Table of Contents

Contributors xxv
Preface xxvii

PART 1 INTRODUCTION TO FOOD ENGINEERING **1**

1 The Food Engineer **3**
Felix H. Barron

1.1 Nature of Work and Necessary Skills 3
1.2 Academic and Industry Preparation 4
1.3 Work Opportunities for a Food Engineer 7
1.3.1 Job description sample 1 7
1.3.2 Job description sample 2 8
1.3.3 Job description sample 3 9
1.3.4 Job description sample 4 9
1.3.5 Job description sample 5 10
1.4 Engineering Jobs 12
1.5 Future Opportunities 14
1.6 Conclusions 14
References 14

2 Food Regulations **15**
Kevin M. Keener

2.1 Background 15
2.1.1 Federal Register 16
2.1.2 United States Code 17
2.2 Sanitation Programs 18
2.2.1 Sanitation 18
2.3 Hazard Analyses and Critical Control Point Program (HACCP) 20
2.3.1 Prerequisite programs 21
2.4 Current Good Manufacturing Processes (cGMP) 22
2.5 Meat Processing 24
2.6 Shell Eggs 26
2.6.1 Egg products 27
2.7 Seafood Processing 27
2.8 Fruits, Vegetables, and Nuts 29

2.9 Beverages 29
2.9.1 Alcoholic beverages 29
2.9.2 Carbonated beverages 30
2.9.3 Bottled water 30
2.9.4 Fruit and vegetable juices 31
2.9.5 Pasteurization 32
2.9.6 Milk and milk products 33
2.10 Canned Foods 34
2.11 Foodservice/Restaurants 35
2.12 Export Foods 35
2.13 Imported Foods 36
2.14 Organic Food Processing 38
2.15 Conclusions 39
References 39
Acronyms 42

3 Food Safety Engineering 45
Raghupathy Ramaswamy, Juhee Ahn, V. M. Balasubramaniam, Luis Rodriguez Saona, and Ahmed E. Yousef

3.1 Introduction 45
3.2 Intervention Technologies 46
3.2.1 Novel non-thermal intervention technologies 46
3.2.2 Chemical interventions 50
3.2.3 Hurdle approach 53
3.3 Control/Monitoring/Identification Techniques 54
3.3.1 Chromogenic microbiological media 54
3.3.2 Molecular and immunological assays methods 55
3.3.3 Biosensors 56
3.3.4 Fourier Transform Infrared spectrometry 58
3.4 Packaging Applications in Food Safety 59
3.4.1 Active packaging 60
3.4.2 Intelligent or “Smart” packaging 60
3.4.3 Tamper evident packaging 60
3.5 Tracking and Traceability 61
3.6 Byproducts of Processing 62
3.6.1 Acrylamide 62
3.6.2 3-monochloropropanediol 63
3.7 Conclusions 63
3.8 Acknowledgment 64
References 64

PART 2 FARM MACHINERY DESIGN **71**

4 Farm Machinery Automation for Tillage Planting, Cultivation, and Harvesting **73**
Brian T. Adams

4.1 Introduction 73
4.2 Vehicle Guidance 74
4.2.1 Guidance strategies 75
4.3 Implement Guidance Systems 80
4.4 Guidance Methods 80
4.4.1 Global Positioning System (GPS) 82
4.4.2 Machine vision 84
4.4.3 Dead reckoning 85
4.4.4 Inertial 85
4.4.5 Crop feelers 85
4.4.6 Furrow following 86
4.5 Challenges Facing Autonomous Vehicles 86
4.5.1 Safety 87
4.5.2 Liability 89
4.6 Conclusions 89
References 91
Other Contacts 91

