

ESSENTIALS OF **THERMAL PROCESSING**

GARY TUCKER ♦ SUSAN FEATHERSTONE

SECOND EDITION



WILEY Blackwell

Essentials of Thermal Processing

Essentials of Thermal Processing

Second Edition

Gary Tucker

Campden BRI, Gloucestershire, UK

Susan Featherstone

Safe Food Consulting, Cape Town, South Africa

WILEY Blackwell

This second edition first published 2021
© 2021 John Wiley & Sons Ltd

Edition History
Wiley-Blackwell (1e, 2010)

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, except as permitted by law. Advice on how to obtain permission to reuse material from this title is available at <http://www.wiley.com/go/permissions>.

The right of Gary Tucker and Susan Featherstone to be identified as the author(s) of this work has been asserted in accordance with law.

Registered Office(s)
John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Office
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

For details of our global editorial offices, customer services, and more information about Wiley products, visit us at www.wiley.com.

Wiley also publishes its books in a variety of electronic formats and by print-on-demand. Some content that appears in standard print versions of this book may not be available in other formats.

Limit of Liability/Disclaimer of Warranty

The contents of this work are intended to further general scientific research, understanding, and discussion only and are not intended and should not be relied upon as recommending or promoting scientific method, diagnosis, or treatment by physicians for any particular patient. In view of ongoing research, equipment modifications, changes in governmental regulations, and the constant flow of information relating to the use of medicines, equipment, and devices, the reader is urged to review and evaluate the information provided in the package insert or instructions for each medicine, equipment, or device for, among other things, any changes in the instructions or indication of usage and for added warnings and precautions. While the publisher and authors have used their best efforts in preparing this work, they make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives, written sales materials, or promotional statements for this work. The fact that an organization, website, or product is referred to in this work as a citation and/or potential source of further information does not mean that the publisher and authors endorse the information or services the organization, website, or product may provide or recommendations it may make. This work is sold with the understanding that the publisher is not engaged in rendering professional services. The advice and strategies contained herein may not be suitable for your situation. You should consult with a specialist where appropriate. Further, readers should be aware that websites listed in this work may have changed or disappeared between when this work was written and when it is read. Neither the publisher nor authors shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

Library of Congress Cataloging-in-Publication Data

Names: Tucker, Gary, author. | Featherstone, Susan, author.
Title: Essentials of thermal processing / Gary Tucker, Campden BRI,
Gloucestershire, UK, Susan Featherstone, Safe Food Consulting Cape Town,
South Africa.
Description: Second edition. | Hoboken, NJ : Wiley-Blackwell, [2021] |
Includes bibliographical references and index.
Identifiers: LCCN 2020056297 (print) | LCCN 2020056298 (ebook) | ISBN
9781119470373 (cloth) | ISBN 9781119470359 (adobe pdf) | ISBN
9781119470328 (epub)
Subjects: LCSH: Food—Effect of heat on. | Food—Preservation. |
Food—Microbiology.
Classification: LCC TP371 .T83 2021 (print) | LCC TP371 (ebook) | DDC
664/.028—dc23
LC record available at <https://lccn.loc.gov/2020056297>
LC ebook record available at <https://lccn.loc.gov/2020056298>

Cover Design: Wiley
Cover Image: © H G Molenaar & Co. (Pty) Ltd

Set in 11/13pt Times by SPi Global, Pondicherry, India

Contents

<i>Preface</i>	xv
<i>Glossary of Terms</i>	xxi
1 History of Thermal Processing	1
1.1 A brief history of the science and technology of thermal processing	1
1.2 Food microbiology as a science	5
1.3 Packaging for heat preserved foods	10
1.3.1 Convenience – the can opener is invented	11
1.3.2 Other forms of packing for ‘canned foods’	12
1.4 Developments in cannery equipment	13
1.4.1 Seaming	13
1.4.2 Processing	13
1.5 Food safety	13
References	15
2 Microbiology of Heat Preserved Foods	17
2.1 Food microbiology	17
2.1.1 Fungi	18
2.1.1.1 Moulds	18
2.1.1.2 Yeasts	20
2.1.2 Bacteria	21
2.1.2.1 Growth and reproduction of bacteria	22
2.2 Factors that affect the growth of micro-organisms	23
2.2.1 pH	24
2.2.2 Moisture	25
2.2.3 Nutrients	26
2.2.4 Oxidation–reduction potential	27
2.2.5 Antimicrobial resistance	28
2.2.6 Biological structures	28
2.2.7 Relative humidity	28
2.2.8 Oxygen content/concentration of gases in the environment	29

