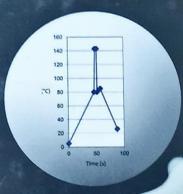
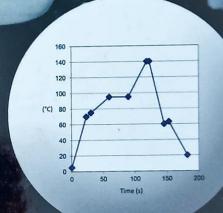
HILTON C. DEETH AND MICHAEL J. LEWIS





High Temperature Processing of

MILK AND MILK PRODUCTS

WILEY Blackwell

## High Temperature Processing of Milk and Milk Products

Hilton C. Deeth

School of Agriculture and Food Sciences, The University of Queensland, Brisbane, Australia

Michael J. Lewis

Department of Food and Nutritional Sciences, University of Reading, Reading, UK This edition first published 2017 © 2017 John Wiley & Sons Ltd

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 Hilton C. Deeth & Michael J. Lewis to be identified as the authors of this work has been asserted in accordance with law.

Registered Office

John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Offices

111 River Street, Hoboken, NJ 07030, USA 9600 Garsington Road, Oxford, OX4 2DQ, UK

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 publisher and the authors 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 fitness for a particular purpose. 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 every situation. In view of ongoing research, equipment modifications, changes in governmental regulations, and the constant flow of information relating to the use of experimental reagents, equipment, and devices, the reader is urged to review and evaluate the information provided in the package insert or instructions for each chemical, piece of equipment, reagent, or device for, among other things, any changes in the instructions or indication of usage and for added warnings and precautions. The fact that an organization or website is referred to in this work as a citation and/or potential source of further information does not mean that the author or the publisher endorses the information the organization or website may provide or recommendations it may make. Further, readers should be aware that websites listed in this work may have changed or disappeared between when this works was written and when it is read. No warranty may be created or extended by any promotional statements for this work. Neither the publisher nor the author shall be liable for any damages arising here from.

Library of Congress Cataloging-in-Publication Data

[9781118460504]

Cover Design: Wiley Cover image: Leong Thian Fu / EyeEm/Gettyimages

Set in 10/12pt Warnock by SPi Global, Pondicherry, India Printed and bound in Malaysia by Vivar Printing Sdn Bhd

10 9 8 7 6 5 4 3 2 1

00077866

259

## Contents

	About the Authors		$x\nu$
	Preface	American Translation X	vii
	List of Abbreviations	and the latest that the x	cxi
1	History and Scope of the Book		1
1.1	Setting the Scene		1
1.2	Scope of the Book		7
1.3	Reasons for Heating Foods		7
1.4	Brief History of Sterilisation Processes		8
Referer		manuscrat little	12
2	Heat Treatments of Milk – Thermisation and		15
2.1	Introduction		15
2.2	Thermisation		16
2.3	Pasteurisation		17
2.3.1	Introduction		17
2.3.2	Historical Background		18
2.3.3	Pasteurisation Equipment	atregal Isolgalaid militi	21
2.3.3.1	Holder or Batch Heating	netrobertek 2	21
2.3.3.2	Continuous Heating	2 July will make the property of	22
2.3.4	Process Characterisation	well gummo lessing len a less less less less less les les les le	24
2.3.4.1	D-value	Binning and made exclusion 150	24
2.3.4.2	z-value	nigstand national Parish S. 2	25
2.3.4.3	Pasteurisation Unit (PU)	Fl-mage anamylhasis now Lie 2	25
2.3.4.4	p*	served such sussioning 22 2	26
2.3.5	Processing Conditions	anall he deliver sent malt.	27
2.3.6	Changes During Pasteurisation	Les respondent la militar de la	28
2.3.6.1	Microbiological Aspects	See Selland Bonnoon See See See See	28
2.3.6.2	Enzyme Inactivation	SUBALIRU SI	29
2.3.6.3	Other Changes	Desired beingladded a 1503	31
2.3.7	Changes During Storage	soul notes and the stage to the	32
2.3.7.1	Changes Due to Post-Pasteurisation Contain	mination (PPC)	32
2.3.7.2	Other Changes		33
2.3.8	Pasteurisation of Other Milk-Based Produc	ets 3	34
Referen	nces		36

