same heat resistance. Others suspect that in a given spore suspension there are a predominant number of spores of relatively low heat resistance, a smaller number with greater heat resistance, and a still smaller number of very heat resistant spores. However, subcultures from heat resistant selections do not yield survivors of uniformly high heat resistance over the parent strain.

Factors Influencing the Heat Resistance of Spores

Concentration.—The heat resistance of a suspension of bacterial spores is related to the number of organisms present (see Fig. 57). The greater the number of spores per ml. the higher resistance of the suspension.

Environmental Factors.—The resistance of bacterial spores is not a fixed property, but one which under ordinary conditions may tend to be relatively constant. The extent of change in resistance is determined largely by the physical and chemical forces which operate from outside the spore cell. Aside from purely theoretical interest, a better understanding of the cause of heat resistance of spores is of fundamental importance to the canning industry. There are relatively few types of



Courtesy of American Can Company

FIG. 55. SEALED, SMALL TIN CANS BEING PLACED INTO THERMAL DEATH TIME APPARATUS

Method of studying heat resistance of micro-organisms.

spore-forming organisms especially endowed with heat resistant properties, but these account for most of the spoilage potential in canning. Spore heredity, the environment in which grown, and a combination of these factors must play some part in the production of highly heat resistant spores.

Different yields of spore crops can be determined in various media. This may be demonstrated by plate count or by direct microscopic count. There is little information indicating a relationship between the physiological factors influencing spore formation and the heat resistance of the spores produced. The reaction (pH value) of the medium in which spores are produced has apparently little influence on their heat resistance.

Continuous drying seems to enhance the resistance of spores, but this is irregular in effect. Freezing tends to weaken spores. The following data for an aerobic spore-forming organism isolated from spoiled canned milk is noteworthy:

Heat Resistance at 248°F.[1]

Spore Treatment	*Survival in Minutes*
Wetted	5
Alternately wetted and dried	6
Dried	7
Frozen	2

[1] From Curran (1935).

Spores formed and aged in soil are found to be more heat resistant than those formed and aged in broth or agar. Natural environmental conditions are evidently more conducive to the development of heat resistant spores than conditions prevailing in artificial cultures. The prolonged action of metabolic wastes from cells appears to decrease the heat resistance of spores.

Bacteria exposed to sub-lethal heat are more exacting in their nutrient and temperature requirements than undamaged bacteria. The composition of recovery media in which organisms are placed after heating may have considerable effect on the apparent thermal destruction time for the organisms. Depending on the choice of media, heat treated bacteria may be found to be dead in one and alive in another.

Thermophilic bacteria which form spores in artificial media produce spores of comparable heat resistance to those formed on equipment and machinery in canning plants.

Spores obtained from soil extractions and remixed with sterile soil are less heat resistant than those heated in the soil directly. The higher natural resistance of spores in soil may be due to some physicochemical influence of the soil and not to any differences between the soil and cultured spores themselves.

Anthrax spores remain viable and virulent in naturally contaminated water for as many as 18 years, while artificial cultures remain in this condition for perhaps five months. Soil organisms on corn may remain viable on naturally contaminated tissue for at least seven years, while the artificially cultured die in three months. Artificial media apparently weakens cultures of organisms.

If a culture is to be kept alive for a long period it is apparently desirable to have a media which permits only a limited growth, limiting metabolic by-products, than media which permits profuse growth. *B. tuberculosis* growing on a relatively poor medium may be kept viable for several years while growth on enriched media has viable organisms for only a few weeks. The preserving influence of natural environments may be a similar phenomena.

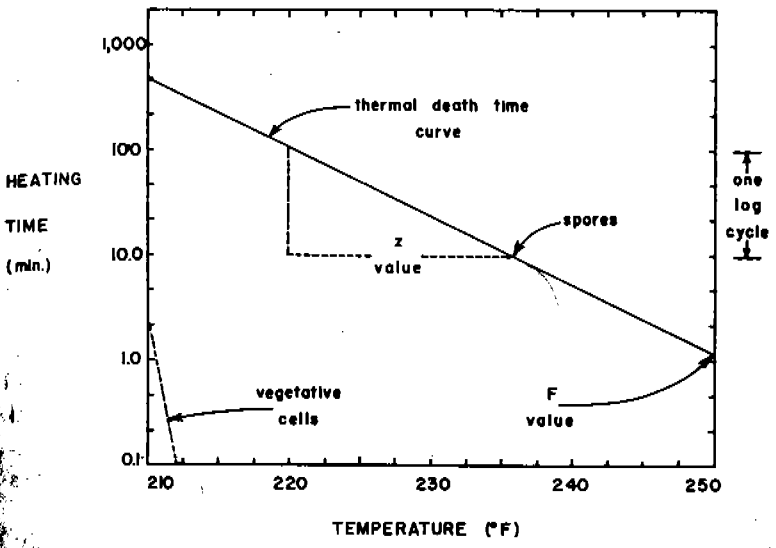


FIG. 56. TYPICAL THERMAL DEATH TIME CURVES FOR SPORES AND VEGETATIVE CELLS OF HEAT RESISTANT ORGANISMS

Spores are heat resistant, vegetative cells generally not.

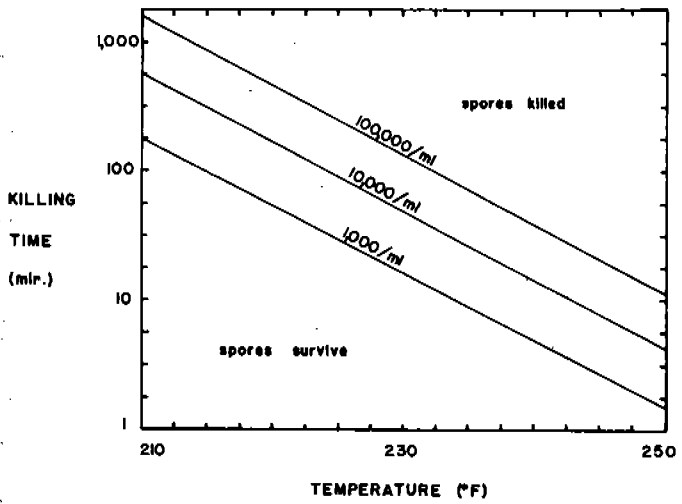


FIG. 57. GREATER THE SPORE CONCENTRATION THE MORE HEAT RESISTANT THE SUSPENSION

Heat resistance of a culture, measured by the presence of survivors, related to the concentration of organisms.

Influence of Food Ingredients on Heat Resistance of Spores

Acids and pH Value of Heating Medium.—Of the many factors which influence the heat resistance of spores, the pH values of the heating medium has profound effects. For most spore-forming bacteria maximum resistance generally occurs in the region of neutrality. Bacterial spores are not heat resistant at low pH values. For foods with pH values higher than 5.0 apparently other factors than pH are important in the resistance of spores. For instance, the heat resistance of spores of *Cl. botulinum* in fish products with a range in pH from 5.2 to 6.8 is approximately the same. At a pH lower than 5.0, a marked reduction in resistance occurs (see Fig. 58). This effect is utilized in the processing of certain vegetables and other low acid foods which do not withstand sterilization under usual canning conditions. The liquors in which these foods are packed are acidified with the result that the resistance of the contaminating organisms is lowered.

Altering the pH of tomato juice with citric, lactic, or acetic acid greatly alters the heat resistance of *B. thermoacidurans*. If the same per cent of acid is added, they differ in their degree of effectiveness in lowering the heat tolerance of the organisms in the order of lactic, citric, and acetic. If based on the pH, the order would be acetic, lactic, and citric. Evidently the undisassociated acid molecule is important in this phenomena.

Differences in the heat resistance of bacterial spores in different foods cannot be explained solely on the basis of the pH value alone.

Organism—P. A. No. 3679

Substrate	pH Value	Number of Minutes to Kill Organism at 250 °F.
Asparagus	5.4	3.3
Peas	5.4	3.0
Spinach	5.4	2.6
Milk	6.3	2.6

The causes of these differences are not known.

Sugar.—Longer heating times are required to kill spores as the concentration of sugar in solution increases (see Fig. 59). Heating yeasts and molds in increasing concentrations of sugar increases their tolerance to heat. Small sugar concentration differences do not evidence this protective effect on spores. Some researchers feel that sugar solutions increase the resistance of spores by a partial dehydration of the cell protoplasm, protecting the proteins from coagulation. Heat coagulation of egg albumin may be retarded with sugar.

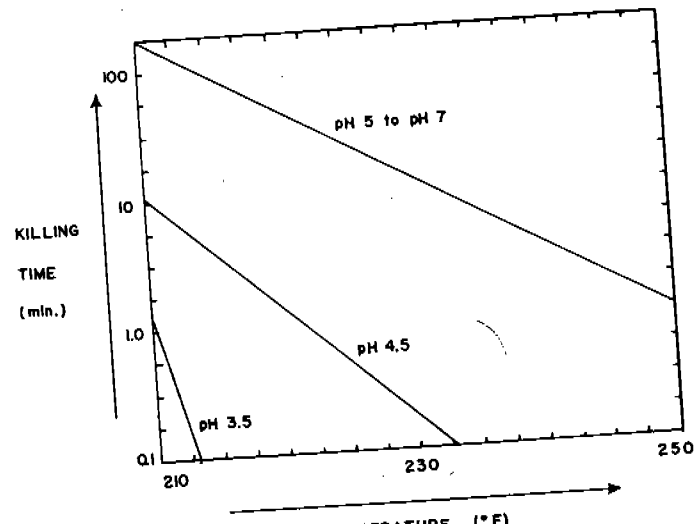


FIG. 58. INFLUENCE OF pH OF HEATING MEDIUM ON HEAT RESISTANCE OF SPORES

The more acid the substrate, the less heat resistance in spore suspensions.

Inorganic Salts.—The concentration of sodium chloride in solution may protect spore heat resistance (up to four per cent) or decrease the heat resistance (eight per cent or more). Salt is effective, it must be remembered, in inhibiting the growth of putrefactive organisms.

Increasing the salt content of tomato juice decreases slightly the heat resistance of flat sour organisms.

Agents commonly used to cure meats have little influence on the heat resistance of spores. Sodium nitrate or sodium nitrite in concentrations of 0.17 per cent in meat are reported to be ineffective in reducing the heat resistance of spores.

The phosphate level of soil and media influences the heat resistance of bacterial spores present. Phosphate ions are important in spore formation, spore germination, and the heat resistance of spores.

Effect of Starch, Protein, Spices and Fat.—It is interesting to note that starch in media permits the growth of greater numbers than will grow without starch. Starch is effective in adsorption of inhibitory substance, including C_{18} unsaturated fatty acids, although starch does not influence the heat resistance of spores, *per se*.

Proteinaceous materials offer some protection to spores against heat.

The essentials oils of many spices, and flavoring materials, i.e., mustard, clove, onion, pepper, garlic, markedly influence the heat resistance of

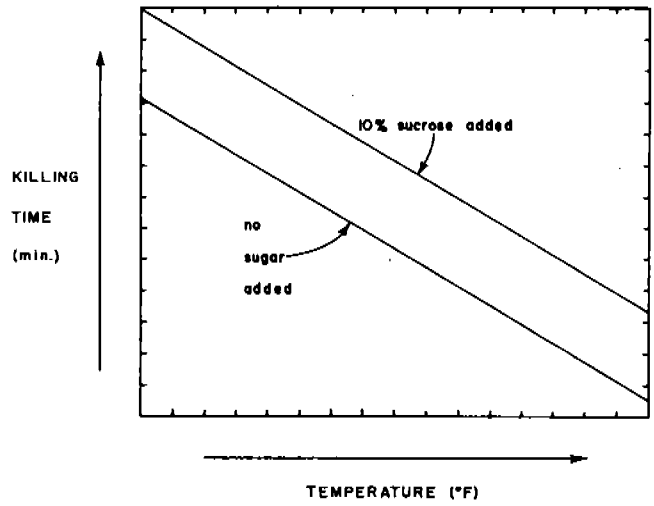


FIG. 59. INFLUENCE OF SUGAR ON THE HEAT RESISTANCE OF BACTERIAL SPORES

High concentrations of sugar protect spores.

bacterial spores. In the presence of any lethal substance, bacterial spores may be expected to be of reduced heat resistance as would be yeasts and molds. It is noteworthy that many vegetable materials contain substances which lower the heat tolerance of bacterial spores. This may account for some of the differences at least in the variation in heat resistance of a spore suspension in different foods of nearly identical chemical composition.

Spice oils employed in foods as flavoring agents may have preservative qualities; some are effective in reducing the heat tolerance of spores.

Fats and oils are hindrances in attempting to kill bacterial spores with moist heat (see Fig. 60). Destruction of bacteria and spores in oil resembles the conditions of dry heat sterilization. Yeasts may be very difficult to kill in salad dressing for example, due to the organism being entrapped in the oil phase. Vegetative, non-heat-resistant bacteria have been isolated from canned fish after high temperature heat treatments.

