

Contents

Preface *XXI*

List of Contributors *XXIII*

1	Postharvest Handling and Preparation of Foods for Processing	1
	<i>Alistair S. Grandison</i>	
1.1	Introduction	1
1.2	Properties of Raw Food Materials and Their Susceptibility to Deterioration and Damage	2
1.2.1	Raw Material Properties	3
1.2.1.1	Geometric Properties	3
1.2.1.2	Colour	4
1.2.1.3	Texture	5
1.2.1.4	Flavour	5
1.2.1.5	Functional Properties	5
1.2.2	Raw Material Specifications	6
1.2.3	Deterioration of Raw Materials	7
1.2.4	Damage to Raw Materials	7
1.2.5	Improving Processing Characteristics Through Selective Breeding and Genetic Engineering	8
1.3	Storage and Transportation of Raw Materials	9
1.3.1	Storage	9
1.3.1.1	Temperature	11
1.3.1.2	Humidity	12
1.3.1.3	Composition of Atmosphere	12
1.3.1.4	Other Considerations	13
1.3.2	Transportation	13
1.4	Raw Material Cleaning	14
1.4.1	Dry Cleaning Methods	14
1.4.2	Wet Cleaning Methods	18
1.4.3	Peeling	20
1.5	Sorting and Grading	21
1.5.1	Criteria and Methods of Sorting	21

- 1.5.2 Grading 24
- 1.6 Blanching 26
 - 1.6.1 Mechanisms and Purposes of Blanching 26
 - 1.6.2 Processing Conditions 27
 - 1.6.3 Blanching Equipment 28
- 1.7 Sulphiting of Fruits and Vegetables 29
- References 30

2 Thermal Processing 33

Michael J. Lewis

- 2.1 Introduction 33
 - 2.1.1 Reasons for Heating Foods 33
 - 2.1.2 Safety and Quality Issues 34
 - 2.1.3 Product Range 35
- 2.2 Reaction Kinetics 36
 - 2.2.1 Microbial Inactivation 36
 - 2.2.2 Heat Resistance at Constant Temperature 36
- 2.3 Temperature Dependence 39
 - 2.3.1 Batch and Continuous Processing 41
 - 2.3.2 Continuous Heat Exchangers 43
- 2.4 Heat Processing Methods 48
 - 2.4.1 Thermisation 48
 - 2.4.2 Pasteurisation 48
 - 2.4.2.1 HTST Pasteurisation 49
 - 2.4.2.2 Tunnel (Spray) Pasteurisers 53
 - 2.4.3 Sterilisation 53
 - 2.4.3.1 In-Container Processing 53
 - 2.4.3.2 UHT Processing 61
 - 2.4.3.3 Special Problems with Viscous and Particulate Products 67
- 2.5 Filling Procedures 68
- 2.6 Storage 68
- References 69

3 Evaporation and Dehydration 71

James G. Brennan

- 3.1 Evaporation (Concentration, Condensing) 71
 - 3.1.1 General Principles 71
 - 3.1.2 Equipment Used in Vacuum Evaporation 73
 - 3.1.2.1 Vacuum Pans 73
 - 3.1.2.2 Short Tube Vacuum Evaporators 74
 - 3.1.2.3 Long Tube Evaporators 75
 - 3.1.2.4 Plate Evaporators 76
 - 3.1.2.5 Agitated Thin Film Evaporators 77
 - 3.1.2.6 Centrifugal Evaporators 77
 - 3.1.2.7 Ancillary Equipment 78

