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Thermal Processing of Packaged Foods

Third Edition

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With a contribution by:

Dr. Cristian Ramirez
Associate Researcher
Universidad Técnica Federico Santa María
Chile

Springer

S. Donald Holdsworth
Stretton-on-Fosse
Gloucestershire, UK

Ricardo Simpson
Universidad Técnica Federico Santa María
Valparaíso, Chile

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This book is dedicated to our wives, Margaret and Anita, and family, Christopher, Martin, Giles, Sarah and José Ignacio, María Jesús, and Enrique.

S. Donald Holdsworth and Ricardo Simpson

Foreword

The first edition of this book "*Thermal Processing of Packaged Foods*" was published in 1997, in which Professor D. Holdsworth gave response to a need of understanding *thermal processing* from an engineering point of view, incorporating concepts such as lethality and food quality. In the second edition published in 2007, Professor Holdsworth in collaboration with Professor Ricardo Simpson made an actualization of the book, which included different topics under a renewed vision, especially in those aspects related to process evaluation techniques, engineering aspects, and optimization techniques for thermal processing.

Presently, during 2015 this third edition was totally renewed and updated including new concepts and areas that are relevant for modern thermal food processing. This new edition is acquiesced by 22 chapters—that retain great part of the first and second edition—which are divided into five parts. The first part, entitled "Fundamentals of Thermal Food Processing," includes five chapters where different topics associated with heat transfer mechanisms, kinetics of microbial death, sterilization criteria, and safety aspects of thermal processing are analyzed. The second part, entitled "Thermal Food Process Evaluation Techniques," includes six chapters, in which Chap. 7 deeply analyzes the *General Method* and its application and similarly Chap. 8 analyzes *Formula Methods* and analytical techniques. It is also remarkable the incorporation of new chapters, such as Chap. 11 entitled "Software of Thermal Food Processing Evaluation and Optimization," where the development of a new software to optimize and estimate the thermal processing time is presented, including a downloadable file. Part III, entitled "Engineering Aspects of Thermal Food Processing," comprises six chapters where subjects related to pressure buildup in containers, simultaneous sterilization, and thermal food processing equipment, amongst other, are presented. Part IV, "Mathematical Modeling, Simulation, Optimization, Control, and Automation," includes four chapters, of which both Chap. 18, dedicated to computational fluid dynamics as a tool for thermal food processing modeling, and Chap. 20, which incorporates the use of multiobjective optimization in thermal food processing, are totally new.

Finally, Part V, entitled “Innovative Thermal Food Processing,” includes a chapter focused on two innovative processes used for food sterilization, such as combination of High Pressure and High Temperature sterilization and the application of Ohmic Heating. Both methods are applied to reduce the process time and the effect of temperature on food quality factors.

It is a great pleasure to have the third edition of *Thermal Processing of Packaged Foods*. I strongly believe that this book will be useful for academics, researchers, engineers, and students that are involved in this thrilling world of thermal food processing.

Valparaíso, Chile Sergio Almonacid

Preface (Second Edition)

In this new edition, the historical perspective of the development of thermal processing has been retained and much new additional material has been added. The development of the subject, as indicated by the amount of research that has been done during the last ten years, has been remarkable and shows that the technology is very viable and expanding worldwide.

The main developments that have been included are as follows: (a) the increased use of new packaging materials, including retortable pouches and the use of containers made from other plastic composite materials, (b) the application of newer processing methods which use heat transfer media such as hot water, air/steam, and steam/water, which are necessary for the newer forms of packaging material, (c) new methods of theoretically calculating the heat transfer characteristics during processing, including three-dimensional modeling and application of computerized fluid dynamics (CFD) techniques, (d) implications of newer models for microbial destruction, (e) revised techniques for process evaluation using computer models, including CD software, (f) development of process schedules for quality optimization in newer packaging materials, and (g) important new aspects of methods of retort control.

Unlike other texts on thermal processing, which very adequately cover the technology of the subject, the unique emphasis of this text is on processing engineering and its relationship to the safety of the processed products.