3	Heat Treatments of Milk – ESL, UHT and in-Container Sterilisation	4
3.1	Introduction	4
3.2	Some Important Definitions	4
3.2.1	Q <sub>10</sub>	4
3.2.2	Bacterial Indices, B* and F <sub>0</sub>	4
3.2.3	Chemical Index, C*	4.
3.3	Extended Shelf-Life (ESL) Milk Processing	4
3.3.1	ESL Milk by Thermal Treatment	4
3.3.1.1	ESL Milk by Thermal Treatment Plus Aseptic Packaging	
3.3.2	ESL Milk by Microfiltration Plus HTST Heat Treatment	4
3.3.3	ESL Milk by Thermal Treatment Plus Bactofugation	4:
3.3.4	ESI, Milk by Thermal Treatment Plus an Antibertanial Agent	50
3.3.5	ESL Milk by Thermal Treatment Plus an Antibacterial Agent ESL Milk by Thermal Treatment Plus a Non-Thermal	50
	Technology Treatment  Technology Treatment	-
3.3.5.1	UV irradiation	50
3.3.5.2		50
3.3.5.3	Gamma-Irradiation	51
3.3.6	ESL Milk by Multiple Thermal Treatments	51
3.4	Sterilisation	51
3.4.1	Introduction	52
3.4.2	UHT Processing	52
3.4.2.1	Introduction	54
3.4.2.2		54
3.4.2.3		54
3.4.3	In-Container Sterilisation	55
3.4.3.1		58
3.4.3.2		58
Referen		60
		61
4	Microbiological Aspects	65
4.1	Introduction	65
4.2	Bacteria in Raw Milk	65
4.2.1	Non-Spore-Forming Psychrotrophic Bacteria and their	03
	Heat-Resistant Enzymes	68
4.2.2	Spore-Forming Bacteria	69
4.2.2.1	Non-Pathogenic Spore-Formers	69
4.2.2.2	Pathogenic Spore-Formers	71
4.3	Heat Inactivation of Bacteria	78
4.4	Microflora in Processed Milks	80
4.4.1	Pasteurised Milk	80
4.4.2	ESL Milk	83
4.4.2.1	Microbiological Issues Related to the Heating Process	83
4.4.2.2	Optimum Processing Conditions for High Microbiological Quality	0.5
	and Safety of ESL Milk	84
4.4.2.3	Microbiological Issues Associated with Post Process Contamination	84
1.4.3	UHT Milk	85
1.4.3.1	Spores in UHT Milk Produced From Fresh Milk	85

		Contents
4.4.3.2	Spores in Milk Powders Used for UHT Reconstituted Milk	87
4.4.3.3	Spores in Non-Milk Ingredients Used in UHT Milk Products	88
4.4.3.4	Other Microbial Contamination	89
4.4.4	In-Container Sterilised Milk	90
4.5	Sterilisation of Equipment and Packaging to Prevent Microbial	
	Contamination of UHT Products	90
Referen		91
5	UHT Processing and Equipment	103
5.1	The UHT Process	103
5.2	Heating	104
5.2.1	Steam-/Hot-Water-Based Heating Systems	104
5.2.1.1	Direct Heating	104
5.2.1.2	Indirect Heating	109
5.2.1.3	Pre-Heating	111
5.2.1.4	Comparison of Indirect and Direct UHT Plants	113
5.2.1.5	Combination Direct–Indirect Systems	113
5.2.1.6	Scraped-Surface Heat Exchanger Systems	115
5.2.1.7	Pilot-Scale Equipment	117
5.2.1.8	Engineering Aspects	123
5.2.2	Electrically Based Heating Systems	146
5.2.2.1	Electrical Tube Heating	146
5.2.2.2	Ohmic Heating	146
5.2.2.3	Microwave Heating	148
5.3	Homogenisation	150
5.4	Deaeration	154
5.5	Aseptic Packaging	155
5.5.1	Types of Packaging	155
5.5.1.1	Paperboard Cartons	155
5.5.1.2	Plastic Bottles	156
5.5.1.3	Pouches	157
5.5.1.4	Bulk Aseptic Packaging	158
5.5.2	Sterilisation of Packaging	158
5.5.3	Establishing and Maintaining a Sterile Environment	158
5.5.4	Aseptic Package Integrity	159
5.5.5	Validation of Aseptic Packaging Operations	159
5.6	Plant Cleaning and Sanitisation	161
5.6.1	Introduction	161
5.6.2	Rinsing	161
5.6.3	Water-Product Changeover	162
5.6.4	Cleaning	162
5.6.5	Methods of Measuring Cleaning Effectiveness	164
5.6.6	Kinetics of Cleaning	166
5.6.7	Disinfecting and Sterilising	167
5.6.7.1	Use of Heat	167
5.6.7.2	Use of Chemicals	168
Reference	es	168