3.1.3	Multiple-Effect Evaporation (MEE)	78
3.1.4	Vapour Recompression	79
3.1.5	Applications for Evaporation	80
3.1.5.1	Concentrated Liquid Products	80
3.1.5.2	Evaporation as a Preparatory Step to Further Processing	82
3.1.5.3	The Use of Evaporation to Reduce Transport, Storage and Packaging Costs	83
3.2	Dehydration (Drying)	85
3.2.1	General Principles	85
3.2.2	Drying Solid Foods in Heated Air	86
3.2.3	Equipment Used in Hot Air Drying of Solid Food Pieces	88
3.2.3.1	Cabinet (Tray) Drier	88
3.2.3.2	Tunnel Drier	89
3.2.3.3	Conveyor (Belt) Drier	89
3.2.3.4	Bin Drier	90
3.2.3.5	Fluidised Bed Drier	90
3.2.3.6	Pneumatic (Flash) Drier	93
3.2.3.7	Rotary Drier	93
3.2.4	Drying of Solid Foods by Direct Contact With a Heated Surface	94
3.2.5	Equipment Used in Drying Solid Foods by Contact With a Heated Surface	95
3.2.5.1	Vacuum Cabinet (Tray or Shelf) Drier	95
3.2.5.2	Double Cone Vacuum Drier	95
3.2.6	Freeze Drying (Sublimation Drying, Lyophilisation) of Solid Foods	96
3.2.7	Equipment Used in Freeze Drying Solid Foods	97
3.2.7.1	Cabinet (Batch) Freeze Drier	97
3.2.7.2	Tunnel (SemiContinuous) Freeze Drier	98
3.2.7.3	Continuous Freeze Driers	99
3.2.7.4	Vacuum Spray Freeze Drier	99
3.2.8	Drying by the Application of Radiant (Infrared) Heat	100
3.2.9	Drying by the Application of Dielectric Energy	100
3.2.10	Osmotic Dehydration	102
3.2.11	Sun and Solar Drying	104
3.2.12	Drying Food Liquids and Slurries in Heated Air	105
3.2.12.1	Spray Drying	105
3.2.13	Drying Liquids and Slurries by Direct Contact With a Heated Surface	110
3.2.13.1	Drum (Roller, Film) Drier	110
3.2.13.2	Vacuum Band (Belt) Drier	112
3.2.14	Other Methods Used for Drying Liquids and Slurries	113
3.2.15	Applications of Dehydration	114
3.2.15.1	Dehydrated Vegetable Products	114
3.2.15.2	Dehydrated Fruit Products	116
3.2.15.3	Dehydrated Dairy Products	117

3.2.15.4	Instant Coffee and Tea	118
3.2.15.5	Dehydrated Meat Products	118
3.2.15.6	Dehydrated Fish Products	119
3.2.16	Stability of Dehydrated Foods	119
	References	121
4	Freezing	125
	<i>Jose Mauricio Pardo and Keshavan Niranjan</i>	
4.1	Introduction	125
4.2	Refrigeration Methods and Equipment	125
4.2.1	Plate Contact Systems	126
4.2.3	Immersion and Liquid Contact Refrigeration	127
4.2.4	Cryogenic freezing	127
4.3	Low Temperature Production	127
4.3.1	Mechanical Refrigeration Cycle	129
4.3.1.2	The Real Refrigeration Cycle (Standard Vapour Compression Cycle)	131
4.3.2	Equipment for a Mechanical Refrigeration System	132
4.3.2.1	Evaporators	132
4.3.2.2	Condensers	133
4.3.2.3	Compressors	135
4.3.2.4	Expansion Valves	135
4.3.2.5	Refrigerants	136
4.3.3	Common Terms Used in Refrigeration System Design	137
4.3.3.1	Cooling Load	137
4.3.3.2	Coefficient of Performance (COP)	137
4.3.3.3	Refrigerant Flow Rate	138
4.3.3.4	Work Done by the Compressor	138
4.3.3.5	Heat Exchanged in the Condenser and Evaporator	138
4.4	Freezing Kinetics	138
4.4.1	Formation of the Microstructure During Solidification	140
4.4.2	Mathematical Models for Freezing Kinetics	141
4.4.2.1	Neumann's Model	141
4.4.2.2	Plank's Model	142
4.4.2.3	Cleland's Model	142
4.5	Effects of Refrigeration on Food Quality	143
	References	144
5	Irradiation	147
	<i>Alistair S. Grandison</i>	
5.1	Introduction	147
5.2	Principles of Irradiation	147
5.2.1	Physical Effects	148
5.2.2	Chemical Effects	152
5.2.3	Biological Effects	153

5.3	Equipment	154
5.3.1	Isotope Sources	154
5.3.2	Machine Sources	157
5.3.3	Control and Dosimetry	159
5.4	Safety Aspects	160
5.5	Effects on the Properties of Food	160
5.6	Detection Methods for Irradiated Foods	162
5.7	Applications and Potential Applications	163
5.7.1	General Effects and Mechanisms of Irradiation	164
5.7.1.1	Inactivation of Microorganisms	164
5.7.1.2	Inhibition of Sprouting	166
5.7.1.3	Delay of Ripening and Senescence	166
5.7.1.4	Insect Disinfestation	166
5.7.1.5	Elimination of Parasites	167
5.7.1.6	Miscellaneous Effects on Food Properties and Processing	167
5.7.1.7	Combination Treatments	167
5.7.2	Applications to Particular Food Classes	167
5.7.2.1	Meat and Meat Products	167
5.7.2.2	Fish and Shellfish	169
5.7.2.3	Fruits and Vegetables	169
5.7.2.4	Bulbs and Tubers	170
5.7.2.5	Spices and Herbs	170
5.7.2.6	Cereals and Cereal Products	170
5.7.2.7	Other Miscellaneous Foods	170
	References	171