2.2.9	Temperature	30
2.2.9.1	<i>D</i> -value	32
2.2.9.2	<i>z</i> -value	32
2.3	Description of some micro-organisms of importance to thermal processing	34
2.3.1	Moulds	34
2.3.2	Yeasts	35
2.3.3	Bacteria	35
2.3.3.1	Thermophiles	36
2.3.3.2	Mesophiles – spore-forming bacteria	44
2.3.3.3	Mesophiles – non-spore-forming pathogenic and spoilage bacteria	46
2.3.3.4	Psychrophiles	47
2.4	Risk of leaker spoilage from damaged or compromised packaging	47
2.5	A guideline for identifying spoilage in canned foods	49
	References	50
3	Hurdles to Microbial Growth	53
3.1	Control of the micro-organism loading	55
3.2	Use of restrictive pH levels	55
3.3	Anaerobic environment or modified atmosphere environment	57
3.4	Low temperatures	58
3.5	Dehydration or low water activity	59
3.6	Chemical preservation	61
3.6.1	Organic acids	62
3.6.1.1	CIMCSEE code	63
3.6.2	Sulphites and nitrites	65
3.6.3	Antibiotics	65
3.6.4	Antioxidants	66
3.7	Irradiation	66
3.8	Combination treatments	67
	References	68
4	Low-acid Canned Foods	69
4.1	Production of a thermally processed food	70
4.2	F_03 sterilisation processes	71
4.3	Commercial sterilisation	74
4.4	Micro-organism death kinetics	76
4.5	Log reductions	78
	References	81

5 Acid Foods and Other Pasteurised Products	83
5.1 Background	83
5.1.1 Naturally acid foods	84
5.2 Pasteurisation	85
5.2.1 Considerations when designing a safe pasteurisation process	86
5.2.2 Calculation of pasteurisation values	87
5.3 Inhibitory factors to micro-organism growth	90
5.4 Pasteurisation value (p-value) guidelines	91
5.4.1 High acid: pH < 3.5	91
5.4.2 Acid: pH 3.5–4.0	93
5.4.3 Acid: pH 4.0–4.2	93
5.4.4 Medium acid: pH 4.2–4.6	94
5.5 Guidelines and general recommendations	95
5.5.1 Guidelines to critical factors in thermal processing of acid foods	97
5.6 Thermal processing of fruit	98
5.6.1 Packaging selection	99
5.6.2 Oxidation reactions inside an internally plain can of acid fruit	99
5.6.3 Pigments that discolour in internally plain cans	100
5.7 Thermal processing of products with low water activity	101
5.7.1 Jam and high sugar preserves	101
5.7.2 Canned cakes and sponge puddings	102
5.7.3 Bacteria of concern	103
5.7.4 Yeast and mould	105
5.7.5 Process recommendations – cake	105
5.7.6 Process recommendations – bread	105
5.8 Thermal processing of cured meats	105
References	106
6 Acidified Foods	107
6.1 Background	107
6.2 Acidity measurement using pH	110
6.2.1 The history of pH	110
6.2.2 The chemistry of pH	110
6.2.3 Measurement of pH	114
6.2.3.1 Potentiometric method	114
6.2.3.2 <i>Colorimetric measurement</i>	115
6.2.4 Equilibrium pH	115
6.3 Acidification of foods	115
6.4 Processing acidified foods	116
6.5 Design of pasteurisation processes	119

6.5.1	Medium acid range: pH 4.2–4.6	121
6.5.2	Acid range: pH 3.5–4.2	121
6.5.3	High acid range: pH below 3.5	121
6.6	Hot fill and hold processing	123
6.7	Critical control points in the production of acidified foods	124
6.7.1	Ingredients	124
6.7.2	Heat processing	125
6.7.3	Post process equilibrated pH	126
6.7.4	Container integrity	126
6.7.5	pH during product shelf life	126
	References	126
7	Heat Preserved Chilled Foods	129
7.1	Understanding microorganism behaviour	130
7.1.1	Pathogenic microorganisms relevant to chilled foods	132
7.1.1.1	<i>Clostridium botulinum</i>	134
7.1.1.2	<i>Bacillus cereus</i>	135
7.1.2	Microorganisms likely to be found in chilled foods	137
7.2	Methods of manufacture	138
7.2.1	Thermal process step applied prior to packaging	140
7.2.1.1	Low care–high care factories	142
7.2.2	Thermal process step applied after packaging	143
7.2.2.1	Caution with latent heat for frozen protein	145
	References	148
8	Processing Systems	151
8.1	In-pack processing: retort systems	151
8.1.1	Condensing steam retorts	152
8.1.2	Crateless retorts	153
8.1.3	Water immersion retorts	154
8.1.4	Water spray and cascade	155
8.1.5	Steam/air retorts	157
8.1.6	Shaka retorts	157
8.1.7	Reel and spiral retorts	158
8.1.8	Hydrostatic retorts	159
8.2	In-line processing: heat exchangers	160
8.2.1	Flow behaviour	161
8.2.2	Choice of heat exchanger	164
8.2.3	Maximising product recovery	169
8.3	New thermal technologies	170
	References	171

