THERMAL PROCESSING

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Summary

This article presents thermal processing as a preservation method. The main focus is on the pasteurization, blanching, sterilization, cooking, frying and applications of electro-technology. A summary is given on the mode of preservation, processing equipments used, and how to maintain food's quality when heating process is applied.

1. Introduction

The term *thermal processing* is used in a general sense and relates to the determination of heating conditions required to produce microbiologically safe products of acceptable eating quality. Thermal processes generally involve heating of foods for a specific period at a predetermined temperature to kill microorganisms of public health concern, and deactivate enzymes that cause deterioration of the food during storage. Nicholas Appert, in 1809, was awarded a prize by the French government for developing a new method for heat preservation of food. The method has since been recognized as appertization (named after Appert), sterilization, or more commonly, canning. Although the method was successful in producing shelf-stable foods that did not undergo spoilage, the scientific basis for preservation was not really known until almost half a century later when another Frenchman, Louis Pasteur, discovered that food spoilage was caused by microorganisms, which are destroyed at elevated temperatures. The technique that bears his name, pasteurization, as we know it today, refers to a relatively mild heat treatment, intended for destroying pathogenic microorganisms in foods, providing short-term extension of shelf life under refrigerated conditions. The original concept of in-container sterilization of foods has gone through a tremendous transformation with respect to processing and packaging. A range of different thermal processes is now employed in the food industry. A variety of packaging materials are used, not just tin-plate, aluminum and glass, but also rigid and semi-rigid plastic materials formed into the shape of cans, pouches, laminated packages, and bottles. The products known originally as canned or bottled products are now referred to as heat-preserved foods or thermally processed foods. Process here is a time-temperature schedule, referring to the *temperature* of a heating medium and the *time* for which it is sustained.

The five main stages in the thermal processing are:

- selection and preparation of suitable foods,
- packing the product in hermetically seal-able containers followed by exhausting, to remove air, and sealing,
- stabilizing the food by heat (while at the same time achieving the correct degree of cooking), followed by cooling to below 38 ^{o}C,
- storing at a suitable temperature below 35 ^{o}C to prevent the growth of food spoilage organisms,
- labeling, secondary packaging, distribution, marketing and consumption.

The primary reason for exhausting and vacuuming operations is to create an anaerobic environment in the can, which would inhibit microbial spoilage. Mechanical exhausting is a means of exposing filled containers of food to heat, generally steam, to drive the air out of the container and remove the occluded air from the product to assist in creating a vacuum in the container after it is closed or sealed. Mechanical vacuuming of food containers is a method of withdrawing a vacuum, by mechanical means, from the container and the food prior to closing, to aid in creating a vacuum in the container.

2. Pasteurization

2.1. Mode of preservation

Pasteurization, a mild heat treatment, is applied to foods with the purpose of destroying selected vegetative microorganisms and inactivating the enzymes that cause spoilage with minimal changes in desired food properties. The process does not destroy all vegetative microbial populations, and thus pasteurized food products must be stored under conditions, such as refrigeration, with additives or under modified atmosphere, with pH control.

2.2. Processing conditions

Pasteurization temperature usually varies from 60 to 90 ^oC for a specified time. The higher the temperature, the lower the processing time required. Fruit juices contain enzymes, such as catalase, peroxidase, polyphenol oxidase, pectin esterase etc, which are capable of changing the characteristics of the product. The minimum processing conditions to inactivate enzymes for the purpose of pasteurization of fruit juices are: 30 minutes at 65 ^oC or 1 minute at 77 ^oC, or 15 seconds at 88 ^oC. Juices of high acidity (i.e. low pH) may be pasteurized at lower temperatures (60 to 65 ^oC). The purpose of pasteurization of carbonated juices is to destroy yeasts and molds. Heating at 60 to 65 ^oC kills yeast, and the resistant mold spores in most cases need a temperature of 80^oC for 20 minutes. But molds require oxygen for growth and for this reason heavily carbonated juice can be pasteurized safely at 65 ^oC, which destroy yeast cells. For the purpose of milk pasteurization (pH>4.5), destruction of pathogens such as *Brucella microabortis* and *Mycobacterium tuberculosis* is achieved by processing milk at 71.5 ^oC for 15 seconds or at 63 ^oC for 30 minutes (Fellows, 1988).

Pasteurization of liquid foods is carried out in-package or prior to packaging. The latter method is good for foods that are sensitive to temperature. The process of pasteurization can be achieved in batch or continuous mode. Batch pasteurization uses lower temperature and longer process time. A batch pasteurizer consists of a steam-jacketed kettle or tank equipped with steam coils in which the juice or milk is heated to the desired temperature. Continuous pasteurization uses higher temperatures and shorter process times. Depending upon the viscosity of fluid food, it is common to use plate, tubular, scraped surface heat exchangers.