vii

U	Changes During Heat Treatment of Milk	17:
6.1	Chemical	17:
6.1.1	pH and Ionic Calcium	177
6.1.1.1	Effects of Addition of Phosphates, Citrate and EDTA	181
6.1.2	Mineral Salts	182
6.1.2.1	Mineral Partitioning and Associated Changes	182
6.1.2.2	Addition of Mineral Salts	183
6.1.3	Proteins	184
6.1.3.1	Whey Protein Denaturation	184
6.1.3.2	Coagulation of Caseins	188
6.1.3.3	Protein Cross-Linking	188
6.1.3.4	Dissociation of Caseins from the Casein Micelle	189
6.1.3.5	Effects on Enzymes	190
6.1.3.6	Effect on Rennet Coagulation of Casein	193
6.1.4	Lactose	195
6.1.4.1	Lactosylation and the Maillard Reaction	195
6.1.4.2	Lactulose Formation	198
6.1.5	Vitamins	200
6.1.6	Flavour	200
6.1.6.1	Volatile Sulfur Compounds	201
6.1.6.2	Monocarbonyl Compounds	207
6.1.7	Chemical Heat Indices	208
6.2	Physical Changes	212
6.2.1	Heat Stability	212
6.2.1.1	Measurement of Heat Stability	212
6.2.1.2	Is HCT a Good Predictor of Heat Stability	212
	in UHT Treatment?	214
6.2.1.3	Stability to UHT Processing and Some Comparisons	214
	with In-Container Sterilisation	216
6.2.1.4	Is Ethanol Stability a Good Predictor of Heat Stability in	216
	UHT Treatment?	220
6.2.2	Fouling	220
6.2.2.1	Introduction	222
6.2.2.2	Terms Used in Fouling	222
6.2.2.3	Measurement of Fouling	224
6.2.2.4	Factors Affecting Fouling	225
6.2.2.5	Fouling Mechanism	229
6.2.2.6	Methods to Reduce Fouling	235
6.2.2.7	Fouling in Other Products	236
6.2.2.8	Biofilms	238
6.3	Kinetics and Computer Modelling	238
Referen		240
Referen		242
7	Changes During Storage of UHT Milk	Territoria de la constantina della constantina d
7.1	Chemical Changes	261
	pH	263
7.1.1	Dissolved Oxygen Content	263
7.1.2	Dissolved Oxygen Content	264