The spores of *Cl. botulinum* survive beyond all resonable expectations when heated in an oil suspension.

Heat Resistance of Enzymes in Food

Energy of Activation.—Current chemical theory indicates that a reactant in an enzymatic reaction must be activated. This activation requires energy. The energy required to activate the reacting molecules is

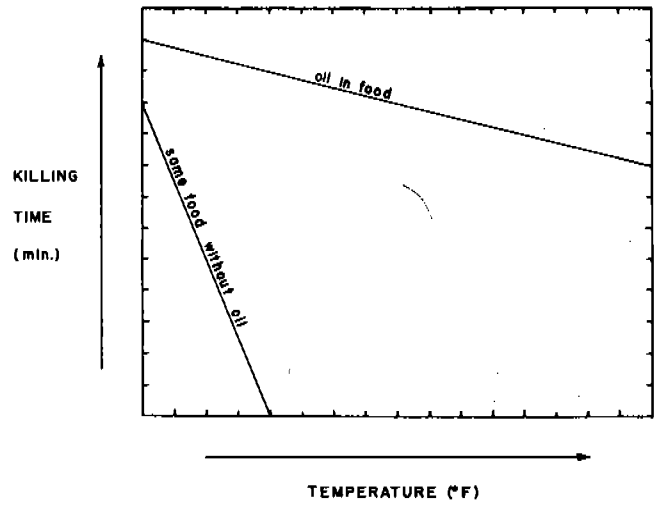


FIG. 60. INFLUENCE OF OIL ON HEAT RESISTANCE OF YEASTS

Organisms trapped in oil phase are killed by dry heat, and have much heat resistance in comparison with organisms in water phase.

called the energy of activation. The function of an enzyme is to bring about the reaction with a lower energy of activation. This is illustrated below (Sumner and Somers 1947).

Reaction	Catalyst	Cal/Mole Required
H_2O_2 decomposition	None	18,000
	Colloidal platinum	11,700
	Liver catalase	5,500
Casein hydrolysis	HCl	20,600
	Trypsin	12,000
Sucrose inversion	Hydrogen ions	26,000
	Yeast invertase	11,500
Ethyl butyrate hydrolysis	Hydrogen ions	13,200
	Pancreatic lipase	4,200

This decrease in the energy of activation due to the catalyst results in increased rates of reaction because a portion of the molecules are sufficiently activated to decompose into products alone.

Enzyme Inactivation with Heat.—The heat inactivation of enzymes is associated with an alteration of the surfaces of the molecules, breaking bonds and opening rings in the protein molecule, with dissociation and loss of structure.

Increasing the temperature of an enzyme-substrate system increases

the velocity of reaction catalyzed by the enzyme. Using the equation:

$$\text{Temperature coefficient} = \frac{\text{velocity at T° + 18°}}{\text{velocity at T°}}$$

The coefficient is usually in between 1.4 to 2.0. This means for every 18°F. increase in temperature, a doubling of the rate of reaction is obtained, a coefficient of 2.

Temperature coefficients for enzyme-substrate reactions decrease with increasing temperatures. A high temperature causes the relative increase in the rate of reaction to become smaller. This is due in part to the destruction of the enzyme itself, as it is proteinaceous in nature and subject to heat damage.

The point of optimum reaction occurs between the temperature at which there is an accelerated reaction due to temperature, and a minimum destruction of the enzyme by heat. At the temperature optimum the temperature coefficient will be 1.0. This is not a specific point, as it varies depending upon the length of time the reaction is run, impurities, etc.

Nearly all enzymes are irreversibly destroyed in a few minutes by heating to 175°F. The effect of heat on the rate of coagulation of protein and the effect of heat on the rate of inactivation of enzymes are two phenomena which have high energies of inactivation, and may be due to similar chemical reactions. The heat inactivation energies for several enzymes are given below (Sumner and Somers 1947):

Enzyme	Heat inactivation, cal/mole
Catalase (blood)	45,000
Amylase (malt)	42,500
Lipase (pancreatic)	46,000
Bromelin	76,000
Sucrase	100,000
Trypsin	41,000

Reactivation of Enzymes After Heating.—Although substantial attentions have been given to the destruction of enzymes in other methods of food preservation (freezing, dehydration) relatively little has been given in canning foods. The assumption has been that the heat process designed to kill micro-organisms is sufficient to inactivate all enzymes. While it is true that heating to 175°F. will inactivate many enzymes, it is only recently that studies have been undertaken to evaluate the heat resistance of enzymes in canned foods. Enzymes play a role in the deterioration of canned acid and high acid foods. Too, enzymes are in some in-

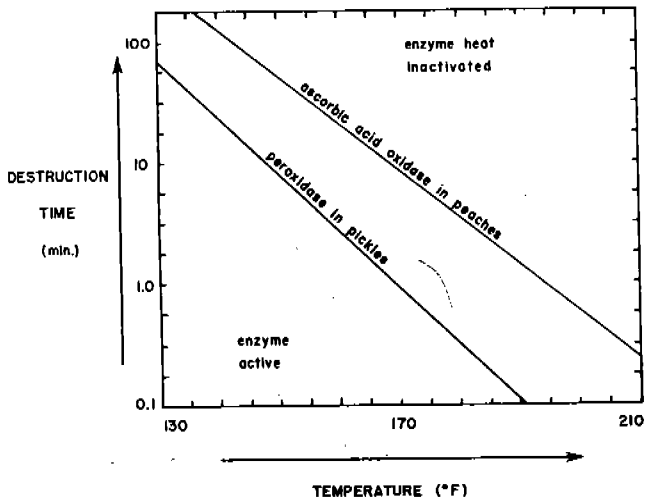


FIG. 61. MOIST HEAT DESTRUCTION OF ENZYMES

Enzymes are generally as resistant as vegetative forms of organisms.

stances reactivated after heating, i.e., peroxidase. This problem has developed from studies of extremely high temperature processing (250–300°F. flash-heat treatments). Micro-organisms are heat inactivated but indications are that some enzymes do survive such treatments.

The peroxidase in pickles is able to withstand heating to 185°F. The heat destruction of this enzyme is increased by the addition of vinegar. Heavy sugar solutions are protective to enzymes to heat inactivation in pears and peaches. The enzymes of the tomato are not altered in heat resistance by the small amount of salt added. Some suggestions that the enzymes of canned tomatoes remain active after the canning process are available. Peroxidase systems of turnip and cabbage have been found to be reactivated after heating.

Thermal destruction curves obtained for ascorbic acid oxidase and peroxidase in acid foods indicate that standard methods may be used in evaluating the heat inactivation of enzymes (Fig. 61).

The internal temperature of fruit and vegetables in the high acid food group, which receive relatively low heat processes in canning, may not rise sufficiently high to inactivate enzymes normally present internally in these tissues. The pectinesterase in canned grapefruit juice is active after an adequate process from the standpoint of microbial spoilage has been administered.

Enzymes—A Chemical Index of Efficiency.—In some instances the

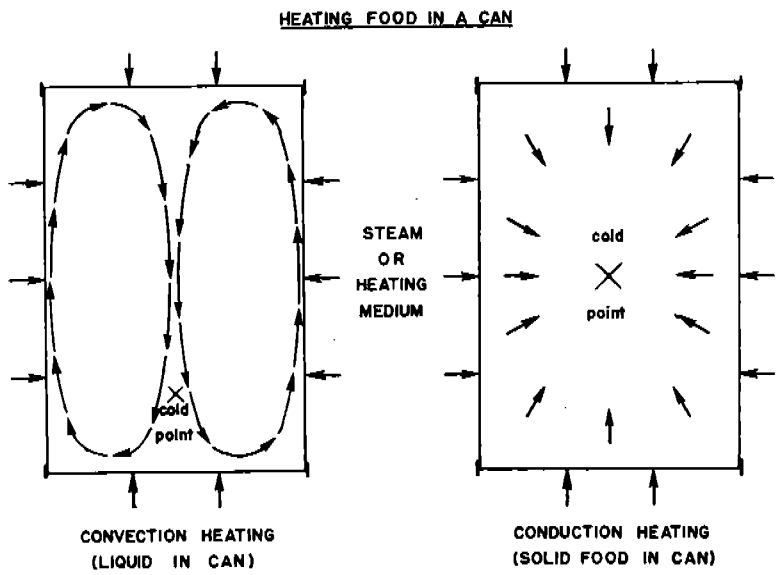


FIG. 62. COLD POINT OF HEATING FOR CONVECTION AND CONDUCTION TYPE PRODUCTS

inactivation of enzymes may be used as an index of the degree of heating of foods. For instance, the pasteurization of milk can be evaluated by its phosphatase enzyme activity. The destruction of phosphatase in milk coincides with the heat treatment designed to kill *B. tuberculosis* and other human pathogenic organisms. An evaluation of milk for this enzyme indicates the minimum degree of heat treatment.

The peroxidase system in fruits may be useful in evaluating the relative efficiency of acid food canning processes. Unless the enzymes are destroyed, they will continue to function in the container, causing deterioration. So too, if the presence of one enzyme is found, what conclusions are possible relative to the hundreds of others which may be functional, but for which there are no methods of evaluation?

Heat Penetration into Food Containers and Contents

Disregarding for a moment the acidity of foods and the spoilage organisms related with these foods, it is necessary to consider the penetration of heat into containers being processed.

Heat.—Heat is a form of energy measured in terms of calories or British thermal units. It cannot be defined in terms of the fundamental dimensions of distances, mass and time. As noted previously, we speak of the temperature of a body but have no clear concept of what kind of a meas-

urement temperature is. Temperature is measured in terms of itself, and notions of hot and cold are relative.

Propagation of Heat.—There are three ways to propagate heat energy: convection, conduction, and radiation. Convection heating means bodily transfer of heated substances, i.e., molecules. Conduction heating means heat is transferred by molecular activity through one substance to another. Radiation heating is a transfer of heat energy in the same manner as light, and with the same velocity. Heat transfer by convection must be accompanied by some conduction heating. Conduction heating is very slow compared to the usual cases of convection heating.

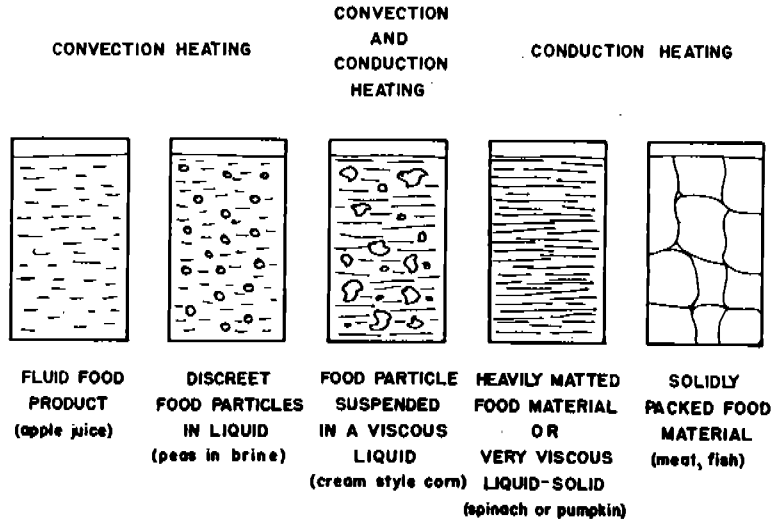
The second law of thermodynamics states that heat energy flows only in one direction, from hot to cold bodies. The difference between a hot and a cold body is a matter of energy. If a hot and cold body are allowed to come to equilibrium, the hot body will cool and the cold body will warm (see Fig. 62).

The sterilization value of steam depends largely on the transfer of the heat of vaporization to the object upon which steam condenses. The difference between moist heat and dry heat are readily experienced by placing one hand in an oven and the other accidentally in steam, both at 250°F.

Steam is the commonly used sterilizing agent in the canning industry. Steam under pressure has the following characteristics:

Lbs. Steam Pressure Per Sq. In.	Temperature, °F.
Boiling water vapor @ 760 mm Hg	212.0
1	215.4
5	227.1
10	239.4
15	249.8

Heat Penetration Characteristics of Canned Foods.—When a can of food is sealed at 180°F. and placed in a steam pressure vessel which is brought to 15 lbs. per sq. in. with steam, the steam chamber is the reservoir of high heat energy and the can of food is the reservoir of lower heat energy. Heat then is transferred from the hot body to the cold. The mechanism of heat transfer in canned food during such thermal processing may be divided into several rather definite classes. To a certain extent, it is possible to place food into heat transfer classes by knowing their physical characteristics (Fig. 63). The heat is transferred by conduction from the steam to the can, and from the can to the contents. The can contents will either heat by developing convection currents or heat by conduction. In some instances, food will heat first by one method then



Courtesy of American Can Co.