9 Cook Values and Optimisation of Thermal Processes	173
9.1 Mathematical analysis of cooking	173
9.1.1 Cooking equations and kinetic data	175
9.1.2 Competition between sterilisation and cooking	180
9.1.3 Optimisation of temperature/time in processing	182
9.2 Setting process targets	188
9.2.1 How to select processing conditions without excess quality damage	189
References	193
10 Process Validation: Temperature and Heat Distribution	195
10.1 Temperature distribution	195
10.1.1 Temperature measurement systems	197
10.2 Heat distribution	199
10.2.1 Modes of heat transfer	201
10.2.1.1 Radiation	201
10.2.1.2 Conduction	202
10.2.1.3 Convection	204
10.2.1.4 Broken heating or mixed heating	207
10.3 Heat distribution testing	210
10.3.1 Conducting a HD test	211
References	214
11 Process Validation: Heat Penetration and Process Calculations	217
11.1 Setting the target process value	218
11.2 Selecting the conditions for the HP study	219
11.2.1 Product	220
11.2.2 Container or package	220
11.2.3 Retort or processing system	221
11.3 Locating the product cold point	221
11.4 Process establishment methods	222
11.4.1 Log reduction methods for HP testing	223
11.4.1.1 Microbiological spore methods	224
11.4.1.2 Biochemical systems	227
11.5 Process calculation methods	228
11.5.1 General method	228
11.5.2 Ball method	229
11.5.3 Numerical methods	231
11.5.4 Continuous flow with particulates	234
References	238

12 Cooling Water Treatment	241
12.1 Chlorine	242
12.1.1 Chlorine demand and residual chlorine	243
12.1.2 Using chlorine	244
12.2 Chlorine dioxide	245
12.3 Bromine	247
12.4 Ozone	247
12.5 Ultraviolet light	249
12.6 Membrane filtration	249
References	250
13 Handling Processing Deviations	251
13.1 What constitutes a process deviation	251
13.2 What can go wrong	252
13.3 Actions required	254
13.3.1 TPA actions	256
13.3.2 Process deviation analysis for broken heating products	258
13.3.3 Reprocessing	262
14 Packaging Options for Heat-Preserved Foods	265
14.1 Metal containers	267
14.1.1 Tin plate	267
14.1.2 Tin free steel (TFS or ECCS)	268
14.1.3 Aluminium	268
14.1.4 Protective coatings (lacquers)	268
14.1.4.1 Vinyl lacquers	269
14.1.4.2 Organosol lacquers	269
14.1.4.3 Epoxy-phenolic lacquer	270
14.1.4.4 Polyester lacquer	270
14.1.4.5 Acrylic lacquers	270
14.1.4.6 Side stripe lacquers to cover the weld	272
14.1.5 Internally plain (unlacquered) cans	273
14.1.6 External covering	274
14.2 Can construction and handling	274
14.2.1 Product specification	276
14.2.2 Storage and handling of empty unused cans and ends	276
14.2.3 Cleaning of empty unused cans	277
14.2.4 Double seam formation and inspection procedures	277
14.2.5 Washing of filled cans	278
14.2.6 Processing of cans	279
14.2.7 Cooling of cans	280
14.2.7.1 Corrosion prevention	280