6 High Pressure Processing 173

Margaret F. Patterson, Dave A. Ledward and Nigel Rogers

6.1	Introduction	173
6.2	Effect of High Pressure on Microorganisms	176
6.2.1	Bacterial Spores	176
6.2.2	Vegetative Bacteria	177
6.2.3	Yeasts and Moulds	177
6.2.4	Viruses	178
6.2.5	Strain Variation Within a Species	178
6.2.6	Stage of Growth of Microorganisms	178
6.2.7	Magnitude and Duration of the Pressure Treatment	179
6.2.8	Effect of Temperature on Pressure Resistance	179
6.2.9	Substrate	179
6.2.10	Combination Treatments Involving Pressure	180
6.2.11	Effect of High Pressure on the Microbiological Quality of Foods	180
6.3	Ingredient Functionality	181
6.4	Enzyme Activity	183
6.5	Foaming and Emulsification	185

6.6	Gelation	187
6.7	Organoleptic Considerations	189
6.8	Equipment for HPP	190
6.8.1	'Continuous' System	190
6.8.2	'Batch' System	191
6.9	Pressure Vessel Considerations	193
6.9.1	HP Pumps	194
6.9.2	Control Systems	195
6.10	Current and Potential Applications of HPP for Foods	195
	References	197
7	Pulsed Electric Field Processing, Power Ultrasound and Other Emerging Technologies	201
	<i>Craig E. Leadley and Alan Williams</i>	
7.1	Introduction	201
7.2	Pulsed Electric Field Processing	203
7.2.1	Definition of Pulsed Electric Fields	203
7.2.2	Pulsed Electric Field Processing – A Brief History	203
7.2.3	Effects of PEF on Microorganisms	204
7.2.3.1	Electrical Breakdown	204
7.2.3.2	Electroporation	205
7.2.4	Critical Factors in the Inactivation of Microorganisms Using PEF	205
7.2.4.1	Process Factors	205
7.2.4.2	Product Factors	206
7.2.4.3	Microbial Factors	206
7.2.5	Effects of PEF on Food Enzymes	206
7.2.6	Basic Engineering Aspects of PEF	208
7.2.6.1	Pulse Shapes	208
7.2.6.2	Chamber Designs	210
7.2.7	Potential Applications for PEF	211
7.2.7.1	Preservation Applications	211
7.2.7.2	Nonpreservation Applications	212
7.2.8	The Future for PEF	213
7.3	Power Ultrasound	214
7.3.1	Definition of Power Ultrasound	214
7.3.2	Generation of Power Ultrasound	215
7.3.3	System Types	216
7.3.3.1	Ultrasonic Baths	216
7.3.3.2	Ultrasonic Probes	216
7.3.3.3	Parallel Vibrating Plates	217
7.3.3.4	Radial Vibrating Systems	217
7.3.3.5	Airborne Power Ultrasound Technology	217
7.3.4	Applications for Power Ultrasound in the Food Industry	218
7.3.4.1	Ultrasonically Enhanced Oxidation	218