2.3. Processing equipment

2.3.1. Packaged liquids

In-container processing is applied to several liquid food products such as beer and fruit juices. Hot water processing is normally used for glass containers to reduce any damage due to thermal shocks. The container is then cooled to 40 ^oC, which also facilitates evaporation of the surface water. This also minimizes external corrosion of metal containers or caps and accelerates the setting of adhesives used in labels.

Hot water bath
A hot water bath is one of the simplest methods of heating for pasteurization of in-container liquid food products. The water bath may be either a rectangular steel tank or a vertical retort. Food containers are arranged in retort crates or in racks and immersed in the bath for predetermined times. Cooling may be carried out in the same tank used for heating, or the containers may be transferred from the heating tank to a cooling tank. A continuous water bath system is an improvement over batch operation. In these systems a conveyor belt with containers on it moves through the tank at a selected speed to provide adequate time in the bath to accomplish pasteurization. The tank is sometimes divided into sections controlled individually at different temperatures.

Steam or water spray system
The water spray system is extensively used for pasteurization of beer and acidic food products. In this type of system, containers are conveyed through the different temperature zones or sections of the pasteurizer to obtain maximum efficiency. These zones are normally first preheat, second preheat, pasteurizing zone, precool, cooling, and final cooling zone. Water spay units are designed so that the water in the first preheat zone drains off the containers in the precool zone, and the water that is sprayed in the precool zone is used in the first preheat zone. In this way a considerable amount of heat is recovered and reused and a reduced amount of cooling water is required. Precautions are taken to avoid thermal shocks to glass containers during heating and cooling. During heating the temperature difference between the heating medium and containers are kept below 21 ^{o}C and under no condition to exceed 38 ^{o}C. Temperatures are more critical during cooling of the glass containers. A temperature difference of 10 ^{o}C is a desirable maximum and under no conditions should it exceed 21 ^{o}C.

Steam tunnels
In this type of system liquid food containers are conveyed through a steam tunnel open at both ends. Cloth baffles are hung between sections but these are not adequate to hold steam in the pasteurizer against strong air currents. The heat transfer rates from steam to the containers depend upon steam temperature and velocity. Air and steam mixtures of different ratio are used to obtain different temperature zones. The cooling is achieved by spraying cold water over the containers. Steam tunnels have the advantages of faster heating, giving shorter residence time, and compact equipment.

2.3.2. Unpackaged liquids

Batch systems
In these systems, a vat or a tank-type heat exchanger is used for pasteurization. The raw liquid product is pumped into the tank, heated to the pasteurization temperature, held for a predetermined time, and pumped out from the tank to cooling equipment. In the case of dairy products, such as milk, the heating medium temperature is only few degrees higher than the milk to reduce fouling of the tank inner surfaces. These tanks are most suitable for small plants and low-volume products. They can handle a variety of products with a wide range of physical characteristics such as buttermilk, sour cream

etc. Tank pasteurization is normally a batch operation and is inherently slow. The recovery of heat is also difficult hence both the heating and cooling process is relatively expensive.

Continuous systems

A number of heat exchangers of different configurations such as plate, tubular and scraped surface are utilized commercially for continuous pasteurization of liquid food products. The continuous systems have several advantages over batch systems: (a) more uniform heat treatment, (b) simpler equipment and lower maintenance costs, (c) reduced space requirements and labor costs, (d) greater flexibility for different products, and (e) greater control over pasteurizing conditions. The holding time of liquid in the heat exchanger is synchronized with its flow rates. The flow rate is regulated by a metering or timing pump. A positive displacement pump of the rotary or piston type is used.

The plate heat exchanger consists of a series of thin vertical stainless steel plates. The plates form parallel channels held tightly together in a metal frame and separated by rubber gaskets to produce a watertight seal. The plates are some time corrugated to induce turbulence for a high heat transfer rate. Adjusting the number of plates can easily vary the capacity of this type of heat exchanger. Generally less viscous liquids are pasteurized by plate heat exchangers. The concentric tube heat exchangers are more suitable for high solids and more viscous products such as dairy products, mayonnaise, tomato ketchup, and baby food. It consists of a number of concentric stainless steel coils, each made from double or triple walled tube. Food passes through the tube, and a heating and cooling medium is recirculated through the tube walls. Liquid food is passed from one coil to the next for heating and cooling, and the heat is regenerated to reduce energy cost. Scraped surface heat exchanger consists of a central rotating shaft carrying a scraping device for the heated surfaces. This prevents burning and fouling of foods at the surface and also provides a mixing action. The system is more suitable for viscous materials.