14.2.8	Secondary packaging	281
14.3	Glass	281
14.3.1	Glass manufacture	283
14.3.2	Closures for sealing glass food containers	284
14.3.3	Sealing mechanisms	284
14.3.4	Inspection procedures	285
14.3.5	Packing and processing	286
14.3.5.1	Inspection and preparation of containers	286
14.3.5.2	Filling	286
14.3.5.3	Capping	286
14.3.5.4	Atmospheric processing	287
14.3.5.5	Pressure processing	287
14.3.5.6	Cooling	288
14.4	Plastics, flexibles, and laminates	288
14.4.1	Advantages of retortable plastics	289
14.4.2	Disadvantages of retortable plastics	290
14.4.3	Polymers used for retortable packaging	290
14.4.3.1	Polypropylene (PP)	290
14.4.3.2	Polyethylene terephthalate (PET)	291
14.4.3.3	Ethyl-vinylalcohol (EVOH)	291
14.4.3.4	Polyvinylidene chloride (PVDC)	291
14.4.3.5	Polyamide (PA)	291
14.4.3.6	Aluminium	291
14.4.3.7	Glass-coated barrier films	292
14.4.4	Types of packages used for thermally processed foods	292
14.4.4.1	Retort pouches	292
14.4.4.2	Plastic cans and pots	294
14.4.4.3	Retortable composite carton	294
14.4.4.4	Processing considerations – control of headspace	296
	References	297
15	Incubation Testing	299
15.1	Purpose of incubation tests	299
15.2	Causes of spoilage	300
15.2.1	Leaker spoilage	301
15.2.2	Under processing	303
15.2.3	Thermophilic spoilage	304
15.3	Descriptive terms for canned food spoilage	306
15.4	Methods for incubation testing	307
15.4.1	Sample size	307
15.4.2	Temperatures and times for incubation	308

15.4.2.1	Thermophilic organisms	308
15.4.2.2	Mesophilic organisms	309
15.4.3	Post-incubation inspection of containers	310
15.5	Biotesting	310
	References	310
16	Critical Factors in Thermal Processing	313
16.1	Background	313
16.2	Key aspects of hygiene control systems for food processing (from codex alimentarius)	314
16.3	Identifying critical control points in thermal processing	315
16.3.1	Microbial load or bio-burden	316
16.3.2	pH of the product	316
16.3.3	Water activity (a_w)	317
16.3.4	Consistency	317
16.3.5	Presence, concentration, and types of preservatives	318
16.3.6	Rehydration	318
16.3.7	Blanching	319
16.3.8	Size and style of in-going ingredients	319
16.3.9	Container, packing, and filling considerations	320
16.3.9.1	Headspace	320
16.3.9.2	Container vacuum and exhausting of containers	321
16.3.9.3	Container size and geometry	322
16.3.9.4	Initial temperature of product	322
16.3.10	Process-related critical factors	323
16.3.10.1	Processing method	323
16.3.10.2	Processing medium	323
16.3.10.3	Type and characteristics of heat-processing system	324
16.3.10.4	Processing temperature	324
16.3.10.5	Processing time	325
16.3.10.6	Processing at high altitude	326
	References	327
17	Environmental Aspects of Thermal Processing	329
17.1	Lifecycle assessment (LCA)	330
17.1.1	Impact categories	331
17.1.1.1	Global warming potential (GWP)	332
17.1.1.2	Pesticide use/ecotoxicity	332
17.1.1.3	Abiotic resource use	332

17.1.1.4	Acidification potential	333
17.1.1.5	Eutrophication potential	333
17.1.1.6	Land use	334
17.1.1.7	Water use	334
17.2	Greenhouse gas emissions	335
17.2.1	Case study: Bottled apple juice	336
17.2.1.1	Raw materials (0.407 kg CO ₂ e/PU)	336
17.2.1.2	Manufacture (0.061 kg CO ₂ e/PU)	338
17.2.1.3	Transportation (0.057 kg CO ₂ e/PU)	338
17.2.1.4	Waste (0 kg CO ₂ e/PU)	339
17.2.1.5	Overall carbon footprint (0.525 kg CO ₂ e/PU)	340
17.2.1.6	GHG emissions for other food products	340
	References	343
	<i>Index</i>	345

Preface

Essentials of Thermal Processing is written by two authors with many years' experience of thermal processing practice, one gained in the northern hemisphere and one in the southern hemisphere. This gives the book a unique appeal. It covers all aspects of thermal processing from its beginnings in 1795 with Nicolas Appert through to modern day computer-controlled processing systems and electronic data capture. The intention was to write a book of practical use to students studying food science and technology as well as for their lecturers, individuals in companies, and research centres that have a need to understand thermal processing principles.

In this second edition, we have tried to expand on the information given so that this book is the one stop, single text required to assist with all thermal processing queries. The second edition starts with the history of thermal processing, from the prize-winning invention in the Napoleonic era, and describes many of the developments that resulted in the precise science that we know today. The next chapter covers basic microbiological principles that govern microbial growth and death. Detail about microorganisms of particular interest to thermal processing specialists is given as well as information about solving spoilage problems. The third chapter is dedicated to the hurdles to the growth of microorganisms so that the reader gains a thorough understanding of how to ensure a safe product.