7.3.4.2	Ultrasonic Stimulation of Living Cells	218
7.3.4.3	Ultrasonic Emulsification	220
7.3.4.4	Ultrasonic Extraction	220
7.3.4.5	Ultrasound and Meat Processing	220
7.3.4.6	Crystallisation	220
7.3.4.7	Degassing	221
7.3.4.8	Filtration	221
7.3.4.9	Drying	222
7.3.4.10	Effect of Ultrasound on Heat Transfer	222
7.3.5	Inactivation of Microorganisms Using Power Ultrasound	222
7.3.5.1	Mechanism of Ultrasound Action	222
7.3.5.2	Factors Affecting Cavitation	223
7.3.5.3	Factors Affecting Microbiological Sensitivity to Ultrasound	224
7.3.5.4	Effect of Treatment Medium	224
7.3.5.5	Combination Treatments	225
7.3.6	Effect of Power Ultrasound on Enzymes	227
7.3.7	Effects of Ultrasound on Food Quality	227
7.3.8	The Future for Power Ultrasound	228
7.4	Other Technologies with Potential	229
7.4.1	Pulsed Light	229
7.4.2	High Voltage Arc Discharge	230
7.4.3	Oscillating Magnetic Fields	230
7.4.4	Plasma Processing	230
7.4.5	Pasteurisation Using Carbon Dioxide	231
7.5	Conclusions	231
	References	232
8	Baking, Extrusion and Frying	237
	<i>Bogdan J. Dobraszczyk, Paul Ainsworth, Senol Ibanoglu and Pedro Bouchon</i>	
8.1	Baking Bread	237
8.1.1	General Principles	237
8.1.2	Methods of Bread Production	238
8.1.2.1	Bulk Fermentation	239
8.1.2.2	Chorleywood Bread Process	239
8.1.3	The Baking Process	242
8.1.3.1	Mixing	242
8.1.3.2	Fermentation (Proof)	242
8.1.3.3	Baking	243
8.1.4	Gluten Polymer Structure, Rheology and Baking	244
8.1.5	Baking Quality and Rheology	249
8.2	Extrusion	251
8.2.1	General Principles	251
8.2.1.1	The Extrusion Process	252
8.2.1.2	Advantages of the Extrusion Process	253

8.2.2	Extrusion Equipment	254
8.2.2.1	Single-Screw Extruders	255
8.2.2.2	Twin-Screw Extruders	256
8.2.2.3	Comparison of Single- and Twin-Screw Extruders	258
8.2.3	Effects of Extrusion on the Properties of Foods	259
8.2.3.1	Extrusion of Starch-Based Products	259
8.2.3.2	Nutritional Changes	264
8.2.3.3	Flavour Formation and Retention During Extrusion	267
8.3	Frying	269
8.3.1	General Principles	269
8.3.1.1	The Frying Process	270
8.3.1.2	Fried Products	270
8.3.2	Frying Equipment	272
8.3.2.1	Batch Frying Equipment	272
8.3.2.2	Continuous Frying Equipment	272
8.3.2.3	Oil-Reducing System	273
8.3.3	Frying Oils	274
8.3.4	Potato Chip and Potato Crisp Production	275
8.3.4.1	Potato Chip Production	276
8.3.4.2	Potato Crisp Production	277
8.3.5	Heat and Mass Transfer During Deep-Fat Frying	278
8.3.6	Modelling Deep-Fat Frying	279
8.3.7	Kinetics of Oil Uptake	280
8.3.8	Factors Affecting Oil Absorption	280
8.3.9	Microstructural Changes During Deep-Fat Frying	281
	References	283
9	Packaging	291
	<i>James G. Brennan and Brian P. F. Day</i>	
9.1	Introduction	291
9.2	Factors Affecting the Choice of a Packaging Material and/or Container for a Particular Duty	292
9.2.1	Mechanical Damage	292
9.2.2	Permeability Characteristics	292
9.2.3	Greaseproofness	294
9.2.4	Temperature	294
9.2.5	Light	295
9.2.6	Chemical Compatibility of the Packaging Material and the Contents of the Package	295
9.2.7	Protection Against Microbial Contamination	297
9.2.8	In-Package Microflora	297
9.2.9	Protection Against Insect and Rodent Infestation	297
9.2.10	Taint	298
9.2.11	Tamper-Evident/Resistant Packages	299
9.2.12	Other Factors	299