The authors hope that they have produced an adequate text for encouraging research workers and professional engineers to advance the operation of the manufacturing processes to ensure the production of high quality products with assured safety.

Stretton-on-Fosse, Gloucestershire, UK — S. Donald Holdsworth
Valparaíso, Chile — Ricardo Simpson

Preface (First Edition)

My credentials for writing this book are three decades of experience in the canning industry, the research that has supported it, and the establishment of a specialized training course on the thermal processing of packaged foods. My first encounter with the industry was to accompany Tom Gillespy around the various factories of the members of Campden Research Association. He took his annual leave for many years visiting the industry and was dedicated to ensuring that the requirements of good manufacturing practice were observed. The occasion on which I accompanied him was his last trip before retirement, and I shall always be grateful to him for the kindly advice he gave me on all aspects of canning and food processing. Nobody could have had a better introduction to the industry. In a small way, this book is an appreciation and a memorial to some of his work. He was greatly respected in academic and industrial circles.

This book is concerned with the physical and engineering aspects of the thermal processing of packaged foods—i.e., the heating and cooling of food products hermetically sealed in containers. The two commonest types of container used for this process are glass bottles and cans, although more recently a variety of plastic containers has been added to the list. The main aim of the book is to examine the methods that have been used to establish the time and temperature of processes suitable to achieve adequate sterilization or pasteurization of the packaged food.

It is written from the point of view of the food process engineer, whose principal role is to design, construct, and operate food processing equipment to produce food of acceptable quality and free from public health hazards. The engineering approach requires a knowledge of the microbiological and physicochemical factors required to solve the necessary equations to establish the safety of the process. In some ways, the canning process is unique, in as much as it requires a mathematical model of the sterilization value to determine the adequacy of the process. Over the last 70 years, a considerable amount of time and energy has been spent around the world on developing suitable mathematical methods to calculate the effectiveness of various processing regimes in order to ensure the safe production of foods. In this book, the various methods and theoretical models on which they are based, for determining adequate times and temperatures for achieving sterility, are discussed and examined.

Most books on canning tend to deal with this subject either by means of a generalized technological description of the process, containers, and products, or from a bacteriological point of view. This book, however, attempts to deal with the more fundamental engineering aspects of the heating and cooling process and the mathematical modeling of the sterilization operation—aspects that are dealt with more briefly elsewhere. Many hundreds of papers have been published on this subject and an untold amount of thermal processing experimental work carried out. Each canning company usually has a person specializing in thermal processing, as well as microbiological laboratory and pilot plant facilities. Much of the academic research work reported is essentially an extension of basic principles and the development of new, and alternative methods of calculation rather than the discovery of new principles. Some of the work makes a critical comparison of various authors' work and assesses the improvements or otherwise that accrue from using a particular method. Some of it uses new mathematical techniques to perform already established methods, while other work analyzes the errors resulting from the use of different methods of heat penetration. The research and development work is important in training people in the principles of one of the best and well-established methods of making shelf-stable food products.

This book will be of interest to technical managers, process engineers, and research workers as a guide to the literature and the principles underlying thermal processing. It will be of use to those in the industry who are concerned with achieving adequate processes as well as to those who are concerned with the development of equipment. It will also act as a guide to those who are concerned with the development of legislation and help them to assess the realities of whatever they wish to impose on the manufacturing industry. Finally, it is hoped that this book will inspire and enthuse research workers to even greater endeavors in this area.

I am most grateful for advice and help from former colleagues and also to many friends throughout the world.

Stretton-on-Fosse, Gloucestershire, UK S. Donald Holdsworth

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Introduction

1.1 Thermal Processing Principles

1.1.1 Thermal Processing

A generation ago the title of this book would have contained such terms as *canning*, *bottling*, *sterilization*, and heat *preservation*; however, with the passage of time it has become necessary to use a more general title. The term *thermal processing* is used here in a general sense and relates to the determination of heating conditions required to produce microbiologically safe products of acceptable eating quality. It conveys the essential point that this book is concerned with the heating and cooling of packaged food products. The only attempt to produce a generic title has been due to Bitting (1937), who used the term *appertizing*, after the process developed and commercialized by Nicholas Appert (1810) to describe the canning and bottling process. Despite the need for a generic term, rather surprisingly, this has never been used to any great extent in the technical press (Larousse 1991).

