HEAT TRANSFER IN PASTEURIZATION AND STERILIZATION

New advances in continuous cooking and high-heat, short-time process methods hinge on successful heat transfer . . . .

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THE APPLICATION of heat to pasteurize or sterilize food products is one of the most important operations in the processing of agricultural products. The food industry is continually on the lookout for new equipment and procedures that will permit them to produce higher quality products at lower cost. The trend in all heat processes is toward more rapid heating and cooling, higher temperatures with correspondingly shorter processing times, and continuous methods to replace batch operations.

When a product is sterilized, it is free of viable microorganisms. Pasteurization on the other hand is a less severe heat process designed to reduce the microbiological population, but does not render the product sterile. Pasteurization is generally carried out at temperatures of 212 deg. F. or below. Food products are pasteurized or sterilized to be made safe from a public health standpoint, and to prevent spoilage. Milk is heat-processed or pasteurized to be made free of pathogenic organisms. The heat process reduces the general bacterial population, giving the product a much longer storage life than the raw product.

In canned food *Clostridium botulinum*, an anaerobic sporeforming organism, can produce a potent toxin that is likely to be fatal if present in the food. All recommended process times for canned foods should be adequate to destroy this organism. In general a sterilization process sufficient to destroy all other spoilage organisms will also free the product from *Clostridium botulinum*. A properly sterilized canned food will be preserved indefinitely.

The pasteurization or sterilization of a food product can cause quality changes that may render the product unsalable. Milk that is over-pasteurized has a cooked flavor. Canned foods may lose color, flavor, and essential nutrients during heat processing; the total quality loss is a function of the time and temperature of the cook. The effect of temperature on reactions that produce quality deterioration is not the same as the effect of temperature on the rate of destruction of bacterial spores. In Fig. 1 a thermal destruction curve for thiamine, a heat labile nutrient used as an index of quality loss, is compared with a curve for Putrefactive Anaerobe No. 3679, a heat resistant sporeforming spoilage organism. D values represent the time for 90 per cent destruction at a given temperature. The quality loss for a given amount of bacterial destruction decreases with increasing temperatures. High temperature sterilization with appropriately shorter holding time produces a higher quality product.

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The time required to reduce the number of organisms present in a food by a given amount decreases as the processing temperature increases. The public health regulation for milk pasteurization, 30 minutes at 143 deg. F. or 15 seconds at 161 deg. F., is an example of how the rate of destruction of bacteria increases with temperature. The term describing the temperature characteristics of an organism is "z value", which is the number of degrees Fahrenheit for the thermal death time curve to traverse one log cycle. It is generally believed that the rate at which bacteria are destroyed is logarithmic. This has practical significance in that a product with a high bacteria count would require a longer process than a product with a low count. Theoretically it is impossible to sterilize a product completely since an infinite time would be required to destroy all microorganisms. In commercial sterilization, the number of organisms present after processing is very low. Stumbo (6) suggests that the probability of survival should be in the range of one in a billion. The temperature coefficient (z) and the rate of destruction D (time

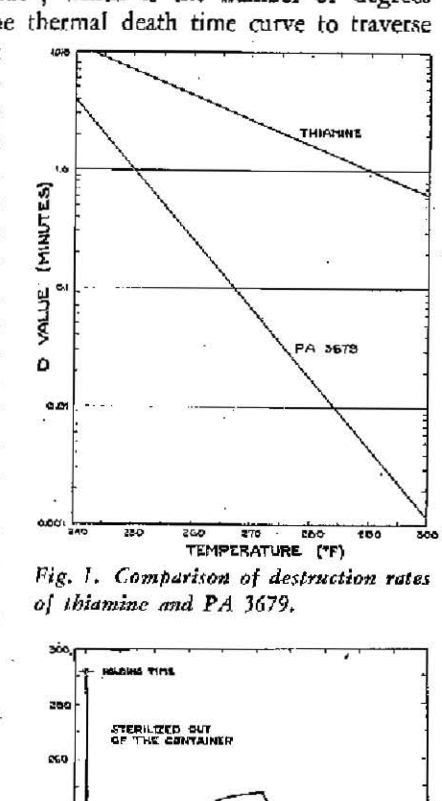


Fig. 1. Comparison of destruction rates of thiamine and PA 3679.