9.3	Materials and Containers Used for Packaging Foods	300
9.3.1	Papers, Paperboards and Fibreboards	300
9.3.1.1	Papers	300
9.3.1.2	Paperboards	301
9.3.1.3	Moulded Pulp	302
9.3.1.4	Fibreboards	302
9.3.1.5	Composite Containers	303
9.3.2	Wooden Containers	303
9.3.3	Textiles	303
9.3.4	Flexible Films	304
9.3.4.1	Regenerated Cellulose	305
9.3.4.2	Cellulose Acetate	306
9.3.4.3	Polyethylene	306
9.3.4.4	Polyvinyl Chloride	306
9.3.4.5	Polyvinylidene Chloride	307
9.3.4.6	Polypropylene	307
9.3.4.7	Polyester	308
9.3.4.8	Polystyrene	308
9.3.4.9	Polyamides	308
9.3.4.10	Polycarbonate	309
9.3.4.11	Polytetrafluoroethylene	309
9.3.4.12	Ionomers	309
9.3.4.13	Ethylene-vinyl Acetate Copolymers	309
9.3.5	Metallised Films	310
9.3.6	Flexible Laminates	310
9.3.7	Heat-Sealing Equipment	311
9.3.8	Packaging in Flexible Films and Laminates	312
9.3.9	Rigid and Semirigid Plastic Containers	314
9.3.9.1	Thermoforming	314
9.3.9.2	Blow Moulding	315
9.3.9.3	Injection Moulding	315
9.3.9.4	Compression Moulding	315
9.3.10	Metal Materials and Containers	315
9.3.10.1	Aluminium Foil	316
9.3.10.2	Tinplate	316
9.3.10.3	Electrolytic Chromium-Coated Steel	319
9.3.10.4	Aluminium Alloy	319
9.3.10.5	Metal Containers	320
9.3.11	Glass and Glass Containers	322
9.4	Modified Atmosphere Packaging	325
9.5	Aseptic Packaging	329
9.6	Active Packaging	331
9.6.1	Background Information	331
9.6.2	Oxygen Scavengers	334
9.6.3	Carbon Dioxide Scavengers/Emitters	337

9.6.4	Ethylene Scavengers	337
9.6.5	Ethanol Emitters	339
9.6.6	Preservative Releasers	340
9.6.7	Moisture Absorbers	341
9.6.8	Flavour/Odour Adsorbers	342
9.6.9	Temperature Control Packaging	343
9.6.10	Food Safety, Consumer Acceptability and Regulatory Issues	344
9.6.11	Conclusions	345
	References	346

10 Safety in Food Processing 351

Carol A. Wallace

10.1	Introduction	351
10.2	Safe Design	351
10.2.1	Food Safety Hazards	352
10.2.2	Intrinsic Factors	354
10.2.3	Food Processing Technologies	355
10.2.4	Food Packaging Issues	355
10.3	Prerequisite Good Manufacturing Practice Programmes	355
10.3.1	Prerequisite Programmes – The Essentials	357
10.3.2	Validation and Verification of Prerequisite Programmes	361
10.4	HACCP, the Hazard Analysis and Critical Control Point System	362
10.4.1	Developing a HACCP System	362
10.4.2	Implementing and Maintaining a HACCP System	370
10.4.3	Ongoing Control of Food Safety in Processing	370
	References	371

11 Process Control In Food Processing 373

Keshavan Niranjana, Araya Ahromrit and Ahok S. Khare

11.1	Introduction	373
11.2	Measurement of Process Parameters	373
11.3	Control Systems	374
11.3.1	Manual Control	374
11.3.2	Automatic Control	376
11.3.2.1	On/Off (Two Position) Controller	376
11.3.2.2	Proportional Controller	377
11.3.2.3	Proportional Integral Controller	378
11.3.2.4	Proportional Integral Derivative Controller	379
11.4	Process Control in Modern Food Processing	380
11.4.1	Programmable Logic Controller	381
11.4.2	Supervisory Control and Data Acquisition	381
11.4.3	Manufacturing Execution Systems	382
11.5	Concluding Remarks	384
	References	384

12	Environmental Aspects of Food Processing	385
	<i>Niharika Mishra, Ali Abd El-Aal Bakr and Keshavan Niranjana</i>	
12.1	Introduction	385
12.2	Waste Characteristics	386
12.2.1	Solid Wastes	387
12.2.2	Liquid Wastes	387
12.2.3	Gaseous Wastes	387
12.3	Wastewater Processing Technology	387
12.4	Resource Recovery From Food Processing Wastes	388
12.5	Environmental Impact of Packaging Wastes	389
12.5.1	Packaging Minimisation	389
12.5.2	Packaging Materials Recycling	390
12.6	Refrigerents	392
12.7	Energy Issues Related to Environment	394
12.8	Life Cycle Assessment	396
	References	397
13	Water and Waste Treatment	399
	<i>R. Andrew Wilbey</i>	
13.1	Introduction	399
13.2	Fresh Water	399
13.2.1	Primary Treatment	400
13.2.2	Aeration	401
13.2.3	Coagulation, Flocculation and Clarification	401
13.2.4	Filtration	403
13.2.5	Disinfection	406
13.2.5.1	Chlorination	406
13.2.5.2	Ozone	408
13.2.6	Boiler Waters	409
13.2.7	Refrigerant Waters	410
13.3	Waste Water	410
13.3.1	Types of Waste from Food Processing Operations	411
13.3.2	Physical Treatment	412
13.3.3	Chemical Treatment	413
13.3.4	Biological Treatments	413
13.3.4.1	Aerobic Treatment – Attached Films	414
13.3.4.2	Aerobic Treatment – Suspended Biomass	417
13.3.4.3	Aerobic Treatment – Low Technology	419
13.3.4.4	Anaerobic Treatments	419
13.3.4.5	Biogas Utilisation	424
13.4	Sludge Disposal	425
13.5	Final Disposal of Waste Water	425
	References	426

