

# Contents

<b>Preface First Edition</b> .....	<b>xiv</b>
<b>Preface Second Edition</b> .....	<b>xvi</b>
<b>1 Introduction</b> .....	<b>1</b>
1.1 Thermal Processing Principles .....	1
1.1.1 Thermal Processing .....	1
1.1.2 The Process .....	1
1.2 Canning Operations .....	2
1.2.1 General .....	2
1.2.2 Methods of Processing .....	3
1.3 Packaging Materials .....	4
1.3.1 Introduction .....	4
1.3.2 Metal Containers .....	4
1.3.3 Glass Containers .....	6
1.3.4 Rigid Plastic Containers .....	7
1.3.5 Retortable Pouches .....	8
1.4 Some Historical Details .....	9
References .....	11
<b>2 Heat Transfer</b> .....	<b>14</b>
2.1 Introduction .....	14
2.1.1 General Aspects .....	14
2.1.2 Mechanisms of Heat Transfer .....	14
2.2 Heat Transfer by Conduction .....	16
2.2.1 Introduction .....	16
2.2.2 Formulation of Problems Involving Conduction Heat Transfer .....	17
2.2.3 Initial and Boundary Conditions .....	21
2.2.4 Mean or Volume Average Temperatures .....	22
2.2.5 Summary of Basic Requirements .....	23

2.2.6	Some Analytical Methods for Solving the Equations . . . . .	24
2.2.7	Some Numerical Techniques of Solution . . . . .	27
2.2.8	Some Analytical Solutions of the Heat Transfer Equation . . . . .	35
2.2.9	Heat Transfer in Packaged Foods by Microwave Heating . .	43
2.2.10	Dielectric Heating . . . . .	45
2.3	Heat Transfer by Convection . . . . .	45
2.3.1	Introduction . . . . .	45
2.3.2	Basic Concepts in Convection Heat Transfer . . . . .	48
2.3.3	Models for Convection Heat Transfer . . . . .	50
2.3.4	Some Experimental Work and Correlations . . . . .	54
2.3.5	Conclusions . . . . .	65
2.4	Radiation Heating . . . . .	65
2.5	Some Computer Programs . . . . .	69
2.5.1	Conduction Heat Transfer Analysis Programs . . . . .	69
	References . . . . .	70
<b>3</b>	<b>Kinetics of Thermal Processing . . . . .</b>	<b>87</b>
3.1	Introduction . . . . .	87
3.1.1	General Effects of Thermal Processing . . . . .	87
3.1.2	The Nature of Microbial Behaviour . . . . .	87
3.1.3	Other Factors Affecting Heat Resistance . . . . .	88
3.1.4	Measuring Heat Resistance . . . . .	89
3.1.5	The Statistical Nature of Microbial Death . . . . .	94
3.1.6	Practical Aspects . . . . .	96
3.2	Methods of Representing Kinetic Changes . . . . .	96
3.2.1	Basic Kinetic Equations . . . . .	96
3.2.2	Decimal Reduction Time . . . . .	99
3.2.3	More Complex Inactivation Models . . . . .	100
3.2.4	Temperature Dependence of Death Rate . . . . .	103
3.3	Kinetics of Food Quality Factor Retention . . . . .	111
3.3.1	Introduction . . . . .	111
3.3.2	Kinetic Representation . . . . .	111
3.3.3	Kinetic Factors . . . . .	112
3.3.4	Experimental Procedures . . . . .	112
3.3.5	Specific Components . . . . .	113
3.3.6	Summary . . . . .	114
	References . . . . .	115
<b>4</b>	<b>Sterilization, Pasteurization and Cooking Criteria . . . . .</b>	<b>123</b>
4.1	Sterilization Value . . . . .	123
4.1.1	Definitions . . . . .	123
4.1.2	Lethal Rates . . . . .	123
4.1.3	Reference Temperatures . . . . .	124