FIG. 63. HEAT TRANSFER CLASSES OF FOOD PRODUCTS

by the other. For convection heating foods, initially, heat is conducted from the can to molecules inside the can. From this point on, food heats by having the energized molecules, now expanded and lighter in density, rise while heavier cooler molecules descend. Canned foods heating by convection have a better opportunity of surviving the process in better condition than those requiring heat to be transferred by conduction, which is slower and therefore requires more time. Heat penetration studies with most food products have been covered and insofar as possible these products have been classified according to the mechanism of heat transfer. Obviously these considerations are altered by deviations in packaging procedures.

Rapid Convection Heating Foods.—Most fruit and vegetable juices. Pulpiness or gelling slows heating.

Broths and thin soup. Small quantities of starch either added or leached from solid ingredients retards heating.

Fruits packed in water or syrup with large pieces present. Heat penetrates slowly within the pieces.

Evaporated milk heats by convection in agitated retorts. Milk does not withstand ordinary still processing successfully.

Meat and fish products packed in a brine if the small pieces are not solidly packed into the containers.

Vegetables packed in brine or water, with pieces as above. Exceptions include corn and leafy vegetables (spinach, greens).

Slow Convection Heating Foods.—Small pieces of fruit, vegetable, meat, or fish products packed in free liquid.

Chopped vegetables with low starch content packed with free liquid.

Products with small pieces which tend to mat but do not, and are packed in liquid which is not viscous.

Broken Curve Heating Foods.—Certain canned foods exhibit a change in heating characteristics representing a definite shift from convection to conduction heating during the process.

Foods containing starch or foods from which starch is readily leached from the solids during a process. Examples are soups, noodle products, chowders, and mixed vegetables.

Syrup packed sweet potatoes.

Cream-style sweet corn.

Conduction Heating Foods.—Solidly packed foods with high water content but little or no free liquid heat by conduction. Examples are: heavy cream-style corn, pumpkin, most thick puréed vegetables, potato salads, and baked beans.

Solidly packed fruit products such as jams, baked apples, and sliced fruit.

Vegetable, meat, fish products in thick cream sauce, creamed potatoes, and chicken-a-la-king.

Concentrated soups of many types.

Meat and vegetable mixtures in thick sauce: chile con carne, chop suey, and meat stews.

Solidly packed starch products: spaghetti, chicken and noodles, etc.

Solidly packed meat and fish products: ham, corned beef, chicken loaf, minced clams, codfish, sandwich spreads, and spiced ham.

Meat and cereal mixtures such as some meat loaf products.

Measuring the Heat Penetration into Canned Foods.—While thermometers can be used to follow certain heating characteristics of foods, the most satisfactory method involves the use of thermocouples. A thermocouple is formed when two dissimilar metal wires are fused together at the ends. If the ends of these wires are placed at different temperatures, a measurable voltage is developed which is related to the temperature difference between the two ends, or thermocouple junctions. By attaching a suitable measuring device (potentiometer) to the thermocouple, it is possible to calibrate it, and follow the temperature changes inside a can which itself is being heated in a retort under steam pressure. Examples of thermocouple measuring systems are presented in Fig. 64. A commonly used thermocouple system is composed of copper-constantan wires and a potentiometer, reading directly in degrees Fahrenheit. Recording potentiometers are also available.

Molded bakelite thermocouple assemblies are manufactured which have insulated wires and great utility in studying the heating of canned foods. Thermocouples may be introduced into glass jars by soldering a stuffing box to the lid, and boring a hole of correct dimensions through the lid. The thermocouple is then adjusted through the stuffing box to any desired position inside the jar. For metal cans, the stuffing box may be soldered at the desired height to the side of the can body, through which a hole is drilled. The thermocouple is then adjusted to the desired position inside the can through the stuffing box.

Prior to use, thermocouples should be calibrated against a standard thermometer throughout the operating range of temperatures important to a study.

Cold Point Determinations.—All points within a container being heated are not at the same temperature. The zone of slowest heating is called the cold point of a container, and is that zone which is most difficult to sterilize due to the lag in heating. With products heating mainly by convection, the cold point is on the vertical axis, near the bottom of the containers. Products heating by conduction have the point of slowest heating approaching the center of the container, on the vertical axis (see Fig. 62).

To determine the cold point, stuffing boxes are soldered to cans, starting one-half inch from the bottom of the first can. A stuffing box is soldered three-fourths of an inch from the bottom of the second can, one inch from the bottom of the third can, etc. Product is prepared, and a uniform fill is maintained in all containers. Cans are sealed, and thermocouples are fitted to each container. Cans then are available with thermocouples located every one-fourth inch from the bottom of cans, starting at one-half inch. The cans are placed into a retort and it is brought to temperature with due precaution to remove air. Temperatures are recorded every minute manually, or if a recording potentiometer is used, the time-temperature values will be plotted on strip charts. These data are then plotted on semi-log graph paper, which yields a straight line relationship between time and temperature, with minor deviations. An example of such data is shown in Fig. 65, for a convection heating product. All subsequent heat penetration studies in this instance would be made at the cold point, locating thermocouple junctions at a position three-fourths of an inch from the bottom of the cans, for this product, under these circumstances. Varying the filling weight alters the heating characteristics. For example in pork and beans, changing the amount of beans per can, and the amount and composition of sauce, changes the heating characteristics (see Fig. 66).

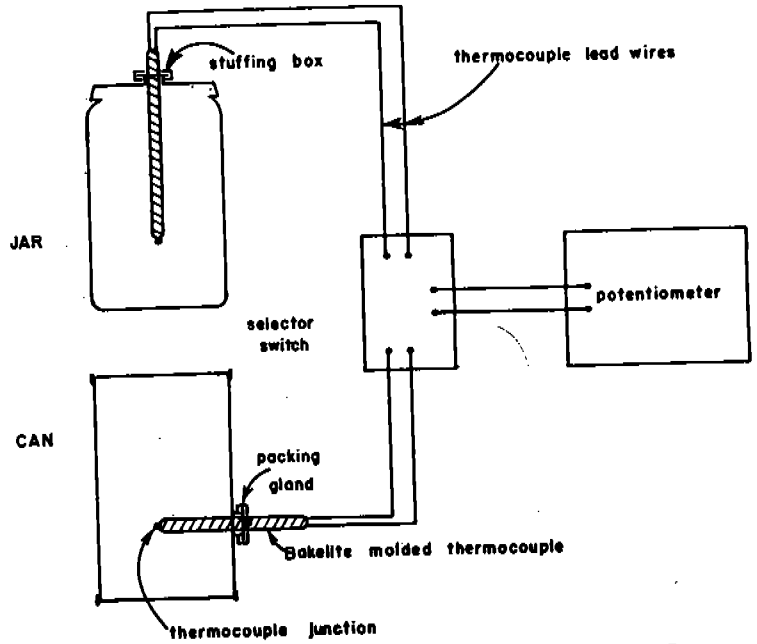


FIG. 64. THERMOCOUPLE INSERTED INTO CONTAINER THROUGH STUFFING BOX

Cooling curves are also established in the same manner. These heating and cooling curves have slopes and for canning technology purposes, are represented as f_h (minutes required for the curve to traverse one log cycle on the graph), the slope of the heating curve, and f_c, the slope of the cooling curve. Also important are the initial temperature (IT) and the retort temperature (RT). Other information is also needed. Zero time would not be the time at which the heating started, but rather the time at which the retort reached the processing temperature. The period of time elapsed from placing the cans into the retort and starting to heat, until the retort reaches processing temperature is termed the come-up-time (see Fig. 67).

A minimum of twelve processing runs should be made for each product to establish heat penetration characteristics for a food.

General Method for Calculating the Process Time for Canned Foods

With information relative to the heat resistance of spoilage organisms to be destroyed in canning and the heating characteristics for the food in question, the information necessary to calculate the processing time

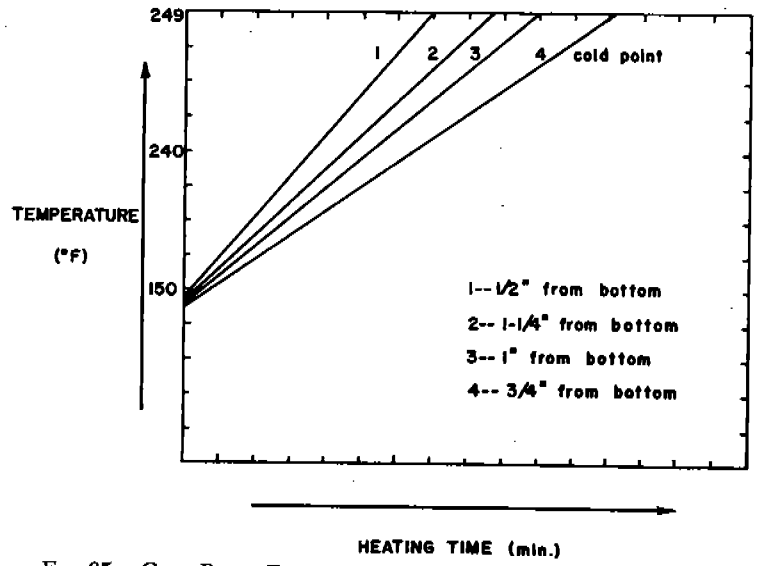


FIG. 65. COLD POINT DETERMINATION—CONVECTION TYPE PRODUCT

for the product is available. Each time-temperature interval during the heating and cooling of the containers has a lethal effect on food spoilage organisms, if the temperatures are above the maximum for growth for the organisms. By correlating the killing effects of these high temperatures with the heating rate of the food, the length of time theoretically required to destroy any specific bacterial spores present in the container of food may be calculated for any given temperature. The calculated length of process will be the actual process necessary, providing all the conditions are given accurate control. Bigelow and co-workers in 1920 devised a method for calculating processing times, called the *General Method* for process time determinations.

The rate of destruction of an organism per minute at any given temperature (T) in a process is the reciprocal of the time in minutes (t) required to destroy the organisms at that temperature. From the thermal death time curve in Fig. 68, a simple geometric relationship exists between the sides of similar right triangles, and may be expressed by the following equations:

$$\frac{\log t - \log F}{\log 10} = \frac{250 - T}{z}$$

$\log 10 = 1$, therefore,

$$\log \frac{t}{F} = \frac{250 - T}{z}$$

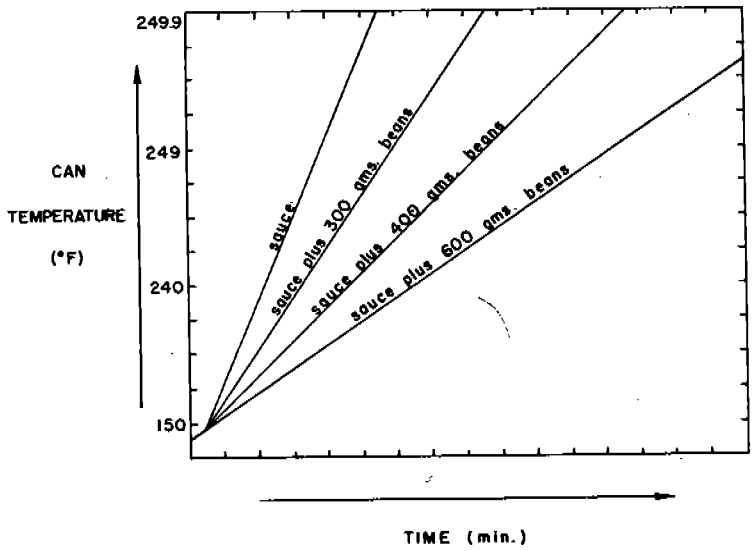


FIG. 66. INFLUENCE OF VARYING WEIGHTS OF BEANS ON HEATING CURVE FOR PORK AND BEANS (NO. 2 CANS)

Important consideration in quality control.

$$\text{and } t/F = \text{antilog } \frac{250 - T}{z}, \text{ or } t = F \text{ antilog } \frac{250 - T}{z}$$

where:

z = slope of thermal death time curve in °F.
F = minutes to destroy the organism at 250° F.
T = temperatures under consideration (°F.).
t/F = the time to destroy the organism at temperature (T) if $F = 1$.
F/t = lethal rate at T.

From the thermal death time curve, F and z are known. At any temperature (T) it is possible to solve the above equation for t/F, from which the reciprocal F/t can be determined. The lethal rate at any temperature can be calculated then once the F and z value are known.

During the processing of a container of food, the temperature inside the container increases to a maximum and then decreases during cooling.