		Contents	ix
7.1.3	Flavour	266	
7.1.3.1	Sulfurous Flavour	268	
7.1.3.2	Cooked/Heated/Sterilised Flavour	268	
7.1.3.3	Stale/Oxidised Flavour	269	
7.1.3.4	Bitterness	270	
7.1.3.5	Hydrolytic Rancidity (Lipolysis)	271	
7.1.3.6	Flavour Improvement Approaches	272	
7.1.4	Proteolysis	273	
7.1.5	Protein Cross-Linking	275	
7.1.6	Deamidation	276	
7.1.7	Lactosylation	277	
7.1.8	Formation of Monosaccharides	278	
7.1.9	Reactivation of Alkaline Phosphatase	278	
7.1.10	Vitamins	279	
7.1.11	Light-Induced Changes	280	
7.2	Physical	282	
7.2.1	Sedimentation	282	
7.2.2	Age Gelation	283	
7.2.2.1	Proteolysis	284	
7.2.2.2	Milk Production Factors	285	
7.2.2.3	Severity of Sterilisation Heating	285	
7.2.2.4	Temperature of Storage	286	
7.2.2.5	Additives	286	
7.2.2.6	Mechanism	288	
7.2.2.7	Practical Issues with Gelation	288	
7.2.3	Thinning	289	
7.2.4	Fat separation	290	
7.2.5	Maillard Browning	292	
7.2.5.1	Browning of Milk and Milk Products	292	
7.2.5.2	Browning of Fruit Juices	298	
7.3	Changes to Some UHT Products Other than Single-Strength Fresh		
	White Cow's Milk	299	
7.4	Accelerated Storage Testing	300	
7.5	Chemical and Physical Changes During Storage		
	Trials of UHT Milk	301	
7.5.1	Storage Trial 1 (DIAL, 2014)	301	
7.5.2	Storage Trial 2 (UCC, 2015)	304	
7.5.3	Other Storage Trials	307	
Referer		307	
8	Quality Control and Assurance	321	
8.1	Introduction	321	
8.2	Safety and Quality Considerations	321	
8.2.1	Safety Issues	321	
8.2.2	Quality Issues	323	
8.3	Heat Treatment Regulations	323	
8.4	Quality Assurance/Commercial Sterility: The Current Approach	327	

x	Content	ts
---	---------	----

8.4.1	Introduction	327
8.4.2		329
8.4.3	Commercially Sterile Products	329
8.4.4	Sampling Theories and Probabilities Characteristic Curves	330
8.4.5		333
8.4.6	Sampling for Process Verification	334
	Sampling Plans for Refrigerated Products	
8.5	Important Quality Considerations for UHT Processing	335
8.5.1	Raw Material Quality	336
8.5.2	Processing Aspects	338
8.5.3	Other Factors	339
8.6	Some Practical Aspects	340
8.7	Microbiological Examination of Heat-Treated Foods	343
8.7.1	Introduction	343
8.7.2	Sample Pre-Incubation	344
8.7.3	Testing for Microbial Activity	345
8.7.4	Plate Counting and Microscopy	345
8.7.5	Rapid Instrumental Methods for Total Bacteria	347
8.7.5.1	Based on DEFT Method	347
8.7.5.2	Based on Impedance Measurement	347
8.7.5.3	Based on Carbon Dioxide Detection	348
8.7.5.4	Based on Dissolved Oxygen Depletion	348
8.7.5.5	Based on Flow Cytometry (FCM)	348
8.7.5.6	Based on ATP of Viable Cells	350
8.7.5.7	Based on Colour Indicators	350
8.7.6	Analyses of Specific Bacteria	350
8.7.6.1	Molecular and Immunological Methods	350
8.7.6.2	Antibody-Based Methods	351
8.7.6.3 8.7.7	Nucleic Acid-Based Methods	352
0.7.7	Indirect Methods Based on the Metabolic	
8.8	Activity of Microorganisms	354
8.9	Non-Invasive Methods The Milk Microbiome	354
8.10		355
8.11	Use of Modelling Procedures UHT Product Alerts and Recalls	356
8.12		357
8.13	Time – Temperature Indicators Conclusions	358
Referen		358
Referen	ces	359
9	Other Shelf-Stable Products	200
9.1	Introduction	365
9.2	Reconstituted and Recombined Milk	365
9.3	Concentrated Milk Products	365
9.3.1	UHT Evaporated Milk	367
9.3.2	Concentration by Membrane Filtration	371
9.4	Lactose-Reduced Milk (LRM)	372
9.5	Mineral-Fortified Milk	373
9.5.1	Calcium	374
		374