2.4. Quality

The nutritional and sensory qualities of most liquid foods are only slightly affected by pasteurization, but the product quality continues to change (deteriorate) during storage. The shelf life depends on the packaging of the pasteurized product and storage conditions. The change of juice color due of pasteurization is minimal—the main cause of color change in fruit juices is enzymatic browning by polyphenol oxidase. This is caused by the presence of oxygen, and fruit juices are therefore routinely deaerated prior to pasteurization.

The difference in color of raw milk and pasteurized milk is due to homogenization. Fat-soluble vitamins A, D, E, and K are relatively less sensitive to heat, and generally there are no losses of these vitamins during pasteurization of milk. Small losses of volatile aroma compounds occur during the mild heat treatment of pasteurization. The haylike aroma from raw milk is generally lost during pasteurization, resulting in a relatively bland product. Other pigments, such as those in plant and animal products, are also unaffected by pasteurization. There is loss of some vitamin C and carotene in fruit juices, but this loss is minimized by deaeration. In milk, thiamine and vitamin C losses are between 10 to 20%. In acidic conditions heat-labile nutrients are relatively stable. Liquid foods such as beer and wines are also deaerated prior to pasteurization in order to reduce oxidative losses.

3. Blanching

3.1. Mode of action

Blanching is a mild heat treatment used to inactivate the oxidative enzymes in fruit and vegetables, given prior to further processing (i.e. canning, freezing, and dehydration), which would otherwise result in undesirable changes in color, flavor, texture, and nutritive value of the product after processing. Other advantages are:

- removal of non-condensable tissue gases (which in turn helps to achieve better vacuum in cans, reduces the load on the can sealing machine and results in reduced oxygen levels in the cans),
- preheating of the product, if the product is further processed, e.g. canning,
- reduction of the microbial load in the products, and
- softening the tissue to facilitate peeling, dicing or packing.

Other pretreatments, such as addition of sulfite or sulfur dioxide, antioxidants, acids, and sugars can also be applied to improve quality attributes of heat-processed products.

3.2. Processing conditions

Of the oxidative enzymes (i.e. peroxidase, catalase, polyphenol oxidase, lipoxigenase, etc.), peroxidase is considered to be most heat resistant. Inactivation of peroxidase has therefore been traditionally used as an index of adequacy of blanching. The blanching time usually depends on the method (water, steam, hot gas, or microwave) and size of the fruit or vegetable, and the temperature. It generally varies from 10 to 30 seconds in the heat shock technique and 1 to 5 minutes in other blanching techniques.

3.3. Processing equipment

Blanching is usually accomplished in equipment especially designed for individual products using hot water or steam. The equipment must be designed to subject the raw materials to a particular temperature range for an optimal period of time. Conventional water blanching has lower capital cost and is energy efficient. However, this method produces a larger volume of effluents. Effluent volume and leaching losses can be significantly reduced with steam blanching when combined with air-cooling. However, uneven blanching can result if the food is blanched in multiplayer piles. This could be avoided by using an innovative process of individual quick blanching (IQB) based on the heat-hold principle. In the first stage of the process, the food product is heated in single layers to a desired temperature and then held in a deep bed for sufficiently long to cause the enzyme inactivation. Some improved blanching equipment makes use of recirculating hot water to improve nutrient retention, reduce leaching losses, and improve energy efficiency. In recent years non-conventional processing methods such as ohmic heating, microwave, and moisturized hot gases combined with air-cooling are being used.

3.4. Quality

Nutrient loss during blanching can occur mainly due to non-thermal effects such as leaching. Water blanching method can result in losses of water-soluble components, including vitamins, minerals, and sugars. Depending on the method and commodity the loss due to blanching can be 40% for minerals and vitamins (especially vitamin C and thiamine), 35% for sugars, and 20% for proteins and amino acids. In the case of vegetables vitamin C losses could be 5 to 39%, vitamin B_1 could be 8 to 62%, vitamin B_2 could be 5 to 25%, and niacin could be 6 to 27%, depending on the types of products. The chemical and physical state of nutrients and vitamins are also changed. On the advantage side some toxic constituents (for examples, nitrates and cadmium in spinach) naturally present in some vegetables may also be leached out. It is important to point that nitrates are also used as preservative although they are toxic to some extent. However the concentration of nitrates must be below its permitted level when used as preservatives. The lethal doses of nitrates in humans vary based on the references, for examples 32 mg/kg body weight or 2 g and 4-6 g (see Rahman, 1999a). Blanching may remove raw flavors from the product. It sets the natural color of certain products under optimal conditions. Although texture degradation is common in most heat treatments, recently low-temperature and long time blanching has been shown to improve the texture of some products (carrots, beans, potato, tomato, and cauliflower) due to activation of pectin methyl esterase.