For each temperature, at definite one minute time intervals the lethal rate (F/t) for that temperature may be calculated. A curve is formed by connecting each of these values when plotted on linear graph paper against time (Fig. 69). The area under this lethality curve represents the total lethal value of the process, and may be measured by means of a planimeter, counting the squares, or cutting the area out, and weighing it. It is now necessary to find the size of the unit sterilization area. By

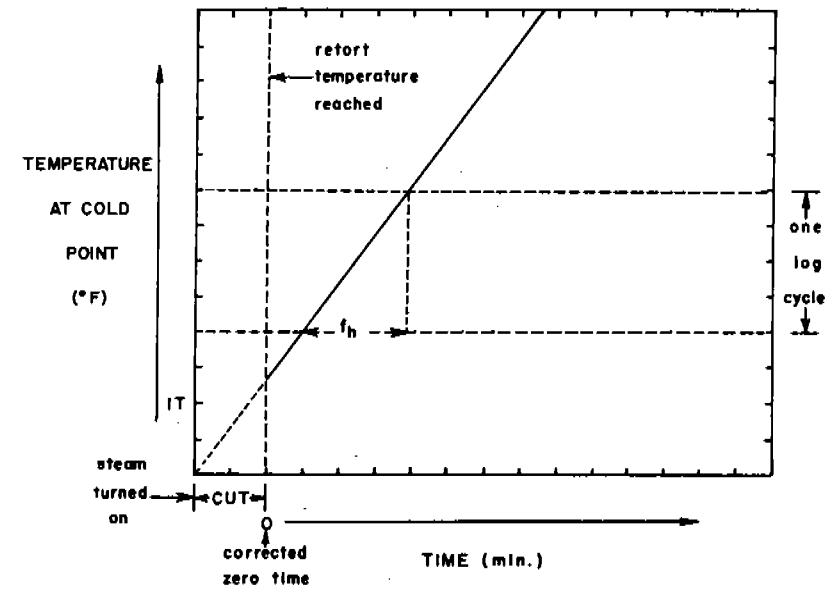


FIG. 67. HEATING CURVE CHARACTERISTICS OF CANNED FOODS

unit sterilization area is meant the area which, if enclosed beneath the lethality curve of a process, represents complete sterilization when the value of F equals one. To define this area a convenient point is arbitrarily chosen on the vertical scale. This represents the height of the unit area. The breadth is found by dividing this arbitrary value into one, which by definition represents the magnitude of the area in terms of lethal rate and time. Since the F values usually required for adequate sterilization are usually greater than one, an adequate process must yield a lethality curve which will enclose an area equal to the F value times the unit area. An adequate process is one which yields a sterilization value (F_0 value) equal to the F value of the organism in the product under consideration (see Table 136 in Appendix).

To determine the exact process for a product, a series of three or more heat penetration runs are made, each at a different process time (Fig. 69). When plotted on linear graph paper, F_0 value vs. process time in minutes, the plotted points fall on a straight line. Process times with any desired sterilization value may be interpolated from this graph; the precise value is obtained where $F_0 = F = 100$ per cent lethality (Table 137).

Another method of establishing a safe heat sterilization process (F_0 requirement) is by use of the D value. This unit is defined as that combination of time and temperature to bring about a 90 per cent reduction in

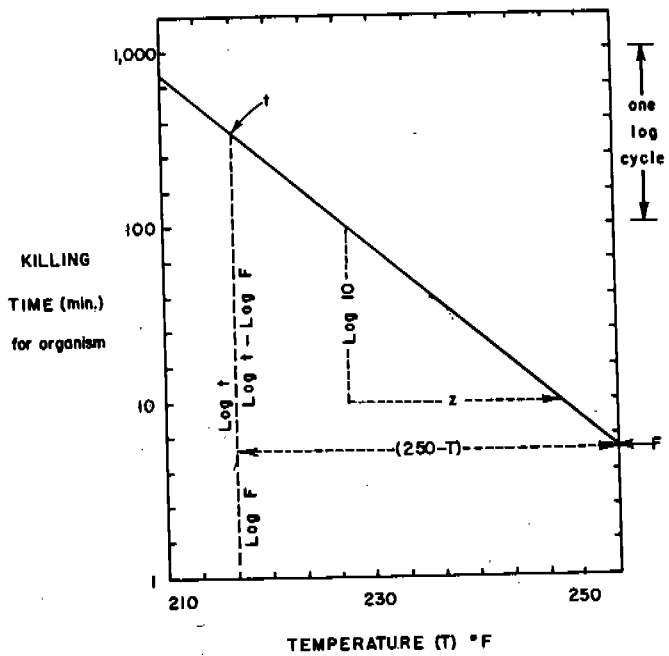


FIG. 68. THEORY OF GENERAL METHOD OF HEAT PROCESS EVALUATION FOR CANNED FOODS

Integration of heat penetration into container with heat resistance of micro-organisms. t = killing time in minutes at temperature (T°F.) F = killing time at 250°F. z = slope of killing curve T = temperature under consideration (°F.).

spoilage organisms (bacterial spores). A reduction to the extent of twelve *D* values is employed in the canning of most foods with pH values higher than 4.5. For acid foods, below 4.5, the following schedule is recommended by the National Canners Association:

pH Value	Number of D Values for Successful Canning
below 3.9	1.0
from 3.9 to 4.3	10.0
from 4.3 to 4.5	20.0

Formula Method of Process Time Calculation.—The method described above is the *General Method* (Bigelow *et al.* 1920) of process time determination. It is possible to determine the process time for a product by formula (Ball's method) and by Nomograph (Olsen and Steven's method). These methods are fully described in the literature.

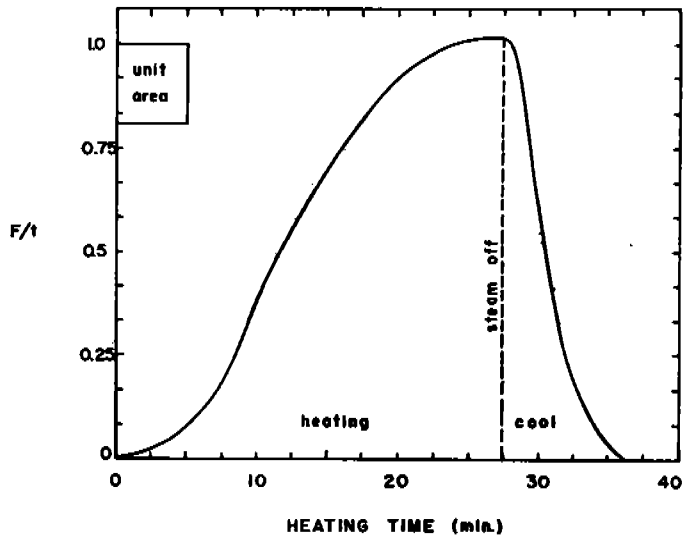


FIG. 69. LETHALITY CURVE FOR A CANNED FOOD HEAT PROCESS

Lethal value of process described by area under curve. Lethal value of this process = Area beneath curve in sq. in./unit area, sq. in. = F_0 value; when $F_0 = F = 100$ per cent sterilization process.

Ball's method for the determination of the processing time for a product which has a straight line semi-logarithmic heating curve is accomplished by the solution of the equation:

$$B_B = f_h \, (\log jI - \log g)$$

where, B_B = the process times in minutes at the retort temperature
f_h = slope of the heat penetration curve
jI = correction factor obtained by extending the heating curve to intersect the time at which the process begins
g = value in degrees below retort temperature where the straight line portion of the heating curve intersects the time at which the heating process ends.

The slope of the heating curve and the point where the extension of the heating curve intersects the time at which the process begins are obtained from heat penetration studies. The formula method value "g" is obtained by finding the number of degrees which exist between the retort temperature and the maximum temperature which must be attained by the cold point of heating in the container during the minimum process which will destroy the spores of the organism the process is intending to kill. The F and z values from the thermal death time curves

TABLE 57

TYPES OF PROBLEMS ON THERMAL PROCESSING OF CANNED FOOD SOLVED BY FORMULA METHOD[1]

Class 1—Simple process
Group 1—The heating curve is a simple logarithmic curve.
PROBLEMS:
I. Calculation of length of process
II. Calculation of a process equivalent to a given process at a different retort temperature
III. Calculation of effect of change in initial temperature upon the time necessary for sterilization
IV. Calculation of time necessary to reach a given temperature at center of can
V. Calculation of temperature attained at center of can in a given length of time
VI. Calculation of the amount of lethal heat at center of can up to a given time, expressed as percentage of heat necessary to sterilize
Group 2—There is a break in the heating curve.
PROBLEMS:
VII. Calculations of length of process
VIII. Calculation of a process equivalent to a given process at a different retort temperature
IX. Calculation of effect of change in initial temperature upon the time necessary for sterilization
X. Calculation of temperature attained at center of can in a given length of time
XI. Calculation of time necessary to reach a given temperature at center of can
XII. Calculation of the amount of lethal heat at center of can up to a given time, expressed as percentage of the heat necessary to sterilize
Class 2—Divided Process
Group 1—The heating curve is a simple logarithmic curve
PROBLEMS:
XIII. Calculation of length of process
XIV. Calculation of divided process equivalent to a given simple process at any retort temperature
XV. Calculation of a divided process equivalent to a given divided process at different retort temperatures
XVI. Calculation of effect of change in initial temperature upon the time necessary for sterilization
XVII. Calculation of temperature attained at center of can in a given length of time
XVIII. Calculation of time necessary to reach a given temperature at center of can
XIX. Calculation of the amount of lethal heat at center of can up to a given time, expressed as percentage of the heat necessary to sterilize
Group 2—There is a break in the heating curve
XX. Calculation of length of process
XXI. Calculation of a divided process equivalent to a given divided process at different retort temperatures and different initial temperatures

[1] From Ball (1928).

are considered in the g value.

Calculation of the thermal process adequate for a product is the solution of the above equation by substituting the appropriate values, and solving for length of process (B_B). Great versatility is found in the formula method. The features relative to thermal processing of canned foods which may be calculated by Ball's method are given in Table 57. It is necessary to refer to the original publications by Ball for graphs and tables used to obtain appropriate values for data in order to solve mathematically the heat process for a canned product. Readers are

referred to the original manuscripts for complete information on the *Formula Method.*

***Nomogram Method* of Process Time Determination.**—A method described by Olson and Stevens is a means of solving the processing equations developed by Ball by nomographic methods. These nomograms greatly reduce the time required to reach a solution to a problem on thermal processing of a product, providing that the thermal death time data and heat penetration data are available. The *nomogram method* is quicker than either the *General Method* or Ball's *Formula Method.* Nomograms are available in published literature and are not reproduced herein. Readers are referred to the original works.

Differences Between the *General Method* and Other Methods of Process Time Determination.—The *General Method* of determining the heat process required for a canned food always gives results in terms of total heating time, and considers the time required to raise the retort to the processing temperature. Providing this does not vary grossly, the *General Method* will yield accurate times for a product under conditions of product composition and bacterial load which the process was intended to consider.

The *Formula* and *Nomogram Methods* require that adjustments in come-up-time (CUT) be established. Ball has established that 42 per cent of the CUT of a retort is usable in terms of the processing temperature. With a 10 minute CUT, 4.2 minutes of this is equivalent in value to actual retort temperature; 4.2 minutes must be subtracted from the calculated processing time. For example, if the calculated process time was 60 minutes at 240°F., and a ten minute come up time is necessary, the corrected process will be 60 minus 4.2 or 55.8 minutes. Once the retort reaches 240°F., 55.8 minutes of holding at that temperature are required to yield an adequate lethal process. The total heating time, on the other hand, from the time the steam is turned on will be 55.8 minutes plus 10 minutes CUT, or 65.8 minutes. In practice this number would be rounded off probably to 70 minutes. There is then a safety factor involved by rounding off the number of minutes of a process, which is the practice.

Inoculated Pack Studies

In order to insure that the calculated processing time for a product is adequately established, it is desirable to prepare inoculated packs. The product is prepared and filled into containers. An inoculum of spores of the spoilage organism, important in the food group in which the product falls, is placed at approximately the cold point in the containers. With viscous foods, such as strained pumpkin, the inoculum will remain some-

what at the position placed. For convection heating foods, the inoculum will be carried in the convection currents formed during heating the containers. For solid packed foods, such as potatoes, the inoculum should be injected with needle one-fourth inch into the flesh of a potato at the cold point. Excessive processing would be required to kill spores in the center of a two-inch diameter potato. The inner surfaces are assumed to be sterile.

The concentration of organisms inoculated per container is important. For P.A. No. 3679, 10,000 spores are commonly inoculated per No. 2 can or pint jar. This will vary with the size of container. For relatively non-heat-resistant organisms, 100,000 may be inoculated per container. The longest period of survival of the organisms in the heated containers will be related to the number inoculated.