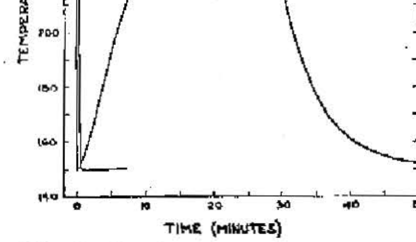


Fig. 2. Heating and cooling curves of a food pre-sterilized at 290 deg. F. compared with in-container sterilization at 250 deg. F.

Pfaudler Co.

Fig. 3. Sanitary tubular heat exchanger.

for 90 percent reduction in numbers of organisms) varies for different organisms and for the same organism in different food products.

The resistance of bacteria to heat is greatly affected by the pH value or acidity of the food product. Canned foods are usually classified according to their pH into (1) acid foods, those with a pH below 4.5 and (2) low acid foods, pH above 4.5. Acid foods can be sterilized effectively by processes at 212 deg. F., but low acid foods must be processed at higher temperatures.

The method of sterilizing or pasteurizing the food product will influence the process time. Low acid foods of pumpable consistency may be rapidly heated in a heat exchanger, then held in a tube until sterilization is complete and finally cooled and filled into sterile containers under aseptic conditions. Acid foods such as fruit juices may be pasteurized by heating in a heat exchanger, holding in a tube or vat until sterilization is complete and then filling the containers with the hot product. In this method the container is sterilized by the hot product.

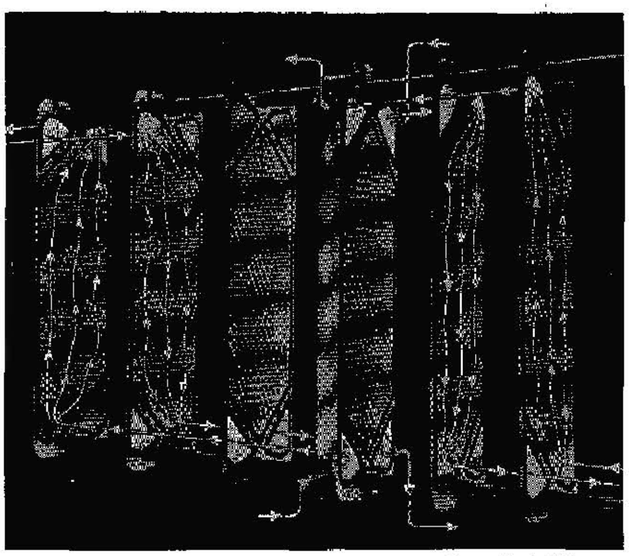
Many foods are placed in the container before they are sterilized or pasteurized. The rate of heating of a filled container depends upon its size and shape, the heating medium, the equipment for heating, and the physical characteristics of the food. Most foods can be classified into one of three categories according to heating characteristics: (1) the product is a liquid or contains free liquid and heats by convection, (2) the product contains starch or exhibits thixotropic characteristics (heats initially by convection but later changes to conduction), and (3) the product heats by conduction only.

Although a great deal is known about the mechanics of heating containers of food, the rate of heating of a product is determined experimentally. Rate of heating data are obtained by locating a thermocouple in the container at the zone of slowest heating (usually called the cold zone) and then by measuring the temperature at regular intervals during the processing cycle. A time-temperature curve can be plotted from the data obtained.

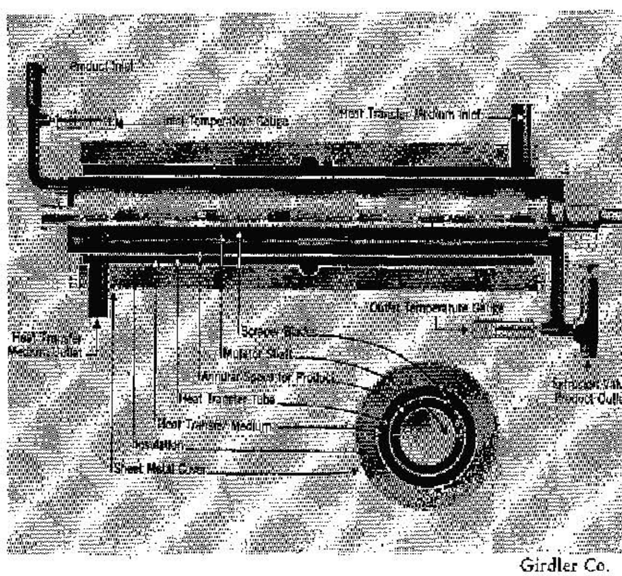
The thermal resistance characteristics of the spoilage organism in the particular food product and the time-temperature heating curve for the food product in the container are necessary to calculate a process time. Process times for food products sterilized or pasteurized in the container are made adequate for the slowest heating or cold zone in the container. The destruction rate characteristics of the organism that the process is designed to destroy and the heating rate data may be integrated in order to arrive at the desired process time. Bigelow (2) originated a graphical method for the solution of this problem, and Ball (1) originated the mathematical method. Olson and Stevens (5) designed a nomograph for the solution of this problem.