4. Sterilization

4.1. Canning

4.1.1. Mode of preservation

Canning is a process the primary objective of which is to destroy microorganisms of public health concern and those causing spoilage of food packaged in hermetically sealed containers (cans, jars, or pouches). Sterilization implies the destruction of all viable microorganisms and since foods are far from being sterile, the term ‘commercial sterilization’ is more appropriate for food. In this process foods are exposed to a high enough temperature for a sufficiently long time and packaged with a hermetic seal to prevent recontamination. It also creates an environment in the container that would suppress the growth or activity of spoilage-type microorganisms during storage, by utilizing one or more of the following methods, oxygen removal, pH control, mild preservatives, and control of storage temperature. The presence of vacuum in the package prevents the growth of most aerobic microorganisms and if the storage temperature is around room temperature (~25 ^{o}C), the heat resistant thermophilies pose little or no problem. From the public health perspective the most important microorganism in low acid (pH>4.5) foods is *Clostridium botulinum*, a heat resistant, spore-forming, anaerobic pathogen. Commercial sterile foods are stable at ambient-temperature and could be stored for about two years. For low-acid foods the aim is to attain a probability of spore survival of one in 10^{12} or better. This corresponds to a 12D process and is known as a minimum process. Processes established on this basis do not always destroy heat-resistant thermophiles; consequently, a process, which deals adequately with pathogenic organisms is called a commercial process and the operation of applying the process is called commercial sterilization. These processes are adequate provided the cans are stored at temperatures below 35 ^{o}C, since above this temperature residual thermophiles may grow and produce a spoiled can. Cans destined for hot climates may require enhanced processes. The heat resistance depends on the species, environmental conditions in forming cells or spores, and environmental conditions during heating (i.e. pH, water activity, oxygen level, solutes, preservatives, oils and lipids, ionic species). In order to determine the extend of heat treatment, several factors must be known: type and heat resistance of the target microorganism, spore, or enzyme present in food, pH of food, storage conditions, heating conditions, thermophysical properties of food, and container size and shape.

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Biographical Sketches

Mohammad Shafiur Rahman is an Associate Professor at the Sultan Qaboos University, Sultanate of Oman. The author or co-author of over 150 technical articles including 54 refereed journal papers, 49 conference papers, 30 reports, 5 popular articles and 2 books. The author of the internationally acclaimed and award winning Food Properties Handbook published by CRC Press, Boca Raton, Florida, which received one of the bestsellers from CRC press in 2002. He is Editor of the Handbook of Food Preservation published by Marcel Dekker, New York, which also secured one of the publisher bestsellers and was translated into Spanish by Acribia, Spain in 2003. Both of the above books are in the process of second edition. He has been invited to serve as one of the Associate Editors for the Handbook of Food Science, and one of the Editors for the Handbook of Food and Bioprocess Modeling Techniques, which will be published by Marcel Dekker, New York. His book Food Properties: Users' Handbook is going to be released soon. Dr. Rahman initiated the International Journal of Food Properties (Marcel Dekker, Inc.) and served as the founding Editor for more than six years. He has served as a member in the Food Engineering Series Editorial Board of Aspen Publishers, Maryland (1999-2003). In 2003 he was invited to serve as a member of the Food Engineering Series Board, Kluwer Academic/Plenum Publishers, New York. He was also invited to serve as a Section Editor for the Sultan Qaboos University journal Agricultural Sciences (1999). In 1998 he was invited to serve as a Food Science Adviser for the International Foundation for Science (IFS) in Sweden. Dr. Rahman is a professional member of the New Zealand Institute of Food Science and Technology and the Institute of Food Technologists, and a member of the American Society of Agricultural Engineers and the American Institute of Chemical Engineers. He received B.Sc. Eng. (Chemical) (1983) and M.Sc. Eng. (Chemical) (1984) degrees from Bangladesh University of Engineering and Technology, Dhaka, an M.Sc. degree (1985) in food engineering from Leeds University, England, and a Ph.D. degree (1992) in food engineering from the University of New South Wales, Sydney, Australia. Dr. Rahman has received numerous awards and fellowships in recognition of research/teaching achievements, including the HortResearch Chairman's Award, the Bilateral Research Activities Program (BRAP) Award, CAMS Outstanding Researcher Award 2003, and the British Council Fellowship.

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