Assuming that the calculated process is 60 minutes at 240°F. for a food product, a processing schedule will be chosen which brackets this calculated schedule. A minimum of 24 inoculated and 12 control containers will be processed at 50, 55, 60, 65, and 70 minutes at 240°F. These containers will be coded, and incubated according to the organism's optimum for growth. Carefully kept records of spoilage are important. Microscopic examination of smears from spoiled cans is useful. At the end of four weeks, all containers not evidencing spoilage are subcultured. From the inoculated pack studies, the safety of the calculated heat treatment will be obvious. Cans heated for 50 minutes and 55 minutes will either all spoil or most of the 50-minute treatments will spoil and a few of the 55-minute treatments will spoil. None of the 60-minute treatments spoil. Under this condition, the 60-minute calculated process will be adequate. The control containers in the inoculated pack studies probably will not be spoiled at the 55-minute process treatments, and even the 50-minute treatments may not be spoiled.

It should be apparent that under this condition there is probably a margin of safety in the established process. This may be demonstrated by the following example of sweet corn packed in glass pint jars. Suppose sweet corn packs are inoculated with 10, 100, 1,000, and 10,000 spores of P.A. No. 3679 and processed for varying lengths of time from 20 to 60 minutes at 240°F. Control containers were also prepared and processed along with the inoculated jars. The results of such a study are shown in Fig. 70. It will be noticed that the control sweet corn spoiled at a level equal to 10 spores and 100 spores per container. Jars inoculated with 1,000 spores spoiled at a level higher than comparable controls. Containers with 10,000 spores inoculated at the cold point spoiled at 50 minutes of heating, while the containers with 1,000 spores spoiled only up to 45 minutes. Control containers viewed as a unit spoiled only up to

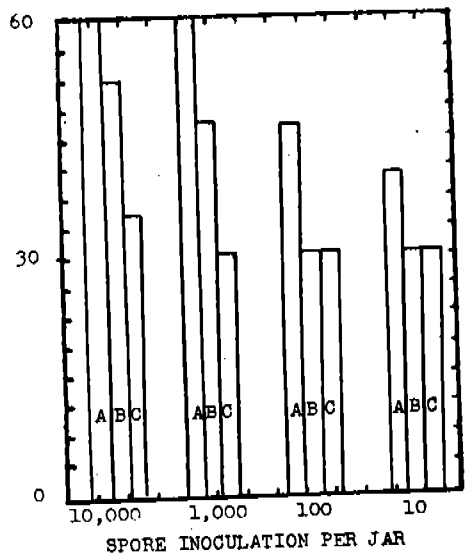


FIG. 70. INFLUENCE OF SPORE LOAD ON SUCCESS OF PROCESS

An important consideration in canning is the sanitary condition of the plant. A—Maximum process given. B—Maximum process where spoilage found in inoculated packs. C—Maximum spoilage in control packs.

a 35 minute process. From this study, an inoculum of 10,000 spores of P.A. No. 3679 would offer a margin of safety in establishing the safe process for sweet corn if the corn is not grossly contaminated.

Adequacy of Heat Processes

There are two considerations relative to safe processing schedules developed, one relative to the heat resistance of spoilage micro-organisms, and the other relative to the heat penetration characteristics of the food in the containers.

A) **Microbiological Considerations.**—As shown by the inoculated pack studies a spore load of 10,000 heat resistant organisms is probably greater than the natural contamination in the corn (Fig. 70). Providing the ingredients and sanitary conditions in the factory are satisfactory, it is unlikely that such a spore load will be present in food processed. Therefore, there is a safety factor involved in the spore concentration employed in establishing the thermal death time characteristics of the spoilage organisms.

B) Heat Penetration Considerations.—In establishing the heat penetration characteristics of a food product, the slowest heating and the fastest cooling curves are used to calculate the lethal effect of the process.

C) Statistical Evaluation of Heat Processes.—When process time is plotted against its lethal value, the relationship between the two variables, if considering a range of processes, is generally linear. In view of this, a linear regression line may be fitted to the lethal value-process time data for each product and the standard error of estimate computed.

The line of regression is defined by the regression equation, $y = a + bx$, in which x equals the process time; y, lethal value of process; a, the constant locating the line vertically; and b, the slope of the line. A parallel line is constructed at a distance of 2.6 times the standard error of estimate below the computed regression line. Assuming normal distribution, the probability of an individual container yielding an F_0 value falling below the lower line is only .005.

The process times determined for products by the three methods (i.e., slowest heating-fastest cooling composite data from heat penetration studies, inoculated pack studies, and the statistical evaluation), contain certain margins of safety. Under certain sanitary conditions they may be excessive. Under poor processing conditions they may be inadequate!

SPOILAGE OF CANNED FOODS

The ends of normal cans of food with a vacuum are slightly concave. Ends which are bulged may be caused by microbial, chemical, or physical actions. A hard swell is one which resists being pushed back to a normal position. The ends of a soft-swelled can may be forced back slightly, but will not resume a normal condition. A springer swell is one which is bulged but which may be forced back into normal position causing the opposite end to bulge by hitting against a solid object. The opposite end flips into the bulged end. Cans may progress through the flipper, springer, soft swell and hard swell stages. The next step is to have the can explode.

The same types of spoilage occur in either cans or jars. For simplicity, can spoilage will be discussed.

Underprocessed cans permit the survival of micro-organisms which grow and cause spoilage after the process. The growth may produce gas and acid, or acid alone. All cans spoiling from the survival and growth of micro-organisms are underprocessed. This may come about by having an extremely large load of bacteria, or the process time may be inadequate.

Unless grossly understerilized, spoiled cans will contain one organism

type. In low and medium acid food, this will be a spore-forming organism. In acid products the organisms may be yeasts, molds, aciduric spore-forming or non-spore-forming bacteria. Non-aciduric spore formers may be present. They will grow poorly if at all at this acidity.

When a mixed culture containing one or more non-heat resistant organisms is present in spoiled containers they were either grossly underprocessed or became infected after heating.

In flat sour types of spoilage, the contamination should be expected from the equipment in the plant or the ingredients. Some inoculation has taken place.

When anaerobic spore-forming organisms are causes of spoilage, it is usual that the contamination came from the raw material. It is unlikely that conditions in a plant are favorable for inoculation of anaerobes into products.

Leaking containers may be contaminated by cooling water. This spoilage may be found to be due to cocci, non-spore-forming rods, and non-heat resistant rods. Yeasts and molds may be present. In acid foods, the substrate will permit few organisms to grow. The principal source of contamination in leaking containers is the cooling water. Chlorination of cooling waters is a recommended practice. The ratio of spoilage in air cooled cans to that of cans cooled in water may be as high as ten times in the latter over the former.

Bacterial spores are more resistant to the effects of chlorine than vegetative forms. Occasionally spore-forming organisms will appear in leaky cans due to the selective action of the chlorine treatment of water in cooling canals. Too, if the chlorine is not allowed to come into contact with spores for at least several minutes, the spores may survive, and be drawn into the leaking container.

Solid products such as meat which have spoiled may have center portions still sterile. The growth may be centered outside the product or on the surface. Internal tissues of plants and animals normally do not contain organisms if the tissues are not diseased.

Microbial Spoilage

Flat Sour.—Spoilage of canned foods need not be accompanied by bulged ends. Flat sour spoilage, as the term implies, is a condition of high acid formation unaccompanied by gas production. Thermophilic bacteria are characteristic in the production of such spoilage. In flat sour spoilage, either the cans have been under-sterilized or the cans have leaked.

Acid and Gas.—Commonly, biological spoilage is evidenced by the

production of acid and gas by the spoilage organisms. P.A. No. 3679, for instance, produces such a condition. Generally the mesophiles will produce acid and gas in containers in which they grow. Their presence will be indicated by swelled containers and decomposed foods.

Chemical Swells.—Generally the cans of spoiled food will have extended ends. Gas is formed inside the containers forcing the ends. There are several causes of swells, aside of those from biological causes.

1) Chemical swells—resulting from the production of gas by action of the can contents on the container. Hydrogen gas is generally produced.

2) Chemical swells—resulting from decomposition of products liberating carbon dioxide, i.e., molasses, malt extracts, syrups. No bacteria or viable organisms are found.

Normal imperfections exist in the tin coating of cans. Scratches or internal damage can cause small areas of iron to be exposed. When the tin and iron are in contact with a substrate with a high organic acid content, an electrocouple is formed. The corrosion is more complicated than that of tin or iron alone. The principal factor influencing the corrosion of tinplate is the polarity of the metal in the couple. The polarity is governed by the presence of an oxide film on the metal surfaces and the ability of the electrolyte to remove the tin ions as a complex. When the oxide film is dissolved, if the electrolyte contains anions such as citrate or oxalate(with which tin forms a stable complex), tin becomes anodic and the attack is confined to the tin surface, while the iron base is protected. If the stable complex is not formed, tin remains cathodic and the iron is attacked and perforated.

Oxygen depolarizes and therefore is important in the corrosion process. Hydrogen gas should be evolved when displaced by the action of acid on the metal. This action is very slow at the tin surface unless oxygen or some other depolarizer is present. If hydrogen is not evolved it exerts a back pressure so to speak, and thus opposes further solution of the iron. The rate of attack is slow in the absence of oxygen. Anthocyanin pigments of fruits may act as depolarizers. Red fruits are prone to perforate cans.

Lacquered cans may be more easily perforated than plain cans, due to the fact that areas of exposed iron are not afforded cathodic protection or the protection of dissolved tin. Imperfections in the lacquered surface tend to concentrate this chemical activity to small areas, and perforation may be rapidly accomplished.

Lids on glass containers may be attacked chemically by some foods.

Physically Induced Swells.—Overfilling cans at low temperatures may cause permanent bulging to cans by heating. Expansion of the solids and liquid of the container may permanently distort it.

Foods packed with low vacuums may bulge when placed at high altitudes where there is lower atmospheric pressure.

Freezing food after being canned may cause physical damage to the contents and cans. Freezing may damage the texture and appearance of canned foods, and there may be damage to the container if the food contains large amounts of water.

Glass packed foods may be injured by light. Bleaching of products, development of light-struck oil flavors, skunky flavor in beer, and loss of certain nutrients due to light catalyzed reactions may occur. Such spoilage is not a physical spoilage but a photochemical reaction.

There is substantial physical damage to food products due to shipping canned foods by rail, truck, or plane. Foods may be degraded in texture noticeably by the agitation of containers and rough handling in general.

Failure of Glass Containers

While the glass container is inert, the closures applied are not inert and may be a source of difficulty. The closure should seal the container and prevent spilling of products. Depending upon the product, metal, glass, or plastic types of closures may be acceptable. A sealing junction is required where the glass of the container meets the closure. The closure must seal to a required tightness, protect the product against contamination, be inert to the product, have a satisfactory appearance after periods of storage with the food, take up any slack between the closure and irregular features of the surface of the glass, must slide easily over the glass when turned, and must not stick to the glass when the jar is opened.

Acid products may react with the closure in the same manner as acid foods react with tinned containers (Fig. 71). Problems are multiplied with foods which contain fat or oil, as the solvent action of oil restricts the use of rubber compounds. Vacuum closing jars presents little difficulty, except that strict attention to closures is required. The ease of opening glass containers is a factor of importance. Many devices have been developed for opening vacuum sealed jars.

Leaking of seals during processing and cooling require special attention. Heat processing of vacuum sealed glass containers requires superimposed pressure (air generally applied) during cooling to hold lids in place.

Closure failures may be due to faulty jars (checks in finish), faulty application of closures, faulty or insufficient processing, reaction of food with closure, misuse of jars and closures prior to and following processing, use of an inadequate sealing compound, and physical and chemical weaknesses of the closure.

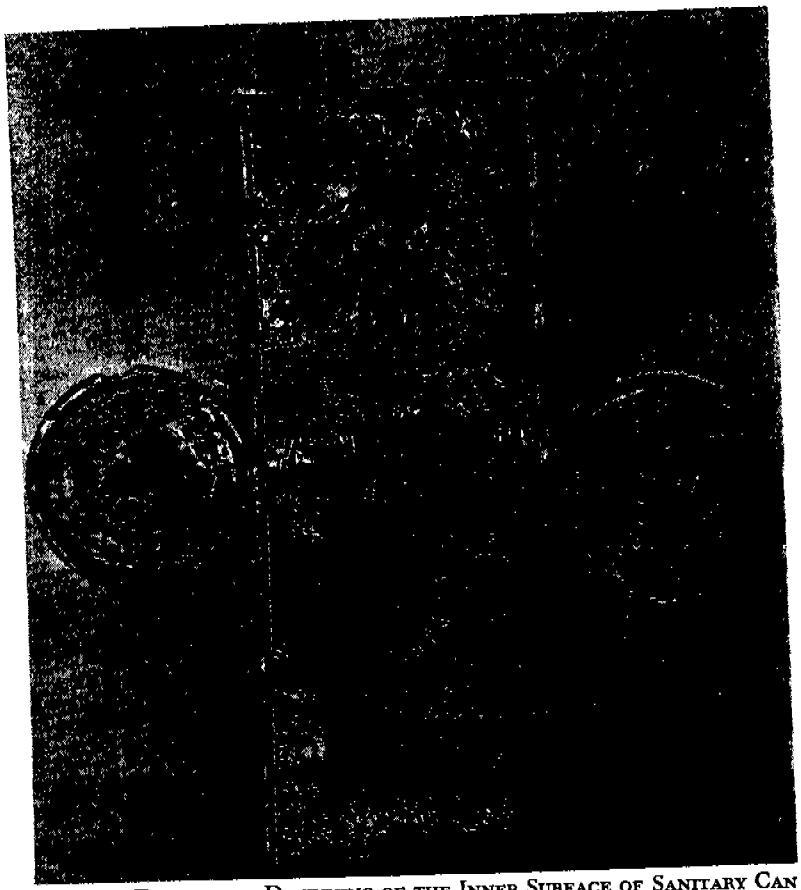


FIG. 71. FEATHERING-DETINNING OF THE INNER SURFACE OF SANITARY CAN

This is particularly a problem with acid foods.