14	Separations in Food Processing	429
	<i>James G. Brennan, Alistair S. Grandison and Michael J. Lewis</i>	
14.1	Introduction	429
14.1.1	Separations from Solids	430
14.1.1.1	Solid-Solid Separations	430
14.1.1.2	Separation From a Solid Matrix	430
14.1.2	Separations From Liquids	430
14.1.2.1	Liquid-Solid Separations	431
14.1.2.2	Immiscible Liquids	431
14.1.2.3	General Liquid Separations	431
14.1.3	Separations From Gases and Vapours	432
14.2	Solid-Liquid Filtration	432
14.2.1	General Principles	432
14.2.2	Filter Media	434
14.2.3	Filter Aids	434
14.2.4	Filtration Equipment	435
14.2.4.1	Pressure Filters	435
14.2.4.2	Vacuum Filters	439
14.2.4.3	Centrifugal Filters (Filtering Centrifugals, Basket Centrifuges)	440
14.2.5	Applications of Filtration in Food Processing	442
14.2.5.1	Edible Oil Refining	442
14.2.5.2	Sugar Refining	442
14.2.5.3	Beer Production	443
14.2.5.4	Wine Making	443
14.3	Centrifugation	444
14.3.1	General Principles	444
14.3.1.1	Separation of Immiscible Liquids	444
14.3.1.2	Separation of Insoluble Solids from Liquids	446
14.3.2	Centrifugal Equipment	447
14.3.2.1	Liquid-Liquid Centrifugal Separators	447
14.3.2.2	Solid-Liquid Centrifugal Separators	448
14.3.3	Applications for Centrifugation in Food Processing	450
14.3.3.1	Milk Products	450
14.3.3.2	Edible Oil Refining	451
14.3.3.3	Beer Production	451
14.3.3.4	Wine Making	451
14.3.3.5	Fruit Juice Processing	451
14.4	Solid-Liquid Extraction (Leaching)	452
14.4.1	General Principles	452
14.4.2	Extraction Equipment	455
14.4.2.1	Single-Stage Extractors	455
14.4.2.2	Multistage Static Bed Extractors	456
14.4.2.3	Multistage Moving Bed Extractors	457
14.4.3	Applications for Solid-Liquid Extraction in Food Processing	459
14.4.3.1	Edible Oil Extraction	459

14.4.3.2	Extraction of Sugar from Sugar Beet	459
14.4.3.3	Manufacture of Instant Coffee	459
14.4.3.4	Manufacture of Instant Tea	460
14.4.3.5	Fruit and Vegetable Juice Extraction	460
14.4.4	The Use of Supercritical Carbon Dioxide as a Solvent	460
14.5	Distillation	462
14.5.1	General Principles	462
14.5.2	Distillation Equipment	466
14.5.2.1	Pot Stills	466
14.5.2.2	Continuous Distillation (Fractionating) Columns	466
14.5.3	Applications of Distillation in Food Processing	467
14.5.3.1	Manufacture of Whisky	467
14.5.3.2	Manufacture of Neutral Spirits	469
14.6	Crystallisation	471
14.6.1	General Principles	471
14.6.1.1	Crystal Structure	471
14.6.1.2	The Crystallisation Process	471
14.6.2	Equipment Used in Crystallisation Operations	475
14.6.3	Food Industry Applications	476
14.6.3.1	Production of Sugar	476
14.6.3.2	Production of Salt	477
14.6.3.3	Salad Dressings and Mayonnaise	477
14.6.3.4	Margarine and Pastry Fats	477
14.6.3.5	Freeze Concentration	477
14.7	Membrane Processes	478
14.7.1	Introduction	478
14.7.2	Terminology	479
14.7.3	Membrane Characteristics	480
14.7.4	Flux Rate	481
14.7.5	Transport Phenomena and Concentration Polarisation	481
14.7.6	Membrane Equipment	483
14.7.7	Membrane Configuration	483
14.7.8	Safety and Hygiene Considerations	486
14.7.9	Applications for Reverse Osmosis	488
14.7.9.1	Milk Processing	488
14.7.9.2	Other Foods	489
14.7.10	Applications for Nanofiltration	489
14.7.11	Applications for Ultrafiltration	490
14.7.11.1	Milk Products	490
14.7.11.2	Oilseed and Vegetable Proteins	492
14.7.11.3	Animal Products	492
14.7.12	Applications for Microfiltration	493
14.8	Ion Exchange	495
14.8.1	General Principles	495
14.8.2	Ion Exchange Equipment	497