The difference between in-container and pre-sterilization (sterilization prior to filling in sterile container) is primarily in the rate of heating and cooling which has a limiting effect on the processing temperature. The processing temperature for products sterilized in the container is usually 250 deg. F. or below. Products may be heated to 300 deg. F. in continuous heat exchangers. In Fig. 2 time-temperature curves are illustrated of equivalent in-container and pre-sterilization processes for the same food product.

Equipment for the high temperature sterilization and aseptic canning of pumpable low acid foods, as exempli-



Cherry Burrell Corp.

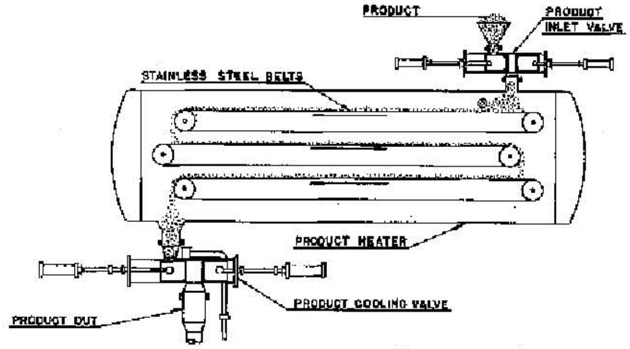


Girdler Co.

Fig. 4 (left) plate heat exchanger showing product and heating medium paths and Fig. 5, sectional view of scraped surface type.

fied by the Martin aseptic canning system, has been developed. (GP, Feb. '53). Such products as soups, juice, fluid milk, and corn have been processed by this method.

A program for the commercial adaptation of the Martin system for glass containers is being carried on by the Glass Container Manufacturers Institute and the James Dole Engineering Co. The initial unit for applying this system to glass is expected to be in commercial use later this year. Food products processed in this manner lose very little of their initial quality. The trend in the industry appears to be directed toward the newer canning methods that utilize higher processing temperatures and continuous handling methods.



H. L. Smith and C. O. Ball

Fig. 6. Diagram of belt cooking unit.

Heat Transfer Equipment

General types of heat transfer equipment in use in the food processing industry are:

A. Heat exchangers for pre-sterilization:
  1. Conventional tubular heat exchangers
  2. The plate heat exchanger
  3. Scraped surface type heat exchangers
  4. Belt cooker for viscous foods

B. Heat exchangers for in-container sterilization:
  1. Vertical and horizontal retorts
  2. Agitating-type retorts
  3. Spray-type heaters and coolers.
  4. Liquid or vapor bath heaters and coolers