Modern glass jar production yields a container fully competitive with other containers relative to function and strength (Fig. 72). However, there are glass breakage problems. These fall into three categories: impact breakage, internal pressure breakage, and thermal shock breakage. These three failures in glass jars are readily determined by inspection of broken containers.

Glass jars are normally balanced in the forces of compression and tension, and these are mobile in character depending upon the conditions under which the jars are subjected.

Glass breakage is due to tension. For example, a rubber band breaks easily if cut when the rubber is in tension. If in compression, the rubber band is hard to cut.

Courtesy of Food Processing

FIG. 72. HIGH SPEED FILLING AND SEALING LINE FOR GLASS CONTAINERS

Glass containers are as functional as tin cans in high speed operations.

Glass is not quite like rubber in this respect, but it is similar. Naturally, glass will be under compression on the outer surface of a jar and in tension on the inner surface. A rubber band in the form of a jar will be in tension on the outer surface and under compression on the inner surface.

It is important to know whether the break was due to poor quality glass or misuse of the jar. Where in the process does the jar fail? Corrective action must be taken to overcome the breakage. Knowledge of glass breakage is important when designing bottles.

If there are flaws in the jar, the lines of force in the glass will be altered.

A broken glass jar will usually yield the following information: (1) a point of origin of the break; (2) the direction of travel of the break; (3) the speed of propagation of the fissure; (4) the violence of disruption; and (5) the causative force (probable).

The three types of breakage are as follows:

Internal Pressure Breakage of glass containers has a definite pattern. This is shown in Fig. 73.

The failure is usually midway from the top to the bottom of the jar. The origin of the break may be on the outer surface, or on the surface containing a scratch or check in the glass. Pressure breaks are slow at first, leaving a mirror surface on the broken glass, then the fissure moves up and down, forking as it moves. If the point of origin is near the shoulder, there may be weakness in design. If the origin is near the bottom, damage may have been done to the jar during handling. Resistance to pressure breaks includes homogeneity of the glass, increasing the temper, and elimination of fabrication defects. The thickness of the glass is important. The heavier a jar for a given capacity, the more pressure it will withstand. On the other hand, this is detrimental to the resistance to thermal shock. The pressure strength increases as the ratio of weight to capacity increases. Pressure strength decreases as size increases. Round surfaces, or better, spherical shapes have greatest pressure strength.

Impact Breakage.—Glass containers are broken by active impact, or by a series of small impacts. Percussion cones may be formed. There is radial forking (see Fig. 73). Damage to outer surfaces, damage to inner surfaces, fabrication defects, temper or annealing difficulties, and thickness of the glass influence impact breakage resistance. Thick glass jars resist impact breakage poorly because their walls are too rigid. Thin walled containers best resist impact.

Thermal Shock Breakage.—When one portion of a glass container is at one temperature and another section is at another, one section expands and the other contracts. Bottles will break from thermal shock by mechanical stress and strain (Fig. 73).

Temperature differences cause differential expansion and internal stress in the glass wall. Shock occurs when one surface is at a different temperature from the other. When the temperatures are equalized, breakage tendencies decrease. Stress established by temperature differences seek out flaws in the container. Surface conditions are important to the onset of temperature shock. These may be applied in four methods:

(1). ***Hot to cold immersion.*** Stress condition: tension outside, compression inside. Example, warm beer bottle in ice water bath.

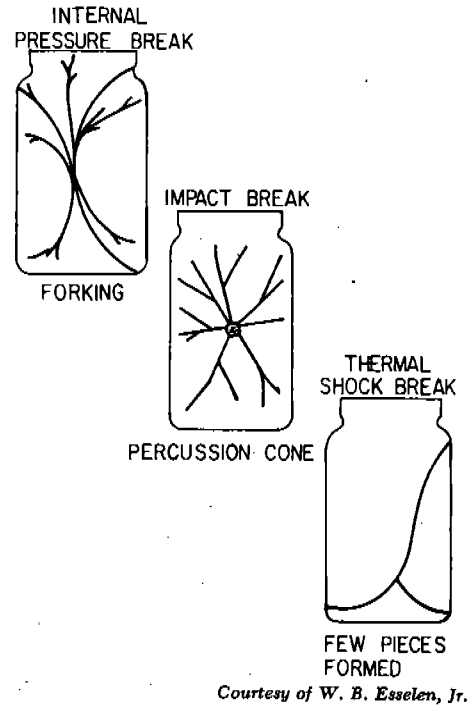
(2). ***Cold to hot immersion.*** Stress condition: compression outside, tension inside. Example, cold packed jars in boiling water bath.

(3). ***Hot pour.*** Stress condition: tension outside, compression inside. Example, hot packed food in a cold jar, catsup in cold bottles.

(4). ***Cold pour.*** Stress condition: compression outside, tension inside. Example, cold bottles placed in a pasteurizer.

Type 3 (above) thermal shock is the most severe.

Typically, thermal shock will originate at the base of a jar. The break



Courtesy of W. B. Esselen, Jr.

FIG. 73. BREAKAGE CHARACTERISTICS OF GLASS JARS

Glass container diagnosis of failures leads to elimination of breakage.

will travel slowly with little violence. A point of injury to the surface locates the origin. Factors influencing thermal shock include the homogeneity of the glass, the annealing conditions (increase temper, increase resistance), fabrication defects, and thickness of the glass. The thicker the glass, the more stress, the more breakage potential. Resistance to thermal shock decreases with the size of the jar. Round or oval shapes have improved thermal shock resistance. If the container is of uniform thickness, it has greater resistance to thermal shock.

It is apparent that glass should be conditioned prior to receiving very hot products, and must be cooled carefully after being filled and sealed. It is desirable that no greater than an 80°F. differential exist between the inner and outer surfaces of bottles. Such a system is easily fabricated to control this feature of breakage. Some glass containers may withstand upwards to 150°F. differentials in temperature and not break.

Surface Markings on Broken Glass

Characteristic surface markings found on the broken surface of glass containers are shown in Fig. 74, with nomenclature.

1) ***Origin of break.*** By tracing the surface markings on the broken surface, it is possible to trace backwards to the origin of the break.

2) ***Ripple markings*** indicate an area of moderate violence in the movement of the fissure.

3) ***Feathering*** is an indication that the fissure forces have slowed.

The origin may be a nick or imperfection of the glass inner or outer surface. The point of origin may not be obvious but it is important that it be established either on the inside or outside surface of the jar.

4) ***Gray area*** is found in pressure breaks, characteristically.

The area of transition between the origin and the appearance of other markings may be mirror-like, especially if the speed of breaking is then at a slow rate. The gray area is the zone of accelerated speed of the break. If the break is uniform, the rough area may not be found.

5) ***Hackle markings*** or grooves are found in a direction parallel to the inner and outer broken surfaces. If found they indicate a split in the wave front, temporarily fluctuating during the break. If the break is at high speed, the ripple marks are covered by hackle markings. If the speed of the break is slow, markings may not be found. Ripple marks show the direction of the travel of the break, and indicate the surface origin.

6) ***Striations*** usually are found when changes in the direction of the break have occurred. They point in the direction of travel of the break.

7) ***Formation of forks*** in broken glass is due to pressure. After hackle marks, forking is observed. In pressure breaks there is usually forking. Impact breaks have radial fissures.

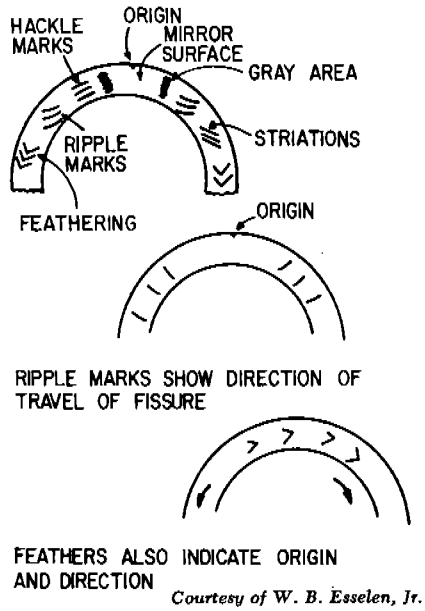
8) ***Percussion cones*** are characteristic of impact breaks. Cones are a diagnostic aid by indicating the point of origin of the impact. If a perfect cone is formed, the break followed the formation of the cone. If there is no cone, the break occurred as the cone was developing.

9) ***Featureless*** surfaces are occasionally seen. The speed with which the breakage occurred is slow with little violence, and is characteristic of thermal shock breaks.

It should be noticed that with very thin glass, these observations may not be helpful in diagnosing breakage. With heavier bottles, this reasoning is more accurate.

VACUUM-PRESSURE RELATIONS IN CANNING PROCESS

A vacuum is a condition where the pressure in a system is reduced from atmospheric pressure. If atmospheric pressure is normally 14.7 lbs. per



Courtesy of W. B. Esselen, Jr.

FIG. 74. SURFACE MARKINGS ON BROKEN GLASS JARS

Tell-tale evidence of cause of failure in glass container.

sq. in. on the surface of the earth, a decrease in this pressure by one pound would create a partial vacuum. Vacuum may be referred to in terms of inches. Two inches of vacuum equals approximately one pound of pressure. If 30 inches of mercury is equal to 15 lbs. of pressure, a vacuum equal to 10 inches of mercury would have a pressure of 5 lbs. per sq. in.

A condition of partial vacuum is desirable in canned foods for biological, chemical, and physical reasons.

Biologically, a vacuum is important in that it restricts the growth of organisms requiring air for growth. This is particularly important for products receiving heat processes of low lethal value. Yeasts, false yeasts, and molds may be retarded from growth. Since the lethal process in canning is designed to kill spoilage micro-organisms, the biological importance of a vacuum in a container is of less significance than for other factors.

Chemically it is important to remove the oxygen from the air in the headspace of containers. In a container having a vacuum equal to 20 inches of mercury, two-thirds of the air in the headspace has been eliminated. If the headspace had a volume of 100 ml. such a vacuum would

reduce the air to one-third its original concentration, leaving 33 ml. of air. Since 20 per cent of air is oxygen, the oxygen concentration would be reduced from 20 ml. to 6.6 ml. If the air were flushed from the container with steam and the steam condensed, the oxygen content could be very low. Vacuums in containers of food help protect color and flavor of products, assist in retaining vitamins, prevent rancidity due to oxidation, help retard the corrosion of tinplate and the corrosion of closures on glass containers.

From a *physical* standpoint, a vacuum is of value in holding the closures on glass jars, keeping the ends concave in cans and reducing the pressure within containers while being heat treated. During the cooling of glass containers it is necessary to superimpose air pressure on glass containers vacuum sealed if the closures are to be kept in place.

Obtaining Vacuum in Containers.—A vacuum may be obtained in a container by replacing the air in the headspace with steam, by causing the contents of containers to expand by heating, then sealing the containers, and by mechanically pumping air from the headspace then sealing the containers.

Factors Influencing Vacuum in Containers.—The amount of food in the container, the temperature of the contents, and the time elapse between filling and sealing are important to the vacuum developed in containers. In addition, such factors as the time in which steam is allowed to flush air from headspaces, or the mechanical conditions of vacuum imposed on the container, if used, would be important.

Factors Contributing to Internal Pressure of Containers.—The expansion of the product, the coefficient of expansion of the product, the initial temperature, the processing temperature, the vapor pressure of gases in the product, the fill and headspace volume contribute to the control of internal pressure in containers during heating. In order to maintain satisfactory processing conditions to protect the containers, the following conditions should receive attention: (1) maintain sufficient headspace in containers; (2) keep the initial temperature high; (3) exhaust containers before sealing: (4) venting of closure on jars during processing; (5) temperature of process; (6) extra air pressure in retort during cooling jars; and (7) vacuum sealing containers.