5 Grain Harvesting Machinery Design **93**
H. Mark Hanna and Graeme R. Quick

5.1 Introduction 93
5.2 History 93
5.3 Machine Design: Pre-harvest Issues 94
5.4 Performance Factors 95
5.5 Heads: Grain Platforms, Corn Heads, and Strippers 95
5.6 Feederhouse 99
5.7 Cylinder or Rotor and Concave 99
5.8 Separation: Straw Walkers and Rotary Separation 103
5.9 Cleaning Shoe 104
5.10 Elevators: Clean Grain and Tailings 106
5.11 Grain Bin and Unloading Auger 106
5.12 Other Attachments 107
5.13 Operator's Station, Adjustments, and Monitoring Systems 109
5.14 Field Performance 110
5.15 Grain Damage 110

5.16 Combine Trends 111
References 111

6 Grain Storage Systems Design 113
Ray Allen Bucklin, Sidney Thompson, Ali Abdel-Hadi, Michael Montross

6.1 Introduction 113
6.2 Materials 114
6.3 Physical Properties of Agricultural Grains 114
6.4 Management Factors 115
6.5 Codes 116
6.6 Drying 116
6.6.1 Purpose of drying 116
6.6.2 Classification of dryer types 117
6.6.3 Theory and simulation of drying 119
6.7 Structural Loads 122
6.7.1 Loads caused by the grain 124
6.7.2 Eccentric discharging of grains from a bin 125
6.7.3 Flumes 126
6.8 Stresses in Granular Materials 126
6.9 Temperature Cables 127
6.10 Thermal Loads and Moisture-induced Loads 128
6.11 Conical Grain Bins 129
6.11.1 Flat storage 129
6.11.2 Janssen's equation 132
6.11.3 Flat storage, shallow, and deep bins 134
6.11.4 Loads on hoppers 135
6.12 Snow and Wind Loads 137
6.13 Seismic Loads 141
6.14 Grain Handling 143
6.14.1 Screw conveyors 144
6.14.2 Belt conveyors 146
6.14.3 Bucket elevators 148
6.14.4 Pneumatic conveyors 151
6.15 Chutes 153
6.16 Grain Cleaning 153
6.17 Testers for Measuring Flow Properties 155
6.17.1 Classification of flow testers 156
6.17.2 Examples of flow testers 156
6.18 Modeling of Granular Materials 158
References 162

7 Milking Machines and Milking Parlors 167
Douglas J. Reinemann

7.1 Introduction 167
7.2 The Milking Routine 167
7.3 The Milking Machine 168
7.4 Milking Unit 169
7.5 Milking Systems 172
7.5.1 Pipeline systems 172
7.5.2 Weigh jar systems 172
7.6 Milking System Piping 173
7.7 Vacuum Production 174
7.8 Vacuum Regulation 176
7.9 Vacuum Gauge 177
7.10 Test Ports 178
7.11 Distribution Tank or Interceptor 178
7.12 Receiver Group 178
7.13 Pipe Sizing and Layout 179
7.14 Milkline Sizing—Pipeline Systems 179
7.15 Pulsator Airline Sizing 180
7.16 Main Airline 181
7.17 Vacuum Pump Sizing 181
7.18 Milking Parlors 182
7.19 Milking Parlor Construction Methods 183
7.20 Environmental Control 183
7.21 Milking Parlor Types 184
7.21.1 Herringbone 184
7.21.2 Parallel 185
7.21.3 Side open or tandem 185
7.21.4 Rotary or carousel 186
7.21.5 Flat 186
7.22 Other Milking Parlor Design Elements and Support Equipment 187
7.22.1 Entrance/exit gates 187
7.22.2 Automatic cluster removers 187
7.22.3 Crowd gates 188
7.22.4 Animal identification and data collection/records systems 188
7.23 Milking Parlor Hygiene 189
References 189

PART 3 FOOD PROCESSING OPERATING SYSTEMS AND MACHINERY DESIGN **191**

8 Dairy Product Processing Equipment **193**
H. Doug Goff

8.1 Introduction 193
8.2 Clarification, Separation, and Standardization 194
8.3 Pasteurization 196
8.4 UHT Sterilization 202
8.5 Homogenization 202
8.6 Membrane Processing 205
8.7 Evaporation 205
8.8 Drying 208
8.9 Ice Cream Manufacturing Equipment 210
8.10 Butter Manufacturing Equipment 212
8.11 Cheese Manufacturing Equipment 213
References 214