		Contents
9.5.2	Other Minerals	376
9.6	Flavoured Milk	377
9.6.1	Fruit-Flavoured Milk	378
9.6.2	Chocolate and Other Confectionery Milk	379
9.7	High-Protein Milk Drinks	383
9.8	Breakfast Milk Products	384
9.9	Starch-Based and Thickened Desserts	385
9.10	UHT Cream	386
9.11	UHT Ice Cream Mix	387
9.12	Infant Formulae	390
9.13	UF Permeate	391
9.14	Whey Proteins	392
9.15	Yogurt and Cheese	392
9.15.1	Yogurt	392
9.15.1.1	Yogurt Produced from UHT Milk	392
9.15.1.2	Ambient Yogurt	395
9.15.2	Cheese made from UHT Milk	395
9.16	Milk from Species other than Cows	396
9.16.1	Buffalo's Milk	397
9.16.2	Goat's Milk	398
9.16.3	Camel's Milk	400
9.17	Non-Dairy Products	401
9.17.1	Soy Milk	404
9.17.2	Peanut Milk	408
9.17.3	Coconut Milk	410
9.17.4	Almond Milk	411
9.18	Other Non-Dairy Beverages	411
9.18.1	Tea and Coffee	411
9.18.2	Fruit Juices, Purees and Drinks	412
Reference		415
10	Non-Thermal Technologies	427
10.1	Introduction	427
10.2	Microfiltration	427
10.3	High-Pressure Processing	433
10.3.1	Effect on Bacteria and Potential for Producing ESL and Shelf-Stable Milk	433
10.3.2	Effect on Milk Components	434
10.3.2	Pulsed Electric Field (PEF) Technology	435
10.4.1	Effect on Bacteria and Potential for Producing ESL	433
10.1.1	and Shelf-Stable Milk	436
10.4.2	Effect on Milk Components	437
10.5	High-Pressure Homogenisation	438
10.5.1	Effect on Microorganisms and Potential for Producing ESL	
10.50	and Shelf-Stable Milk	440
10.5.2	Effect on Milk Components  Bactofugation	442
III	Pactomogram	4/12

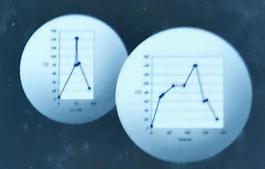
χi

xii	Contents
-----	----------

10.7	UV Irradiation	444
10.8	Gamma Irradiation	446
10.9	Carbon Dioxide	447
10.9.1	High Pressure Carbon Dioxide	449
Reference		450
Reference		
11	Analytical Methods	461
11.1	Introduction	461
11.2	Commonly Used Analytical Methods	461
11.2.1	Amylase	461
11.2.2	Browning	462
11.2.2.1	Colour Meter Analysis	462
11.2.2.2	Colourimetric Analysis	463
11.2.3	Density/Specific Gravity	463
11.2.4	Dissolved Oxygen	463
11.2.5	Fat Separation and Fat Particle Size	464
11.2.5.1	Fat Separation	464
11.2.5.2	Fat Particle Size	464
11.2.6	Flavour Volatiles	467
11.2.7	Fouling of Heat Exchangers	469
11.2.8	Freezing Point Depression (FPD)	470
11.2.9	Furosine	471
11.2.10	Hydrogen Peroxide	471
11.2.11	Hydroxymethyl Furfural (HMF)	472
11.2.12	Lactulose	472
11.2.13	Lysinoalanine (LAL)	473
11.2.14	Lipase	473
11.2.15	Lipolysis (Free Fatty Acids)	475
11.2.16	Lysine – Blocked and Reactive	475
11.2.16.1	Blocked Lysine	475
11.2.16.2	Chemically Reactive or Available Lysine	477
11.2.17	Minerals and Salts	477
11.2.17.1	Ionic Calcium	480
11.2.18	pH and Titratable Acidity	484
11.2.18.1	pH	484
11.2.18.2	Titratable Acidity (TA)	485
11.2.19	Protease	486
11.2.19.1	Plasmin	486
11.2.19.2	Bacterial Proteases	486
11.2.20	Protein	
11.2.21	Proteolysis (Peptides)	487
11.2.21.1	Distinguishing Peptides Produced by Plasmin and Bacterial Proteases	488
	by Analysis of Primary Amine Groups	400
11.2.21.2	HPLC Analysis	490
11.2.21.3	Polyacrylamide Gel Electrophoresis (PAGE) Analysis	490
11.2.22	Sediment Sediment	491
11.2.22		492