Internal pressure problems may develop within containers during the cooling period. With large containers (No. 10 cans) difficulties may be encountered when the sides are drawn in, paneling the container. Conditions to overcome this require attention to the filling and sealing conditions to such containers, and careful cooling. Glass jars, too, require careful attention during the cooling cycle.

Pressure conditions during the heating and cooling of cans and glass

jars must be recognized and controlled.

TABLE 58

INFLUENCE OF STORAGE TEMPERATURE ON RANCIDITY VALUES, THIAMIN RETENTION AND CONDITION OF INTERIOR CAN SURFACES OF CANNED FRANKFURTERS AND BEANS IN STORAGE[1]

Storage		Rancidity Values		Thiamin,	
Temperature, °F.	Time, Months	Peroxides, M-Mols./Kg.	Free Fatty Acids, Per Cent as Oleic	Mg./ 100 Gm.	Can Rating[2]
...	0	5.0	3.8	0.059	8.6
100	6	3.6	6.0	0.042	6.6
	12	2.4	3.0	0.027	5.9
	24	1.1	6.9	0.015	4.8
70	6	4.7	4.1	0.057	7.7
	12	2.6	2.8	0.050	6.7
	36	1.8	2.0	0.036	6.4
	72	0.0	3.5		5.2
47	6	3.9	4.0		8.3
	12	3.6	1.8		7.6
	36	2.1	1.4	0.046	6.9
32, 0, −20	6	4.2	4.3	0.064	8.6
	12	3.3	2.4		8.5
	36	2.8	1.3	0.052	7.1
	72	0.0	1.6		6.3

[1] From Cecil and Woodroof (1962).
[2] On a scale of 9 (no corrosion) to 1 (interior surface completely corroded).

STORAGE OF CANNED FOODS

If the canning processes have been successful, the containers should be in condition where biological spoilage will not occur. Thermophilic organisms may be present, but unless temperature conditions in the storage chamber are excessive, such spoilage is unlikely. However, while the biological forces may not be operative, chemical reactions are not eliminated. Chemical reactions bring about many changes in canned foods during storage. The temperature of the storage is directly related to the storage life of the products. If it is considered that 50°F. is a highly desirable storage temperature, increasing the temperature to 68°F. probably will halve the storage life of the commodities, and raising the temperature of the storage room to 86°F. will halve the storage life over that at 68°F. If the color is degraded at 50°F., at 86°F. it will take one-fourth as long to arrive at an equal stage of degradation. Chemical reactions taking place during storage of canned foods will affect the flavor, color, texture and nutritive value of the foods. Internal corrosion of the cans will follow the same pattern.

The nutritive value of foods is maintained satisfactorily if the storage conditions are not excessively high. As an example, changes in the

thiamin value of canned foods on storage for animal and vegetable products are indicated in Table 58.

In order to keep chemical changes to a minimum, temperatures of storage rooms for foods should be held just above the freezing point of the canned product. Summer temperature in warehouses may exceed 100°F. in Southern United States and will fall below 32°F. in the winter months in the North. It is desirable to cool warehouses in the South and heat in the winter in the North.

While freezing temperatures will not damage food nutritive values, unsightly products result from the freezing action.

Glass packed foods should be protected from light. Light catalyzed reactions include bleaching of color, destruction of vitamins, and flavor deteriorations.

External Corrosion of Cans

The presence of moisture on the surfaces of cans leads to rust formation. Rusting conditions may result from "sweating" of containers when moisture from air condenses on cans when their temperature is below the dew point of the air. When the relative humidity is high and the temperature of the cans is low, condensation may be expected. Warehousing at dry atmospheric conditions and constant, low temperatures is important to prevent deterioration of cans and products. Proper air circulation, heating or cooling, and ventilation around stacks of cased products with adequate temperature control, reduce danger to corrosion of cans.

Sweating may also occur when canned foods are shipped from cool warehouses to warm and humid storage areas.

An important consideration in controlling the corrosion of cans of food relates to the temperature of cans after being cooled. If the temperature is reduced much below 105°F., there may not be sufficient heat to vaporize the moisture on the cans, and these will remain moist for prolonged periods if placed in a wet condition into cartons in warehouses. Cans must be dry when stored. As a general rule, a can which does not feel slightly warm to the touch is cooler than 105°F.

Storage of canned foods near oceans requires that precautions be taken to reduce the potential of corrosion due to the action of salt in moisture in the atmosphere. Dry, ventilated warehouses which avoid entrance of air currents from an ocean are required.

Coding the Pack

It is important that canned foods be coded when placed into ware-

houses. In the event of spoilage, lots may be isolated in blocks from the main product. In addition, products of poor quality may be isolated and controlled.

INFLUENCE OF CANNING ON THE QUALITY OF FOOD

The general scheme of commercial canning may be depicted as follows: receive raw products; prepare product (wash, sort, peel, trim, chop, bone, etc.); fill food into containers; exhaust filled containers; seal lids to filled containers; heat process; cool containers; and finally store canned foods.

Unfortunately, the application of sufficient heat to destroy food spoilage micro-organisms and enzymes also results in some undesirable changes in the foods. There are alterations in the color, flavor, texture, and nutritive value of foods in canning.

The prompt dispatch of raw perishable foods through the canning operations is required if high quality products are to result. Any decomposition in the product will be detrimental to the processed foods. There are losses in quality that may occur throughout the canning process. Proper attention to procedures is required. If products are blanched at too high a temperature, if products become contaminated and decomposed, if partially prepared foods are exposed to air and high temperatures for long periods of time, it may be expected that the quality of the processed foods will be poor. Under standard operating procedures in commercial canning plants, the following alterations in quality of foods may be anticipated in greater or lesser degree, depending upon plant operation.

Color

Heating foods changes their physical and chemical qualities. In some instances the changes are desirable, making meat more tender. In other cases, the changes are detrimental to the food, destroying color characteristics (Table 59).

Foods that have been altered by heat can be expected to have altered abilities to reflect, scatter, and transmit light. If this occurs, there will be determinable changes in the color of foods.

Heating pure pigments causes color characteristics of the pigments to be altered. Heating pigments in complex substrates such as a canned food, results in degradation of the natural color characteristics. The degradation of color may be enhanced by the action of metals (loss of color of red fruits in tin containers).

The heat impairment of the lycopene (red pigment) of tomato juice is of interest, particularly the influence of equal lethal heat treatments at various temperatures. High temperature exposures for short times, as expected, result in less color degradation than equivalent processes at

lower temperatures for longer times.

In addition to the destruction of pigments by heating, colored products may be formed by heating foods. Refluxing reducing sugars with

TABLE 59

INFLUENCE OF EQUAL LETHAL HEAT TREATMENTS AT VARIOUS TEMPERATURES ON THE OPTICAL DENSITY OF BEET JUICE[1]

Heat Treatment, °F.	Optical Density, 530 mμ
Unheated control	1.90
230	0.78
240	0.74
250	0.55
260	0.56
265	0.76

[1] From Ammerman (1957).

amino acids produces a brown color, the color of maple syrup for example. Caramelization is a process resulting from heating polyhydroxycarbonyl compounds (sugars, polyhydroxycarboxylic acids) to high temperatures in the absence of amino compounds. Oxidative browning may occur in foods heated in the presence of oxygen, i.e., browning of tomato paste when concentrated in open kettle processes. There are enzymatic browning reactions which are inhibited by heating. For example, the browning of a cut slice of apple exposed to the air does not occur in canned apples.

Flavor and Texture

The flavor of a food is a dual response of odor and taste. When combined with the feel (consistency and texture) of foods in the mouth, the consumer is able to distinguish one food from another. Heating may be expected to degrade both flavor constituents and the physical character of foods. The degree of change is related to the sensitivity of the food to heat. Unfortunately, the objective methods of evaluation of flavors of foods are lacking. Subjective evaluations are subject to the usual failings of fatigue, memory, etc.

Assuming equal lethal heat treatments, high temperature short time exposures to heat are less destructive upon flavor and texture than low temperature–long time processes, within limits.

Prolonged heating causes gelatin to degrade and lose its gelling powers. Starch will also lose its thickening power when given severe heat treatments. Pectin requires heating at low temperatures to thicken foods but elevated temperatures or prolonged heat destroys its gelling power.

While heat may be damaging to food quality, the flavor of some products such as pork and beans are improved by heating longer than necessary to sterilize products. Meat is improved in flavor by cooking.

Protein

Denaturation of protein may be brought about by heat in the presence of moisture as mentioned before (p. 31). When so denatured, the configuration of the native protein molecule is lost and specific immunological properties which distinguish most proteins are diminished. The

TABLE 60

INFLUENCE OF EQUAL LETHAL HEAT TREATMENTS AT VARIOUS TEMPERATURES ON THE FREE SULFHYDRYL GROUPS IN A TWO PER CENT EGG ALBUMIN SOLUTION[1]

Heat Treatment, °F.	Mg. SH/Ml.
Control	7.3
220	19.0
230	20.0
240	18.0
250	19.7

[1] From Ammerman (1957).

activity of enzymes disappears when heated. There is an increase in the free sulfhydryl groups (Table 60), a change in availability of the protein to enzymatic hydrolysis, and an increase in the viscosity of the protein solution. After denaturation, proteins undergo further alteration known as coagulation or flocculation, and finally precipitation. Coagulation is a process involving the joining together of adjacent protein molecules by means of side-chain hydrogen bonds.

For a process with an F_o value of 4.0, there is a reduction in the rate of trypsin reaction with heated casein compared to unheated, regardless of the temperature of process. Between 220° and 250°F., equivalent processes inflict no apparent differences in the rate of enzyme reaction with the heated protein.

There is evidence that heat impairs the nutritional value of protein, without altering the amino acid content as determined chemically. Failure of proteolytic enzymes to digest heated protein as readily as unheated may be the explanation of the reason why animals thrive less well on highly heated protein than on slightly heated protein.

However, heat processes of equal lethal value usually used in canning do not alter the viscosity of protein solutions significantly.

Fat and Oil

Fats are subject to two main types of rancidification, hydrolytic and

oxidative. Enzymatic hydrolysis is characterized by the production of free fatty acids. Oxidative rancidity is an autocatalytic chemical reaction with atmospheric oxygen characterized by the production of peroxides.

Heat has profound influences on both types of deterioration of fats and oils.

Lipases produced by micro-organisms are destroyed by the heat process. Oxidative rancidity is accelerated by heat, metallic ions, and light. The rate of oxidation of fat is doubled for each increase in temperature of 18°F. The presence of metallic ions (cans) and light (jars) may increase the reaction. Moisture accelerates oxidative rancidity. Fats heated in the presence of oxygen have lowered melting points, lower iodine numbers, and increased acidity. Heating is used to accelerate aging of fats in stability tests.

Flavor reversion occurs in unsaturated fats and oils; heat accelerates the reactions.

Fats are stable to moist heat in the absence of oxygen. Under these conditions, fats and oils in canned foods remain relatively unchanged by canning processing temperatures.

Fat and oil heated to high temperatures (400°F.) have decreased nutritive values.

Carbohydrates

Sugars and starches are degraded by prolonged heating at high temperatures. Browning-type reactions (of organic acid, amino acids and reducing sugars) are produced by heating under moist conditions. The production of caramel color is an example, too, of the degradation possible with heat. Caramelization of carbohydrates in sweet corn in No. 10 containers is evidence of heat damage.

Vitamins

The vitamins are divided into two groups, those soluble in oil and those soluble in water.

Water Soluble.—Thiamin, riboflavin, and ascorbic acid have been studied extensively relative to their heat destruction in canning. Thiamin is heat labile, its loss in canning may be substantial. Acid foods retain a higher percentage of thiamin due to their lower processing requirements and increased stability of thiamin in acid foods. Peas may lose 50 per cent of their thiamin during canning preservation. Losses have been found as high as 80 per cent in canned lima beans and corn, but very little loss in canned carrots. Canned meats may lose in the vicinity of two-thirds their thiamin content.

Riboflavin is stable to heat, but light sensitive. Glass packed foods may lose more riboflavin than tinned foods. It is not uncommon to find analyses for riboflavin which report more than 100 per cent of this vitamin present. In these instances, more riboflavin is made available by heating for evaluation by present chemical and microbiological assays. Browning reaction end products fluoresce and may confuse results of some assays.

Ascorbic acid is destroyed by heating at low temperatures for long periods of time. This may be due to factors other than heat alone. High temperature, short time processes destroy little ascorbic acid if there is low oxygen tension. The destruction of this vitamin is accelerated by oxygen, copper ions, and ascorbic acid oxidase enzyme. Tin protects vitamin C in solution.

High temperatures for short time exposures are less destructive of the water soluble vitamins generally than lower temperatures for longer periods.