The phrase *packaged foods* is also used in a general sense, and we shall be concerned with a variety of packaging materials, not just tin-plate, aluminum, and glass, but also rigid and semirigid plastic materials formed into the shape of cans, pouches, and bottles. The products known originally as canned or bottled products are now referred to as heat-preserved foods or thermally processed foods.

Thermal Processing is part of a much wider field—that of industrial sterilization—which includes medical and pharmaceutical applications. Those concerned with these subjects will find that much of the information in this book will apply directly to their technologies.

S.D. Holdsworth, R. Simpson, *Thermal Processing of Packaged Foods*,
Food Engineering Series, DOI 10.1007/978-3-319-24904-9_1

1.1.2 The Process

It is necessary to define the word *process*. Generally in engineering, a process is defined as the sequence of events and equipment required to produce a product. Here, however, *process* is a time–temperature schedule, referring to the *temperature* of the heating medium (condensing steam) and the *time* for which it is sustained. Tables of processing schedules are available: In the USA, the National Food Processors' Association produces guides (e.g., NFPA 1996; GMA 2007). In France such schedules are referred to as *Barèmes de Sterilization* (e.g., Institut Appert 1979). In the UK various guidelines are available from Campden BRI, which are discussed in later chapters of this text.

1.2 Canning Operations

1.2.1 General

Figure 1.1 *Illustrates the canning process which consists of five main stages*:

Stage 1. Selecting suitable foods, taking them in prime condition at optimum maturity, if appropriate, followed by preparation of the foods as cleanly, rapidly, and perfectly as possible with the least damage and loss with regard to the economy of the operation.

Stage 2. Packing the product in hermetically sealable containers—together with appropriate technological aids—followed by removing the air and sealing the containers.

Stage 3. Stabilizing the food by heat, while at the same time achieving the correct degree of sterilization, followed by cooling to below 38 °C.

Stage 4. Storing at a suitable temperature (below) 35 °C to prevent the growth of food spoilage organisms

Stage 5. Labeling, secondary packaging, distribution, marketing, and consumption

The instability of foods at the time they are sealed in containers is due to the presence of living organisms that, if not destroyed, will multiply and produce enzymes that will decompose the food and in some cases produce food-poisoning toxins. Stability, i.e., the production of shelf-stable products, is attained by the application of heat, which will kill all the necessary organisms (For further details, see Sect. 3.2.1). Of the above listed operations only the stabilization operation, Stage 3, commonly known as processing, will be covered in this text. The technological aspects of the subject are well covered by many texts, among them Downing (2013), Jackson and Shinn (1979), Hersom and Hulland (1980), Lopez (1987), Rees and Bettison (1991), and Footitt and Lewis (1995). Most of these texts do not elaborate on the subject of this book, which is dealt with only in the classical works of Ball and Olson (1957) and Stumbo (1973), as well as in the individual