14.8.3	Applications of Ion Exchange in the Food Industry	500
14.8.3.1	Softening and Demineralisation	500
14.8.3.2	Decolourisation	502
14.8.3.3	Protein Purification	502
14.8.3.4	Other Separations	503
14.8.4	Conclusion	504
14.9	Electrodialysis	504
14.9.1	General Principles and Equipment	504
14.9.2	Applications for Electrodialysis	506
	References	507
15	Mixing, Emulsification and Size Reduction	513
	<i>James G. Brennan</i>	
15.1	Mixing (Agitation, Blending)	513
15.1.1	Introduction	513
15.1.2	Mixing of Low and Moderate Viscosity Liquids	513
15.1.2.1	Paddle Mixer	515
15.1.2.2	Turbine Mixer	515
15.1.2.3	Propeller Mixer	516
15.1.3	Mixing of High Viscosity Liquids, Pastes and Plastic Solids	517
15.1.3.1	Paddle Mixers	519
15.1.3.2	Pan (Bowl, Can) Mixers	519
15.1.3.3	Kneaders (Dispersers, Masticators)	519
15.1.3.4	Continuous Mixers for Pastelike Materials	519
15.1.3.5	Static Inline Mixers	520
15.1.4	Mixing Dry, Particulate Solids	520
15.1.4.1	Horizontal Screw and Ribbon Mixers	521
15.1.4.2	Vertical Screw Mixers	522
15.1.4.3	Tumbling Mixers	522
15.1.4.4	Fluidised Bed Mixers	523
15.1.5	Mixing of Gases and Liquids	523
15.1.6	Applications for Mixing in Food Processing	524
15.1.6.1	Low Viscosity Liquids	524
15.1.6.2	Viscous Materials	524
15.1.6.3	Particulate Solids	524
15.1.6.4	Gases into Liquids	524
15.2	Emulsification	524
15.2.1	Introduction	524
15.2.2	Emulsifying Agents	526
15.2.3	Emulsifying Equipment	527
15.2.3.1	Mixers	527
15.2.3.2	Pressure Homogenisers	528
15.2.3.3	Hydroshear Homogenisers	530
15.2.3.4	Microfluidisers	530
15.2.3.5	Membrane Homogenisers	530

15.2.3.6	Ultrasonic Homogenisers	530
15.2.3.7	Colloid Mills	531
15.2.4	Examples of Emulsification in Food Processing	532
15.2.4.1	Milk	532
15.2.4.2	Ice Cream Mix	533
15.2.4.3	Cream Liqueurs	533
15.2.4.4	Coffee/Tea Whiteners	533
15.2.4.5	Salad Dressings	534
15.2.4.6	Meat Products	534
15.2.4.7	Cake Products	535
15.2.4.8	Butter	535
15.2.4.9	Margarine and Spreads	536
15.3	Size Reduction (Crushing, Comminution, Grinding, Milling) of Solids	537
15.3.1	Introduction	537
15.3.2	Size Reduction Equipment	540
15.3.2.1	Some Factors to Consider When Selecting Size Reduction Equipment	540
15.3.2.2	Roller Mills (Crushing Rolls)	541
15.3.2.3	Impact (Percussion) Mills	544
15.3.2.4	Attrition Mills	546
15.3.2.5	Tumbling Mills	548
15.3.3	Examples of Size Reduction of Solids in Food Processing	550
15.3.3.1	Cereals	550
15.3.3.2	Chocolate	552
15.3.3.3	Coffee Beans	554
15.3.3.4	Oil Seeds and Nuts	554
15.3.3.5	Sugar Cane	555
	References	556
	Subject Index	559