Fat Soluble Vitamins.—Vitamin A is relatively heat stable. If heating occurs in the presence of oxygen, appreciable losses occur. If air is excluded, heating to 240°F. has little effect on vitamin A. Prolonged storage of heated products at high room temperatures will cause losses of this vitamin, however.

Vitamin D has been shown to be moderately heat stable and resistant to oxidation. However, heat and oxygen together cause rapid destruction. Vitamin D added to boiling oil is rapidly lost. If added to oil at low temperatures, the vitamin is relatively stable.

Vitamin E is stable to heat in the absence of oxygen, but heating causes rapid destruction of vitamin E in the presence of oxygen, and heating in this condition may yield almost complete destruction of the nutrient.

MISCONCEPTIONS RELATING TO CANNED FOODS

The term ptomaine is derived from the Greek and means a dead body. Ptomaines are produced in putrefying meat and other proteinaceous foods. These are substances which belong to the group of compounds known as amines. They result mainly from the decarboxylation of amino acids. A typical decomposition is as follows:

$$CH_3CHNH_2COOH \rightarrow CH_3\ CH_2\ NH_2 + CO_2$$
$$\text{alanine} \rightarrow \text{ethylamine} + \text{carbon dioxide}$$

Alanine loses carbon dioxide yielding the ptomaine ethylamine. Ptomaines appear in advanced stages of putrefaction and are not eaten as foods by man, in his stable mind. Ptomaines are poisonous when injected into man. There is question as to the toxic action of ptomaines when taken by mouth. As noted in a previous chapter, the ptomaine theory

of food poisoning is a misconception. Other common ptomaines in decomposed flesh are cadaverine (from lysine), and putrescine (from arginine). Foods containing these materials are too decomposed to be held in the stomach of modern man.

There are widely held notions relating to the safety of opened canned food containers. One is that opened cans of food rapidly become poisonous. The notion does not include evaporated milk, evidently, as it is common to punch holes in these cans and hold them at room temperature without ill effects. In truth, such products should be refrigerated, as should all perishable foods. Canned foods will spoil more rapidly than fresh foods, once an inoculation has occurred in the opened canned products.

Certain foods should be removed from opened containers not from the aspect of danger to health but from the loss of quality of the food. Pigmented foods may bleach in opened cans, and corrosion of tinplate is accelerated by oxygen from the air.

In many circumstances, opened cans are the best container for the food, and may be the most sterile containers available in a household. The food and container are at least not hazards to public health unless contaminated. A dish or a pan is likely to be a source of bacteria which will find the food a suitable environment for growth. In any event, opened canned foods should be treated as perishable. The container in which the food is held is of minor significance if it is clean.

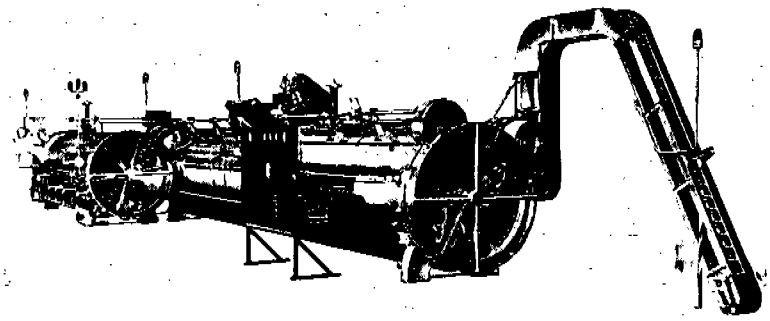
Another common notion is that the tinned flavor sometimes obtained from cans is toxic. Unless the amount of tin consumed is very large, it has no harmful effects. Tin has been shown to actually protect vitamin C in foods.

IMPROVEMENTS IN CANNING TECHNOLOGY

Generally speaking, for each increase in 18°F. in the temperature, beyond the maximum conditions for growth, a tenfold increase in the destruction of organisms occurs. Such an increase in temperature results in a doubling of the rate of chemical reactions responsible for product deteriorations. Therefore, heat treatments (of equal lethal influence on bacteria) at high temperatures for short periods of exposure should effect greater retention of the natural quality characteristics of products than equivalent low temperature heating for longer periods of time. Research data, canner experience, and consumer acceptance of processed foods have demonstrated this to be true.

With still-retort heating of canned foods (Fig. 45), processing temperatures of 240 to 250°F. represent the upper limit of heat intensity which yields acceptable finished products. Heating at higher tempera-

tures in still retorts results in deterioration of the quality of the processed foods, particularly conduction heating products.



Courtesy of Food Machinery and Chemistry Corp.

FIG. 75. FMC CONTINUOUS PRESSURE COOKER AND COOLER

Continuous high speed processing of canned foods.

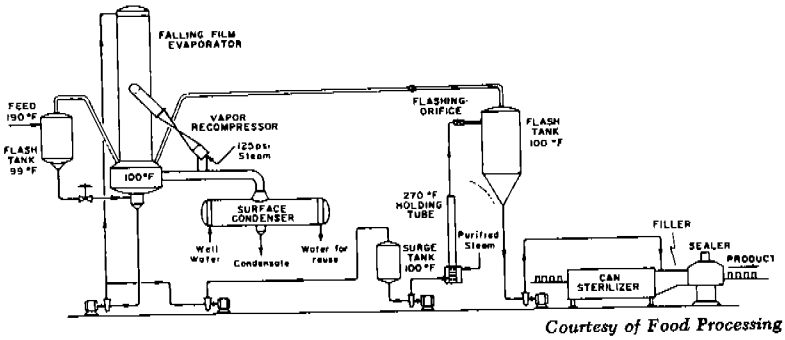
While the first successful closed, still retort was invented in 1874, a retort was invented in 1884 which could agitate cans. Studies on the manufacture of canned condensed milk (containing added sugar) led to the possibility of canning evaporated milk without the addition of sugar or preservatives. Evaporated milk of acceptable stability cannot be obtained in still retorts. Agitation increases the rate of heat transfer from container to product by renewing the surface in contact with the hot container; the "burned" and "cooked" flavors are reduced in intensity. Agitation prevents the complete coagulation of milk proteins and prevents milk solids from adhering to the walls of cans.

Agitated cookers are used in the canning industry for many products at present. Modern units consist of three sections (Fig. 75): the preheater, the cooker and the cooler. Each unit contains a revolving reel and a spiral track. The cans, placed in individual compartments, are rotated during part of the revolution by movement of the reel, and at the same time, are guided by tracks from the inlet to the outlet continuously.

There are many patents concerning agitating cookers. Some deal with reciprocal movement of cans, others have reciprocating movements combined with revolving about an axis in cookers. Cans are held in trays in many of these cookers.

Ball considered the ideal method for food canning to be sterilization of the product prior to filling and aseptically filling sterile cans with the mi-

crobe-free product. Martin described a practical application of this procedure in 1948 (Fig. 76).



Courtesy of Food Processing

FIG. 76. ASEPTIC CANNING LINE DIAGRAM FOR CONCENTRATED MILK PROCESS

Milk is concentrated and sterilized outside the container, then filled into sterile containers in sterile atmosphere.

It involves the following steps: (a) sterilization of the product by flash heating and cooling in a tubular type heat-exchange system; (b) sterilization of the containers and covers with superheated steam; (c) aseptic filling of the relatively cool, sterile product into the sterile containers; and (d) application of sterile covers to the filled containers and sealing the cans in an atmosphere of either saturated or superheated steam.

This process has been shown to be advantageous for heavy or viscous products which are adversely affected by sterilization in a sealed container. This method has been demonstrated to be practical. Another advantage is that the procedure may be used as a continuous operation, although it is not applicable to solid foods.

The following types of agitation in processing vacuum packed vegetables have been reported in the literature: (1) continuous end-over-end rotation; (2) continuous axial rotation; and (3) intermittent axial rotation.

All three types of agitation increased the rate of heat penetration over that attained by still processing. In studies involving end-over-end rotation, it is observed that the rate of heat penetration is only slightly influenced by the speed of rotation in the range of 10 to 40 revolutions per minute. On the basis of information obtained from experimentation a substantial reduction in agitating process times over still retort treatments is possible.

Roberts and Sognefest checked the accuracy of results obtained from the heat penetration studies with inoculated packs of peas and corn. One milliliter of a suspension containing 200,000 to 250,000 spores of P.A. No. 3679 per can was used. Listed below are some of the results obtained:

Product	Process	Temperature, °F.	Calculated Sterilization Value, F_0	Minimum Time of Processing Which Did Not Give Swells in Inoculated Packs, Minutes
Peas	End-over-end	250	7.8	9
Peas	Intermittent axial	250	9.2	12
Peas	Still	240	8.5	45
Corn	End-over-end	250	8.0	12
Corn	Intermittent axial	250	9.2	14
Corn	Still	250	10.9	40

On the basis of these results, it may be concluded that heat penetration measurements are reliable as a basis for calculating agitated can processes, and that substantial reductions in processing times may be effected.

Clifcorn and coworkers developed an experimental, agitating cooker in which reciprocal and rotational movements could be attained at speeds varying from 0 to 360 r.p.m. and at steam pressures corresponding to 300°F.

The first such studies were made with 300 × 314 cans filled with water to $^5/_{16}$ inch headspace, with a retort temperature of 260°F., and with variable speed of 0 to 200 rotations or reciprocations per minute.

When cans were maintained horizontally and subjected to 120 reciprocations a minute through a one-inch stroke, agitation reduced the time from 4.3 to 1.4 minutes to heat the contents of the can to 1°F. below retort temperature in the range of 60° to 259°F. A two-inch stroke increased the rate of heat penetration but was considered to be impractical for a commercial operation. Results of experiments in which the axes of rotation were inside or at the sides of the cans indicated that the end-over-end type of agitation was superior. A reduction in processing time is obtained when cans were maintained bottom-down and perpendicular to the axis of rotation. End-over-end rotation at the proper speeds is superior to reciprocation, especially if the amount of mechanical work is taken into consideration.

The resultant of forces when the cans were subject to the simultaneous action of both gravity and centrifugation has been studied. By selecting a proper speed, the headspace void can be made to pass through the liquid at various levels. When the speed is such that the centrifugal force equals the weight of the liquid contents, the headspace void passes

through approximately the center of the can. When this occurs, maximum turbulence results with the greatest rate of heat penetration (see data below).

The speed of rotation must be decreased for viscous products to allow the headspace volume to cross through the center of the can.

In experiments with end-over-end rotation of large-sized cans, placing the can adjacent to the axis of rotation allows maximum agitation, particularly at moderate speeds. The best speed for a 603 x 700 (No. 10) can with a path radius of 3.5 inches is considered to be 100 r.p.m., depending on the product, of course.

Application of these studies to practical canning results in a decrease in heating time for the end-over-end methods when compared to conventional still processes.

Results are quoted below to indicate the improvement possible.

Product	Can Size	Process-Agitated at 260°F.		Conventional	
		Time, Min.	Temp., °F.	Time, Min.	Temp., °F.
Peas	307 × 409	4.90	260	35	240
Carrots	307 × 409	3.40	260	30	240
Beets—sliced	307 × 409	4.10	260	30	240
Asparagus spears	307 × 409	4.50	270	16	248
Asparagus—cuts and tips	307 × 409	4.00	270	15	248
Cabbage	307 × 409	2.75	270	40	240
Asparagus spears					
brine packed	307 × 409	5.20	260	50	240
brine packed	603 × 700	10.00	260	80	240
vacuum packed	307 × 306	5.00	260	35	250
Mushroom soup	603 × 700	19.00	260	...	...
Evaporated milk	300 × 314	2.25	200	18	240

Another advantage to agitation retorting is that higher temperatures may be used with less danger of overcooking.

Using the thiamin content as an index of the chemical changes taking place during processing, greater retention is found with agitated than in still processes.

Agitation retorting permits successful canning in large sized containers for low acid foods. No. 10 cans of cream-style sweet corn are caramelized by still retort processes. Agitation processes for corn and most foods result in improved quality retention.

Substantial improvements in color and texture of products that normally become degraded with prolonged heat treatments are possible with agitation retorts. Spaghetti and meat cooked in No. 10 cans by agitating retort have "home cooked" color and texture qualities. Another benefit is

found for small canning operations in processing relatively unexploited, heat-sensitive food products. Field tests with canned whole milk indicate the product to be substantially as good as freshly pasteurized milk, yet will keep at least 10 times as long without refrigeration.

SUMMARY

The high quality foods in great demand are also the highly perishable foods. Fortunately, we now know how to preserve these foods and canning remains one of the key building blocks of a sound, effective food supply. Further details concerning the process are presented in Chapter 13.

New canning technology is permitting the introduction of new processing container types, forms, and sizes. Major strides already are underway with easy opening containers, and canning in flexible pouches. Weight reduction in containers, and the increased use of aluminum and plastic units are aiding the ever increasing applications of the growing technology of food preservation by canning.

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