4.1.4	A processing Point of View to Derive $F$ value	127
4.1.5	Integrated $F$ -values, $F_S$	128
4.1.6	$F$ -values for Cans of Differing Sizes	129
4.1.7	Arrhenius Approach	130
4.2	Cooking Values	131
4.2.1	Historical Perspective	131
4.2.2	Origin and Rationale of Cooking Value	133
4.2.3	Quality Retention	134
4.3	Pasteurization Value	134
4.4	Minimally Processed Foods	135
4.4.1	Acidified Products	135
4.4.2	Pasteurized/Chilled Products	136
4.4.3	Electrical Methods of Heating	136
4.4.4	Other Processes	137
4.5	Process Achievement Standards	137
4.5.1	Sterilization	137
4.5.2	Cooking	138
	References	138
<b>5</b>	<b>Heat Penetration in Packaged Foods</b>	<b>142</b>
5.1	Introduction	142
5.1.1	Heat Transfer and Product Characteristics	142
5.2	Experimental Determination	145
5.2.1	Temperature Monitoring	145
5.2.2	Thermocouple Errors	147
5.2.3	Thermocouple Calibration	148
5.2.4	Thermocouple Location: Slowest Heating Point	148
5.2.5	Model Systems	150
5.3	Graphical Analysis of Heat Penetration Data	151
5.3.1	The Linear Plot	151
5.3.2	The Semi-logarithmic Plot	152
5.3.3	Analysis of Heat Penetration Graphs	152
5.4	Theoretical Analysis of Heat Penetration Curves	159
5.4.1	Conduction-Heating Packs	159
5.4.2	Convection-Heating Packs	160
5.4.3	Computer Modeling	161
5.5	Factors Affecting Heat Penetration	161
5.5.1	Effect of Container Shape and Dimensions	161
5.5.2	Effect of Initial Temperature	163
5.5.3	Effect of Position Inside the Container	164
5.5.4	Effect of Headspace	164
5.5.5	Effect of Variation of Physical Properties with Temperature	164
5.5.6	Effect of External Heat-transfer Coefficients	164

5.5.7	Effect of Container Material and Thickness . . . . .	166
5.5.8	Effect of Can Rotation . . . . .	166
5.5.9	Statistical Aspects of Heat Penetration Data . . . . .	167
5.5.10	Extrapolation of Heat Penetration Data . . . . .	167
5.6	Simulation of Thermal Processing of Non-symmetric and Irregular-Shaped Foods Vacuum Packed in Retort Pouches: A Numerical Example . . . . .	167
5.6.1	Reverse Engineering by 3-D Digitizing . . . . .	168
5.6.2	Simulation of Heat Conduction Processes . . . . .	169
5.6.3	Finite Element Analysis . . . . .	170
5.6.4	Experimental Validation . . . . .	170
References	. . . . .	171
<b>6</b>	<b>Process Evaluation Techniques . . . . .</b>	<b>176</b>
6.1	Determination of $F$ -Values: Process Safety . . . . .	176
6.2	The General Method . . . . .	176
6.2.1	Graphical Methods . . . . .	177
6.2.2	Numerical Methods . . . . .	178
6.2.3	An Extension of General Method: <i>Revisited General Method</i> (RGM). . . . .	181
6.3	Analytical Methods . . . . .	189
6.3.1	Constant Temperature with Time . . . . .	190
6.3.2	Linear Temperature Gradient. . . . .	190
6.3.3	Exponential Temperature Rise. . . . .	190
6.3.4	The Exponential Integral . . . . .	191
6.4	Some Formula Methods . . . . .	192
6.4.1	Introduction . . . . .	192
6.4.2	Ball's Methods . . . . .	192
6.4.3	Gillespi's Method . . . . .	201
6.4.4	Hayakawa's Method . . . . .	206
6.4.5	Other Methods . . . . .	209
6.5	Mass-average Sterilizing Values . . . . .	213
6.6	Some Factors Affecting $F$ -Values . . . . .	214
6.6.1	Introduction . . . . .	214
6.6.2	Statistical Variability of $F$ -Values . . . . .	215
6.7	Microbiological Methods . . . . .	218
6.7.1	Introduction . . . . .	218
6.7.2	Inoculated Pack Method . . . . .	218
6.7.3	Encapsulated Spore Method . . . . .	219
6.7.4	Biological and Chemical Indicators . . . . .	219
6.7.5	Conclusion. . . . .	222
6.8	A Guide to Sterilization Values . . . . .	223
6.9	Computerised Process Calculations . . . . .	224
References	. . . . .	227