The next chapters take the reader through the different food categories that present their unique challenges for thermal processing. This includes the traditional sector of low acid foods in which the familiar F_03 concept was derived from heat resistance studies originally undertaken by Esty and Meyer in 1922. Low acid foods are a group of foods that do not contain any preservation hurdles to microorganism growth and rely on the heat process to control microorganism numbers in the food and a hermetically sealed package to prevent recontamination. Chapters 5 and 6 are

on acid and acidified foods. The chapters are separated to describe the different principles and the types of thermal processes that are applied. In the acid foods chapter, information is included about other products that can be pasteurized. The last of the chapters that deals with a specific food group is on heat preserved chilled foods, which is one of the most rapidly growing sectors in Europe. This includes the ready meal concept and ready-to-eat meat, fish, and poultry products. Shelf-life requires refrigerated storage and is typically up to 10 days when a very mild process is used or it can be extended beyond this with more severe thermal treatments.

Chapter 8 describes processing methods that can be used for manufacturing heat preserved foods. It is divided into in-pack or in-line systems, often known as retorts and continuous systems. The focus of this chapter is the operating principles of the different designs. The main types of retort are described, for example steam, steam-air, water immersion, raining, and sprayed water, also included are the in-pack continuous retorts such as hydrostatic and reel and spiral cooker-cooler systems. Equipment choice for a continuous or in-line system depends mostly on the food viscosity and whether the flow behaviour is laminar or turbulent.

Thermal processing of foods has a dual purpose, which is to commercially sterilize the product and to cook it to an acceptable level. The chapter on cooking and process optimization addresses the challenges of maximizing a specific quality attribute without damaging the thermal processing effect on microbial reduction. Examples are given on the different quality parameters appropriate to heat preserved foods and how these can be mathematically analysed with the aim of adjusting processes so that maximum quantities of a nutrient, such as a vitamin, are retained.

Techniques for establishing and validating thermal processes are described in two chapters. Temperature and heat transfer are explained and process calculation methods are discussed. Measurement techniques for in-pack processes include temperature sensors of various types and log reduction methods that can be either microbiological or biochemical. Process calculation techniques are introduced, which allow process conditions to be calculated from the temperature measurements and analysis of deviations to be carried out. Differences in the techniques required for batch (in-pack) and continuous (in-flow) heat processes are described.

Chapter 12 discusses cooling water; almost all types of microorganisms can be found in water, and water is most often the vehicle of transmission for these organisms. Poor quality cooling water or inadequate cooling is arguably the most significant causes of public health issues from canned foods in the last century. Examples of spoilage incidents caused by cooling issues are dealt with in several chapters, and so, this chapter solely describes the different methods of disinfecting cooling water.

Despite the best efforts to control all aspects of a thermal processing operation, all factories will experience process deviations from time to time. Chapter 13 is dedicated to process deviations and describes methods to assess whether a process deviation has made a critical impact on the commercial sterility or safety of a product. Methods to assess a deviation are many and include calculation methods as well as experimentally recreating the deviation using retort simulators.

Packaging of the product also demanded its own chapter. Understanding packaging options and the way they work together with the product is critical to the success of any food packaging system. The functions of packaging are to contain, protect, preserve, portion, inform, promote, and make foods portable. Packaging options for thermally processed foods are many and include metal (mainly tinplate, but some aluminium), glass, cartons, and specific plastics (laminates and composites). Primary packaging must be able to hold a hermetic seal, withstand the process temperature, provide a physical barrier, withstand the physical stresses during processing, transport, storage, and distribution, and must not react adversely with the food.

Incubation of processed packs is commonplace in the food industry; however, a variety of incubation practices occurs, which suggests that there is no standardized approach. Chapter 15 describes the objectives of incubation together with some recommendations for times and temperatures that different types of microorganism require. It includes suggestions for sample size and methods for interpretation of results.

The penultimate chapter is about the critical control factors (CCP's) involved in thermal processing of food. HACCP (Hazard Analysis Critical Control Point) is a tool to assess hazards and establish control systems that focus on prevention rather than relying mainly on end-product testing. Examples are given of CCPs of relevance to thermal processing.

The final chapter presents a different focus for thermal processing in that it deals with environmental aspects and presents a positive case for thermal processing. As a technology for preserving food, it can be environmentally beneficial because the goods are stored ambient, thus avoiding the need for refrigeration, and allows agricultural products to be processed close to where they are grown, thus avoiding transportation emissions and forcing crops to grow out of season. An example of a carbon footprint assessment is given in this chapter for a bottled apple juice.



Gary Tucker
Susan Featherstone

The authors during a practical training course session in Cape Town.