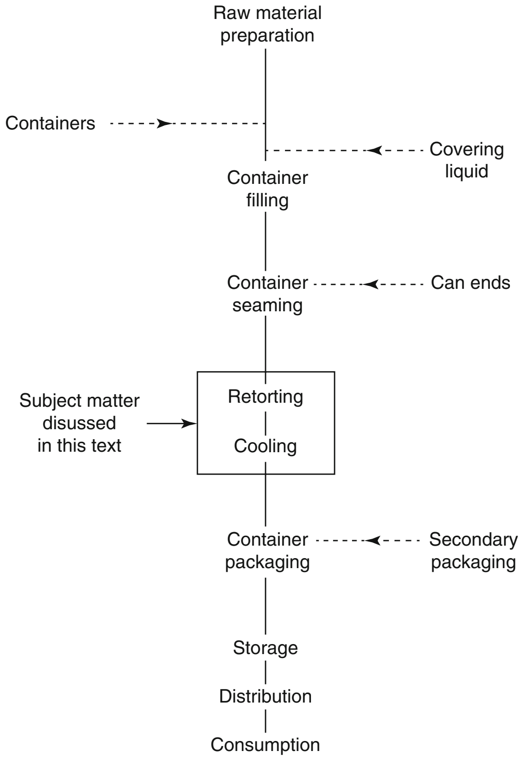

Fig. 1.1 General Simplified flow diagram for a canning line

specialized texts (Pflug 1982) and other publications from the various food processing centers. A particular important basic text, used in training courses, has been published by Tucker and Featherstone (2010).

1.2.2 Methods of Processing

The most widely used systems are vertical batch retorts, with a lid at the top, which are cylindrical pressure vessels operating at temperatures usually between 100 and 140 °C. The sequence of operations consists of putting the cans in baskets, placing them in the retort and closing the lid. Steam is then introduced, leaving the vent valve open, so that the air in the retort can be suitably expelled, thereby leaving an atmosphere of almost pure steam. When the processing temperature has been reached the vent is closed and the temperature maintained for the appropriate time dictated by the given *process*. After the time and temperature requirements have been achieved, cooling water is introduced while maintaining the pressure in the retort using air. Pressurized cooling of this type is required for larger-sized cans so that the pressure differential on the cans is reduced slowly in order not to cause irreversible can deformation. When the pressure has been reduced to atmospheric and the cans sufficiently cooled, the retort is opened and the cans removed. The subsequent operations involve drying, labeling and packaging the cans in the required manner for marketing.

Modifications to the above processing are the use of hot water made by steam injection, either in the retort or externally, and the use of air–steam mixtures for processing retortable pouches of food.

Batch retorts also come in a horizontal format with either square or circular cross-sections, with trolleys on wheels for handling the baskets. Some retorts also have facilities for internal rotation of the cans, or external rotation by end-over-end motion of the retort.

High-speed continuous retorts are now widely used in modern production. There are two main types. With *rotary sterilizers*, the cans pass through mechanical valves into a horizontal, cylindrical steam chamber and rotate around the periphery of the shell. Special pressure valves allow the passage of the heated cans into the cooling shell prior to discharge. *Hydrostatic cookers* are valveless sterilizers in which the pressure in the vertical steam chamber is balanced by water legs of appropriate height to match the temperature of the processing steam. The cans are conveyed through the system on horizontal carrier bars, which pass vertically upwards through the preheating leg and vertically downwards through the precooling section. Various different types are available, including facilities for rotating cans in the carrier bar system. Details of the heat transfer in these cookers, and the achievement of the correct processes, are given in Chap. 17.

1.3 Packaging Materials

1.3.1 Introduction

The packaging material and its ability to prevent recontamination (*integrity*) are of paramount importance to the canning industry. A large number of spoilage incidents have been attributed to leaker spoilage, subsequent to processing, due to incorrect sealing or the use of unchlorinated water for cooling the cans. The use of the double-seaming technique and can-lid-lining compounds has been effective in reducing leaker spoilage.

1.3.2 Metal Containers

Cylindrical cans made of metal are the most widely used and in the highest production world-wide. Containers made of tin-plated steel are widely used, although lacquered tin-free steels are gradually replacing them. Aluminum cans, and also thin steel cans with easily opened ends, are widely used for beer and beverage packing. The standard hermetically sealable can, also known as a sanitary can in some countries, has various geometries and consists of a flanged body with one or two seamable ends. In the three-piece version one of the ends is usually—but not always—seamed to the body, and the other is seamed after filling. In the two-piece version, which has steadily increased in use, the body is punched out or drawn in such a way that only one flange and lid are necessary. Cans are usually internally lacquered to prevent corrosion of the body and metal pick-up in the products.