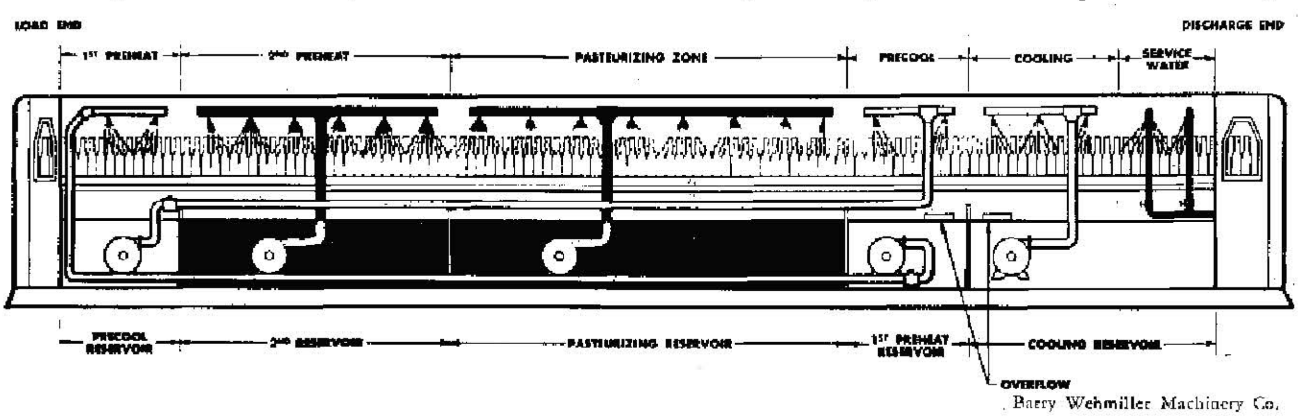
The conventional tubular heat exchanger consists of one or more small tubes inside a larger tube. The food product flows through the small tubes, while the heating medium surrounds the outside of the tube or tubes and is contained by the outside tube or jacket. When a true tube within a tube heater is used, the heating medium and product flow counter-currently.

Many of the tubular heaters manufactured today, an example of which is shown in Fig. 3, contain four or more tubes inside the jacket, and the product that is being heated or cooled passes through the heater a number of times. Flow through the heater is directed by returns milled in the heads or by special directing grids or gaskets. The heads can be quickly opened for inspection and cleaning. All parts in contact with the food product are of stainless steel. Steam is usually the heating medium when these units serve as heaters; and either sweet water or direct expansion ammonia or freon, when the units serve as coolers. In general there is no limit to the maximum temperature to which a product can be heated in this type of equipment, provided the steam jacket and tubes will withstand the necessary pressures.

The plate heat exchanger is very important to the food industry in general and it is the heart of the "high short" milk pasteurizer. The heat exchanger is made up of formed stainless steel plates. Between the plates is a gasket that prevents leakage and serves to direct flow. The plates contain inlet and outlet ports for both the product and heating medium, as illustrated in Fig. 4. The heating medium is directed in a counter current pattern to the material being heated. After each use both the product side and heating medium side of the plate can be thoroughly cleaned. Since both sides of the heat exchanger are sanitary, the hot pasteurized milk can be used to heat the cold raw incoming milk. This portion of the high-short unit is called the regeneration section and reduces the steam or heat requirements of the operation by about 75 per cent.

The plate heat exchanger is a very compact unit when physical size is compared to the square feet of heat transfer area. With this type unit plates can be added or removed to vary the heat transfer area, also the length of time the product is in the heat exchanger can be controlled by varying the number of parallel paths.

The maximum temperatures attainable in the plate heat exchanger are limited by the gasket material and the pressure the gaskets will stand without rupture. The dairy type unit is usually limited to temperatures below 212 deg. F. Plate heat exchangers are available that can be used to heat liquid food products to temperatures of 280 deg. F. The heating medium is water with the water temperatures maintained by the addition of steam in the heating water surge tank. When the plate heat exchanger



Barry Wehmiller Machinery Co.

Fig. 7. Cross-section view of a spray pasteurizer showing path of containers through treatment sections and water transfer.

is used for cooling, sweet water or brine is the refrigerant.

The scraping type heat exchanger (Fig. 5) was first used for the continuous freezing of ice cream where the scraping action was necessary to obtain high heat transfer rates after freezing started. The heat transfer in a viscous product not agitated is primarily by conduction. The product next to the heating medium surface is quickly heated, but the temperature gradient drops rapidly because of the low thermal conductivity and high heat capacity of the product mass. By mechanically scraping the surface and by mixing the product at the same time, the effect of thermal conductivity of the product is overcome, and a rate of heat transfer is obtained that is limited primarily by the resistance of the heat transfer surface and the convection coefficient of the heating medium.

The scraping type heat exchanger is ideal for heating purees, puddings, and soups up to the sterilization temperatures in a single pass. In this unit the ratio of heat exchange area to volume is high, and the quantity of product in the heat exchanger is small; therefore, the time of heating is very short. This type of heat exchanger is being used to heat and cool products prior to aseptic canning. Many near-liquid foods that normally suffer severe quality loss during in-can sterilization can be processed with little flavor change by this method.