Glossary of Terms

Acid	A substance which increases the concentration of hydrogen ions (H ⁺) in water, and reacts with a base to form a salt.
Acid Foods	A food that has a natural pH of 4.6 or below (in Europe it is common to use pH 4.5 as the upper limit).
Acidified Low-Acid Food	A food which has been treated so as to attain an equilibrium pH of 4.6 (or 4.5 in Europe) or lower after heat processing.
Acidified Food	A low-acid food to which acid(s) or acid food(s) are added and which has a finished equilibrium pH of 4.6 or below and a water activity (a _w) greater than 0.85.
Acidulant	An acidifying agent, such as acetic acid or vinegar.
Aciduric	Micro-organisms that can grow in high acid foods, i.e., with a pH value below 3.0. Generally, are of low heat resistance.
Aerobes	Micro-organisms that need oxygen for growth. Obligate aerobes cannot survive in the absence of oxygen.
Aerobic	Living or active only in the presence of free oxygen.

Anaerobes	Micro-organisms that grow in the absence of oxygen. Obligate anaerobes cannot survive in the presence of oxygen. Facultative anaerobes normally grow in oxygen, but can also grow in its absence.
Anaerobic	Living or active in the absence of free oxygen.
Anti-Microbial	A compound which inhibits the growth of a microbe.
Antioxidants	Substances that retard the oxidative rancidity of fats, or the oxidation of other substances.
Aseptic Processing and Packaging	The filling of a commercially sterile product into sterilised containers followed by hermetical sealing with a sterilised closure in an atmosphere free from micro-organisms.
Asepsis	Clean and free of micro-organisms.
Autoclave	A vessel in which high temperatures can be reached by using high steam pressure. Bacteria are destroyed more readily at elevated temperatures, and autoclaves are used to sterilize food, for example in cans.
Bacillus	A rod-shaped bacterium. Some <i>Bacillus</i> produce spores.
<i>Bacillus Cereus</i>	Spore-forming, rod-shaped bacterium, aerobic to facultative aerobic, proteolytic. It produces gastroenteritis caused by the release of an exo-enterotoxin during lysis of <i>B. cereus</i> in the intestinal tract.
Bactericide	Any substance that destroys bacteria, although not necessarily the spores of bacteria.
Bentonite	Colloidal clay used as an absorbent. Also used in model systems for determining rate of heat penetration.

Biodegradability	Susceptibility of a chemical compound to depolymerization by the action of biological agents.
Biological Oxygen Demand (BOD)	Micro-organisms consume oxygen in their respiration. The BOD test determines uptake of oxygen by a contaminated material, e.g., sewage, water, etc., as a measure of microbial activity.
Blanching	Heating by direct contact with hot water or live steam. It softens the tissues, eliminates air from the tissues, destroys enzymes, and washes away raw flavours.
Body Hook	That flange portion of the can body that is turned back for the formation of the double seam.
Body Maker	A machine for automatic forming of a cylindrical metal can or drums body from a body blank. In the manufacture of tin cans, the body maker may also automatically weld the side seam.
Boiler Scale	Deposit left inside boilers caused by evaporation of water and precipitation of water-soluble and insoluble substances.
Botulism	A poisoning caused by substances formed by the bacterium <i>Clostridium botulinum</i> under conditions of improper processing and storage of food. The spores of this bacterium are often found in soil and are likely to be present on soil-contaminated food.
Break-Point Chlorination	Addition of chlorine to water beyond the point where chloramines are oxidized, and where further increases in the dosage of chlorine will result in a proportional increase of chlorine residual.
Brines	Salt solutions used in canning and pickling.

Brix	The measure of density of a solution, more particularly a solution containing sucrose, as determined by a hydrometer. Degrees Brix equal Percent sucrose in water solution at 20°C.
Broken Heating Curve	A heating curve which shows a distinct change in the rate of heat transfer such that the curve may be represented by two or more distinct straight lines.
Broth Medium	A liquid medium for growth of microorganisms.
Browning Reaction	A reaction in foods, usually deteriorative, involving amino (e.g., from amino acids or proteins) and carbonyl (e.g., from glucose) groups; this reaction often leads to a brown discolouration and sometimes to off-flavours and changes in texture.
Buffer	Any substance in a fluid which tends to resist the change in pH (hydrogen-ion concentration) when acid or alkali is added.
Canned Food	Commercially sterile food in hermetically sealed containers.
Carbohydrates	Carbohydrates are essential food nutrients that can get broken down into glucose to be used as energy. They are comprised of C, H and O. Examples include starches, sugars and fibre.
Carcinogen	A cancer causing agent.
Cation	Positively charged ion such as K^+ , NH_4^+ .