Full details of the fabrication of containers are given in Rees and Bettison (1991) and Footitt and Lewis (1995). Some typical container sizes are given in Tables 1.1, 1.2, and 1.3.

Recent developments have reduced the amount of material used in can manufacture, including the necked-in can, which has the advantage of preventing seam-to-seam contact during storage and handling and has cost-saving benefits. New can seam designs—for example the Euroseam and the Kramer seam, which reduce the seam dimensions, especially the length—have been reported (Anon 1994). There is also interest in the design of easy-open ends, especially made of less rigid material such as foil seals (Montanari et al. 1995). Two examples, are the Impress Easy Peel® lid, (Isensee 2004) and the Abre-Facil produced by Rojek of Brazil. The latter is a vacuum seal like a closure for a glass jar (May 2004).

The effect of different types of process, e.g., hydrostatic and reel and spiral pressure cookers on can performance, in terms of can distortion, has been discussed by Pape (2008).

1.3.3 Glass Containers

Glass jars are also widely used for packing foods and beverages. They have the advantages of very low interaction with the contents and visibility of the product. However, they require more careful processing, usually in pressurized hot water, and handling. Various types of seals are available, including venting and non-venting types, in sizes from 30 to 110 mm in diameter, and made of either tin or tin-free steel. It is essential to use the correct overpressure during retorting to prevent the lid being distorted. It is also essential to preheat the jars prior to processing to prevent shock breakage.

1.3.4 Rigid Plastic Containers

The main requirement for a plastic material is that it will withstand the rigors of the heating and cooling process. Again it is necessary to control the overpressure correctly to maintain a balance between the internal pressure developed during

Table 1.1 A guide to UK and US can sizes (1995 revised 2005)

Imperial size[a] (in)	Metric size[b] (mm)	Gross liquid volume (ml)	Common name
Cylindrical cans			
202 × 108	52 × 38	70	70 g tomato paste
202 × 213	52 × 72	140	Baby food
202 × 308	52 × 90	180	6Z (US) or Jitney
202 × 314	52 × 98	192	6 oz juice
202 × 504	52 × 134	250	25 cl juice
211 × 202	65 × 53	155	5 oz
211 × 205	65 × 58	175	6 oz milk
211 × 300	65 × 100	234	8Z Short (US)
211 × 301	65 × 77	235	Buffet or 8 oz picnic
211 × 304	65 × 81	256	8Z Tall (US)
211 × 400	65 × 100	323	No. 1 Picnic (US)
211 × 400	65 × 101	315	Al–10 oz
211 × 414	65 × 124	400	Al tall – 14 oz
			No. 211 Cylinder (US)
300 × 108	73 × 38	125	
300 × 201	73 × 515	185	
300 × 204.5	73× 57.5	213	Nominal ¼ Kg
300 × 207	73 × 61	230	8 T—U8
300 × 213	73 × 71	260	250 g margarine
300 × 303 ½	73 × 82	310	400 g (14 oz) SCM
300 × 401	73 × 103	405	14Z (E1)
300 × 405	73 × 110	425	Nominal ½ kg
300 × 407	73 × 113	449	No. 300 (US)
300 × 408 ¾	73 × 115	445	UT
300 × 410	73 × 118	454	16 oz
300 × 509	73 × 146	572	No. 300 Cylinder (US)
300 × 604	73 × 158	630	
301 × 407[c]	74 × 113	440	
301 × 409	74 × 116	459	No. 1 Tall (UK)
301 × 411	74 × 118	493	No. 1 Tall (US)
303 × 406	74 × 113	498	No. 303 (US)
303 × 509	74 × 141	645	No. 303 Cylinder (US)
307 × 113	83 × 46	215	7 oz
307 × 201	83 × 52	235	
307 × 306	83 × 82	434	No. 2 Vacuum (US)
307 × 403	83 × 106	540	
307 × 408	83 × 114	580	A2
307 × 409	83 × 115	606	No. 2 (US)
307 × 510	63 × 142	761	Jumbo (US)

(continued)