The belt cooker (Fig. 6) is a recent inovation that makes possible the heating and subsequent sterilization of food products that cannot be pumped. This apparatus is simple in principle and operation and has made possible continuous pre-sterilization of nonflowing conduction heating, food products. The entire conveying unit can be rolled out of the pressure chamber for cleaning and inspection.

The vertical or horizontal retort is still standard in many plants where the food products are pasteurized or sterilized in the container. These retorts or autoclaves are primarily used for sterilizing food products at temperatures up to 250 deg. F. Loading and unloading these units is a batch operation, and in many cases they are still manually controlled. It is possible to control vertical or horizontal retorts by instruments so that the entire cook is carried on automatically. This type of operation produces a more uniform product at a lower cost.

Much Recent Retort Design Work Done

When food products heat completely or partly by conduction, the process times necessary to sterilize the cold zone in the container are much longer than the requirements at the surface of the can and result in severe overcooking of this part of the product. A great deal of work has been carried on in designing retorts that would induce convection currents into these slower heating products and thereby produce a better quality product. At the present time there are several designs of agitating-type retorts available.

The continuous agitating retort is being used in a number of large canneries. This type unit has a rotating inner cylinder and a helical can track around the periphery of the retort. The containers of food enter the retort through a star valve, are rolled and carried around the track, which induces rapid heating, and are valved out as they reach the other end of the unit. It is usually necessary to cool the containers under air pressure in a second unit to prevent buckling of cans.

An agitating retort using end-over-end agitation, as proposed by Clifcorn (3), makes possible the processing of viscous semi-liquid products in the larger can sizes without overcooking. Heating is speeded in this unit by rotating the basket at a speed that will cause the head-space bubble to cross the center of the container, heating and mixing the product as it proceeds.

Zoned Pasteurizers Cut Shock to Glass

When cans, jars, or bottles are to be pasteurized, it is often practical to use a spray pasteurizer (Fig. 7), which is a water-spray-type heater and cooler combination. This apparatus may be as much as 120 ft. long and up to 10 ft. in width with a conveyor system to move the cans, bottles, or jars through the unit at a relatively slow rate. Water sprays are located above the conveyor with the temperature controlled water reservoirs located below the conveyor. The containers of food go in one end, proceed slowly through the apparatus, and leave at the opposite end. The water sprays in this type pasteurizer may operate at three to five different temperature levels. In proceeding through the pasteurizer, the product goes through a first preheat zone, a second preheat zone, and then into the pasteurizing zone. After the containers are pasteurized, or have reached the pasteurization temperature, they go through a pre-cooling zone and are finally cooled by a cold water spray. The purpose of the different zones in the pasteurizer are to keep thermal shock to a minimum when glass containers are used and to obtain uniform heating. This type of apparatus is used extensively for pasteurizing processed dill pickles, and beer.

Many food plants employ the water spray principle in continuous cooling methods. A majority of these units, designed and constructed by the engineering or maintenance department of the food plant, are ingenious in their design and effective in their operation. In the majority of these units some method is used for agitating or spinning the containers under cold water sprays.

Acid foods are often processed in boiling water. The water may be heated by a steam coil in the bottom of the tank or steam may be injected directly into the water. For batch operation the filled container is packed in crates and immersed in the bath for the desired length of time. The crate is then cooled by placing it in a tank or cooling canal of cold water. Continuous water bath pasteurizers utilize a belt conveyor that moves the product through the controlled temperature water bath. In many plants the containers are cooled in a continuous water bath cooler.

A patent (4) was recently issued for the continuous processing of food products by carrying them through an oil bath at temperatures of 250 to 300 deg. F. The bath is at atmospheric pressure. After sterilizing, the containers are thoroughly sprayed to remove any oil adhering to the containers and are then cooled. This process is particularly suitable for processing the smaller sizes of cans that will not buckle under this type of process. Organic solvents that have boiling points between 250 and 300 deg. F. can be used in this type equipment. In general these compounds are easier to remove from the can and have better heat transfer characteristics than oil.

From the foregoing discussion it is obvious that the application of heat transfer and engineering principles play an important role in the successful thermal processing of foods. With the advent of high temperature short-time sterilization and aseptic canning methods the application of such basic principles are of particular significance.

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