- lag phase, 22, 24, 132
- laminates for packaging, 265, 288, 294
- land use change, 334
- latent heat, 145, 146, 200, 201
- Leeuwenhoek, Antoine van, 2, 3
- lifecycle assessment (LCA), 329–332, 334, 335
- lifecycle impact assessment (LCIA), 331, 334
- Lister, Joseph, 6, 7
- Listeria spp.*, 37–39, 58, 71, 84, 89, 104, 219
- log phase for microorganism growth, 22, 132
- log reduction, 74, 78–81, 88, 90, 104, 105, 122, 142, 176, 218, 219, 222–229, 305
method, 81, 199, 219, 223–225
- longitudinal agitation, 157
- low acid food, 14, 36, 44, 56, 69–81, 83–86, 107, 116–118, 122–127, 225, 308, 316
- low care environment, 132, 142
- lysozyme, 28, 134, 135
- master temperature indicator (MTI), 195, 197, 324
- maximum velocity, pipe flow, 162–164
- mean velocity, pipe flow, 162–164
- membrane filtration, 242, 249, 250
- mercury-in-glass thermometer, 324
- mesophilic organisms, 117, 308, 309
- metabiosis, 72
- metabisulphite, 65, 276
- microbial load, 55, 89, 316, 319
- microwave processing, 66, 170, 171
- mortality phase with microorganisms, 132
- multi-tube heat exchanger, 165–167
- mycotoxin, 18–20, 34, 35
- Neosartorya spp.*, 40, 91, 309
- nesting of cans, 154, 220
- Newtonian fluid, 161, 164, 237
- nisin, 61, 65, 66
- nitrite, 45, 54, 61, 65, 106, 318
- non-Newtonian fluid, 161, 164
- numerical calculations, 10, 231, 233
- numerical program, 10, 234, 236
- nutrients for microorganism growth, 23, 26, 109
- nylon-6, 288, 291
- ohmic heating, 170, 171
- organic acids, 20, 28, 36, 57, 62, 63, 90
- organosol, 269, 273
- osmophilic organisms, 26, 102, 317
- overpressure in processing, 144, 151, 153–157, 210, 253, 287, 290, 294, 296
- oxidation, 27, 29, 99, 176
- oxidation deterioration, 57, 66, 321
- oxygen barrier, 140, 290, 291
- ozone, 242, 247–249
- pack deflection, 144, 145
- particulate, 161, 167–171, 207, 209, 234–239
- particulate integrity, 161, 286
- PAS 2050, 330, 332, 335, 336, 339, 340
- Pasteur, Louis, 4–6
- pasteurisation, 54, 81, 85–88, 91, 98, 104–106, 118–120, 129, 293, 340
- Patulin, 19, 20
- peach, 40, 41, 85, 93, 96, 179
- peaking of cans, 279–280

- pear, 85, 94, 96, 121, 316
Penicillium spp., 19, 20, 35, 87, 104, 121
phosphate buffer, 40, 73, 75, 79, 134, 136
pickling, 24, 55, 56
pigging system, 169
pigment, 47, 100, 173, 178, 179, 270
pillow pouch, 292
pineapple, 85, 96, 99, 179
plastic tray, 144, 171, 306
platinum resistance thermometer, 197, 324
polyamide, 288, 291
polyester, 270, 288, 291
polyethylene, 270, 272, 288, 291
polyethylene terephthalate (PET), 270, 288, 291
polypropylene, 206, 211, 270, 288, 290, 293, 337
polyvinylidene chloride (PVDC), 291
potable water, 241, 242, 315
pre-cooling of retorts, 116, 118
Prescott, Samuel Cate, 6–7
preserves, 60, 67, 101
pressure cooling of retorts, 156, 157
probability of a non-sterile unit (PSNU), 32
process
 deviation, 209, 217, 234, 251–264, 299, 325
 optimisation, 173–193
 scheduled, 97, 109, 118, 217, 228, 231, 251–253, 256, 264, 315
 value, 120, 174, 180, 195, 198, 218, 219, 223, 224
product
 initial temperature, 97, 189, 223, 229, 231, 251–253, 286, 320, 323
 texture, 59, 84, 143, 145, 173
 propionic acid, 61–63, 112, 113
 proteins, 27, 62, 244, 327
 Pseudomonas spp., 38, 47, 89
 psychrophilic organisms, 30, 131
 psychrotrophic organisms, 130–137, 141, 219
 PTFE, 197, 211
 Pyrococcus furiosus, 227
 quality of product, 12, 13, 33, 53, 98, 100, 160, 183, 188–193, 208, 251, 290
 ready meal, 129, 133, 137, 140, 142, 144–147, 294, 341
 recontamination of packaged foods, 47, 69, 70, 76, 104, 309
 redox potential, 23, 27, 28
 reference temperature, 77, 78, 86, 90, 117, 176, 223, 224, 228, 235
 rehydration of products, 220, 318, 319
 remote loggers, 195
 REPFEDS, 130, 142
 residence time distribution, 161
 resistance temperature detectors (RTDs), 197
 retort type
 condensing steam, 151–153, 157, 159, 210
 continuous, 153, 158, 260
 crateless, 153, 154
 hydrostatic, 13, 158–160, 260
 raining water, 13, 98, 124, 221
 reel and spiral, 158, 159, 205, 260, 261, 300
 steam/air, 144, 157, 212, 214, 221, 257, 323
 water cascade, 155, 156, 210, 212, 214, 323
 water immersion, 154, 155, 196, 210, 212, 214, 221, 230, 323