		Contents xiii
11.2.23	Sensory Characteristics	493
11.2.24	Separation Methods	496
11.2.24.1	Dialysis and Ultrafiltration	496
11.2.24.2	Centrifugation	498
11.2.25	Stability Tests	499
11.2.25.1	Ethanol Stability Test	499
11.2.25.2	Other Heat Stability Tests	501
11.2.25.3	Accelerated Physical Stability	502
11.2.26	Viscosity	502
11.2.27	Vitamins	503
11.2.28	Whey Protein Denaturation	503
11.2.28.1	Soluble Tryptophan	504
11.2.28.2	Turbidity Test	504
11.3	Advanced Analytical Techniques	505
11.3.1	Chemometrics	505
11.3.2	Nuclear Magnetic Resonance (NMR)	506
11.3.3	Proteomics	508
11.3.4	Ultrasonic Techniques	509
Reference		510
12	Concluding Comments	527
12.1	Spore-Forming Bacteria	527
12.1.1	Highly Heat-Resistant Spores	527
12.1.2	Enzymes Produced by Spores	527
12.1.3	Sources of Spores	527
12.1.4	Identification of Spores	528
12.1.5	Spore Counts in Raw Milk	528
12.1.6	Conditions of Activation and Germination of Spores	528
12.1.7	Psychrotrophic Spore-Formers	529
12.2	Biofilms	529
12.3	Age Gelation	530
12.3.1	Mechanism	530
12.3.2	Early Prediction of a Milk's Susceptibility	530
12.4	Predictive Modelling	530
12.5	The Shelf-Life of UHT Milk	531
12.6	The Shelf-Life of ESL Milk	532
12.7	Non-Thermal Technologies	533
12.8	Analytical Methods	533
12.9	Using the Literature	533
12.10	Further Reading	534
Reference		534
	eading: References to Books, Book Chapters and Reviews Arranged	
	cally within Publication Type	536
	Index	541

## High Temperature Processing of MILK AND MILK PRODUCTS



High Temperature Processing of Milk and Milk Products covers many aspects of thermal processing of milk and milk products with particular focus on UHT processing.

The book begins with an overview of the major thermal processing technologies: thermisation, pasteurisation, extended-shelf-life (ESL), UHT and in-container sterilisation. It discusses the principles of the technologies, the processing and packaging equipment used, processing issues such as temperature-time profiles, heat stability, fouling and cleaning, and the quality and safety aspects of the products produced. It provides a balance of the engineering aspects of the processes and the chemical, microbiological and sensory aspects of the products. The changes that occur in products during processing and storage, and the related defects which can arise, are central to the book. The discussions of these changes will be an aid to industry personnel in identifying the causes of quality defects in these products and devising measures which can be taken to eliminate or minimise the defects.

A unique feature is a chapter on analytical methodologies applicable to thermally processed dairy products. There are also chapters on high-temperature processed products other than white cows' milk, including products based on plant materials, and on non-thermal technologies which may be used in place of or as adjuncts to thermal processing.

The book concludes with a chapter outlining some of the challenges with the technologies and treated products, and a compendium of relevant reviews, chapters and books.

## About the Authors

of Queensland, Australia, and consultant to the dairy industry

MICHAEL J. LEWIS, Honorary Fellow, Department of Food and Nutritional Sciences, Taught and researched at The University of Reading, Whiteknights, UK, for 38 years and now working as an adviser on milk and milk products

Cover Design: Wiley
Cover Image: © Leong Thian Fu / EyeEm/Gettyimages

www.wiley.com/wiley-blackwell

WILEY Blackwell