<b>7</b>	<b>Quality Optimization</b> .....	<b>239</b>
7.1	Introduction .....	239
7.2	Cooking versus Microbial Inactivation .....	240
7.3	Process Evaluation .....	242
7.3.1	Some Models for Predicting Nutrient and Cooking Effects .....	242
7.3.2	Some Typical C-values .....	243
7.4	Optimization of Thermal Processing Conditions .....	244
7.4.1	Graphical Approach .....	244
7.4.2	Optimization Models .....	246
7.5	Quality Assessment Through Mass Balance .....	258
7.5.1	Demonstration Examples .....	259
7.5.2	Corollary .....	262
7.6	Conclusions .....	262
	References .....	262
<b>8</b>	<b>Engineering Aspects of Thermal Processing</b> .....	<b>270</b>
8.1	Thermal Processing Equipment .....	270
8.1.1	Introduction .....	270
8.1.2	Batch Retorts .....	273
8.1.3	Continuous Cookers .....	277
8.1.4	Heat Transfer Media .....	280
8.2	Total and Transient Energy Consumption in Batch Retort Processing .....	292
8.2.1	Mathematical Model for Food Material .....	293
8.2.2	Mass and Energy Balance During Venting .....	293
8.2.3	Mass and Energy Consumption between Venting and Holding Time (To Reach Process Temperature) .....	295
8.2.4	Mass and Energy Balance During Holding Time .....	296
8.2.5	Numerical Results .....	297
8.3	Pressures in Containers .....	297
8.3.1	Development of Internal Pressures .....	297
8.3.2	Internal Pressure Calculation .....	298
8.3.3	Processing Requirements .....	299
8.3.4	Semi-rigid Containers .....	299
8.4	Mechanical Agitation and Rotation of Cans .....	300
8.4.1	End-over-end Agitation .....	300
8.4.2	Axial Rotation and Spin Cooking .....	300
8.4.3	Steritort and Orbitort Processes .....	304
8.4.4	Shaka™ Retort Process .....	304
8.5	Commercial Pasteurizers .....	304
8.6	Computer Simulation of Fluid Dynamics Heat Transfer .....	305
8.7	Batch Processing and Retort Scheduling .....	305
8.7.1	Batch Processing Problem Structure in Canned Foods .....	306
8.7.2	Batch Processing in Canned Food Plants .....	307

8.7.3	The Hierarchical Approach . . . . .	308
8.7.4	Retort Scheduling . . . . .	308
8.8	Simultaneous Sterilization of Different Product Lots in the Same Retort . . . . .	312
8.8.1	Simultaneous Sterilization Characterization . . . . .	313
8.8.2	Mathematical Formulation for Simultaneous Sterilization . . . . .	313
8.8.3	Computational Procedure . . . . .	315
8.8.4	Expected Advantages on the Implementation of Simultaneous Sterilization . . . . .	315
	References . . . . .	315
<b>9</b>	<b>Retort Control . . . . .</b>	<b>325</b>
9.1	Process Instrumentation . . . . .	325
9.1.1	Introduction . . . . .	325
9.1.2	Temperature Measurement . . . . .	326
9.1.3	Pressure Measurement . . . . .	328
9.1.4	Water Level . . . . .	328
9.1.5	Rotation Monitors . . . . .	329
9.1.6	Lethality Measurement . . . . .	329
9.2	Process Control . . . . .	330
9.2.1	Introduction . . . . .	330
9.2.2	Control Valves and Actuators . . . . .	331
9.2.3	Interfaces . . . . .	331
9.2.4	Control Systems . . . . .	332
9.2.5	Computer Control . . . . .	332
9.2.6	Process Dynamics . . . . .	333
9.3	Retort Control . . . . .	334
9.3.1	Control of Batch Retorts . . . . .	334
9.3.2	Efficient and General On-line Correction of Process Deviations in Batch Retort . . . . .	335
9.3.3	Control of Hydrostatic Sterilizers . . . . .	341
9.3.4	Control of Continuous Reel and Spiral Pressure Cookers . . . . .	342
9.3.5	Derived-value Control . . . . .	342
9.3.6	Guidelines for Computer Control . . . . .	343
9.4	Industrial Automation of Batch Retorts . . . . .	343
	References . . . . .	349
<b>10</b>	<b>Safety Aspects of Thermal Processing . . . . .</b>	<b>354</b>
10.1	Introduction . . . . .	354
10.2	Information Sources . . . . .	354
10.2.1	Legislation and Codes of Practice . . . . .	354
10.2.2	GMP Guidelines and Recommendations . . . . .	355

10.2.3	Technical Training . . . . .	355
10.3	Some Techniques for the Implementation of GMP . . . . .	356
10.3.1	HACCP Techniques . . . . .	356
10.3.2	Process Audits . . . . .	357
10.4	Aspects of GMP . . . . .	357
10.4.1	Identification of Critical Factors . . . . .	357
10.4.2	Process Deviations . . . . .	359
10.5	Thermal Process Validation . . . . .	359
10.5.1	Process Establishment . . . . .	359
10.5.2	Lethality Assurance . . . . .	360
10.5.3	Records . . . . .	360
	References . . . . .	361
	<b>Appendix A: Kinetic Factors for Microbial Inactivation . . . . .</b>	<b>363</b>
	<b>Appendix B: Kinetic Factors for Quality Attributes . . . . .</b>	<b>375</b>
	<b>Appendix C: Heat Penetration Protocols . . . . .</b>	<b>392</b>
	<b>Appendix D: FDA Food Process Filing . . . . .</b>	<b>393</b>
	<b>Index . . . . .</b>	<b>394</b>