- water spray, 155, 156, 159,
 210, 214, 287, 323
 rheological properties, 161,
 236, 260
Rhizopus spp., 34, 92
Rhodotorula spp., 35, 38

Saccharomyces spp., 35, 38,
 89, 104
Salmonella spp., 37–39, 46, 58,
 63, 71, 89, 104, 133, 303
 sampling plans for incubation, 307
 seals in packages
 integrity, 286, 293, 300
 tear down method, 278
 testing methods, 310
 semi-rigid containers, 220, 289,
 294, 306
 sensible heat, 147, 200
 shear rate, 164, 260
 shear thinning fluid, 161
 shelf-life of products, 24, 56, 99,
 129, 130, 137, 142, 265,
 267, 268, 273, 290
 silica oxide barrier material,
 292, 293
 simple heating product, 213,
 222, 258
 slowest heating point, 116,
 151, 152, 190, 203, 217,
 221, 222
 sorbic acid, 61, 62, 112, 113
sous-vide products, 130
 spoilage organisms, 21, 35, 36,
 49, 57, 70, 74, 75, 78–87,
 93–95, 102, 109, 137,
 300–309, 314, 317
 spoilage types
 gross, 301
 incipient, 301, 302
 leaker, 47–49, 242, 299,
 301, 308
 thermophilic, 34, 63, 301, 304,
 305, 308, 309
 spore germination, 91, 304
 stand-up pouch (SUP), 293
 Staphylococcus aureus, 38, 46,
 58, 104, 302
 starch gelatinization, 208,
 209, 259
 stationary phase in microorganism
 growth, 132
 steam injection, 155, 196
 sterilisation, 71–75, 78, 85,
 158–160, 170–182, 308
 stress corrosion cracking, 281
 sulphide staining of cans,
 268, 270
 sulphite preservative, 54, 276

Talaromyces spp., 40, 91
 tamper evidence, 285
 temperature
 coefficient, 174
 distribution, 13, 156, 195–214,
 256, 287
 sensors, 175, 197, 198, 212,
 219, 223, 235
 terminal death time, 72
 thermal centre of containers, 196,
 221, 319
 thermal process authority, 213,
 214, 221, 222, 252, 255
 thermistor, 197
 thermophilic organism, 43, 131,
 227, 280, 301, 304, 305,
 308, 309
 thermophilic spoilage, 280, 301,
 304, 305, 308, 309
 thiamine, 177, 180, 182–184
 time–temperature integrators
 (TTIs), 227, 235
 tin free steel (TFS), 267, 268, 284
 tinsplate, 99, 267–270, 273–276, 292
 tomato, 38–42, 85, 87, 89, 96,
 119, 121, 138, 139, 163,
 177, 179, 316
 toxic equivalency potentials, 332
 transitional region (for flow), 162
 trapezoidal method, 228

- UHT, 40, 160, 169
- ultraviolet light, 34, 242, 248
- under-processing of containers, 301, 303, 304
- Underwood, William Lyman, 8

- vacuum in cans, 220, 242, 287, 321, 332
- velocity profile, 162, 164, 237
- venting, 144, 153, 157, 159, 252, 280
- vent schedule, 221, 324
- viscoelastic properties, 164
- viscous products, 162
- vitamins, 26, 176, 178, 185

- water activity, 25, 26, 29, 35, 44, 53–55, 58–62, 69, 70, 83, 91, 101–109, 120, 317
- worst case conditions, product, 189, 190, 219–221, 251

- xerophiles, 26, 90, 102, 317

- yield stress, 164, 167
- yield value, 164, 166

- z-value, 32, 33, 37–40, 43, 75, 88, 89, 117, 122, 134, 136, 176–180, 183, 224
- Zygosaccharomyces spp.*, 35, 37, 38, 89, 104