9 Grain Processing Engineering **215**
Athapol Noomhorm, Imran Ahmad and Porntip Sirisoontaralak

9.1 Introduction 215
9.2 Drying 215
9.2.1 On-farm drying 216
9.3 Pre-storage Grain Treatments 219
9.3.1 Grain damage from insects 220
9.4 Post-harvest Value Additions 225
9.4.1 Artificial aging 225
9.4.2 Aroma enhancement of milled rice 229
9.5 Cooking and Processing 231
9.5.1 Retort packaging 231
9.5.2 Quick cooking brown rice 235
9.6 Quality Evaluation 238
9.6.1 Image analysis 238
9.6.2 Texture evaluation of cooked rice 239
9.7 Conclusions 242
References 242

10 Technology of Processing of Horticultural Crops **251**
Conrad O. Perera, Bronwen Smith

10.1 Introduction 251
10.1.1 General background 251

10.1.2 Importance of fruit and vegetables 251
10.1.3 Fruits and vegetables suitable for processing 252
10.1.4 Location of processing operation 252
10.1.5 Processing systems 252
10.2 Properties of Fruits and Vegetables 253
10.2.1 General background 253
10.2.2 Fruit development 254
10.2.3 Chemical composition 255
10.2.4 Structural features 261
10.3 Biological Deterioration and Control 262
10.4 Methods for Minimizing Deterioration 264
10.4.1 Physical methods of reducing deterioration 264
10.4.2 Methods for preserving fresh fruit and vegetables 266
10.5 General Methods of Fruit and Vegetable Preservation 267
10.5.1 Storage of fresh produce 267
10.5.2 Preservation by manipulation of water activity 267
10.5.3 Chemical preservation 268
10.5.4 Preservation by acidification 269
10.5.5 Preservation with sugar 272
10.5.6 Preservation by heat 272
10.5.7 Food irradiation 273
10.6 Some Important Methods of Processing of Fruits and Vegetables 274
10.6.1 Canning 274
10.6.2 Dehydration 276
10.6.3 Freezing 276
10.6.4 Semi-processing 277
10.6.5 Sugar preserved products 277
10.6.6 Juice processing 278
10.6.7 New trends—including minimal processing 284
10.7 Quality Control/Assurance 287
10.7.1 Traceability 289
10.7.2 HACCP 290
10.8 Fruit and Vegetable Processing Units 290
10.8.1 Preliminary studies 290
10.8.2 Production sites 291
10.8.3 Equipment specifications for processing of horticultural crops 295
References 296

11 Food Drying and Evaporation Processing Operations 303
William L. Kerr

11.1 Introduction 303
11.2 Water in Foods 303

11.3 Types of Water in Foods 305
11.4 Food Stability and Moisture Relationships 306
11.5 Drying 310
11.5.1 Psychrometrics 310
11.6 Drying Curves and Mechanisms of Drying 311
11.7 Types of Dryers 316
11.7.1 Hot air dryers 316
11.7.2 Sun or solar drying 317
11.7.3 Batch dryers 317
11.7.4 Rotary dryers 318
11.7.5 Vacuum dryers 318
11.7.6 Continuous dryers 319
11.7.7 Belt dryers 320
11.7.8 Fluidized bed dryer 320
11.7.9 Puff-drying 320
11.7.10 Drum drying 321
11.7.11 Spray drying 322
11.7.12 Osmotic drying 324
11.7.13 Freeze drying 324
11.8 Quality Changes during Drying 326
11.9 Evaporation 328
11.10 The Basic Evaporator 329
11.10.1 Pan and batch evaporators 329
11.11 Tube Evaporators 330
11.11.1 Short tube evaporator 330
11.11.2 Rising film evaporator 331
11.11.3 Falling film evaporator 331
11.11.4 Rising-falling film evaporator 332
11.11.5 Agitated film evaporator 333
11.12 Single Effect Evaporators 334
11.13 Multi-Effect Evaporators 335
11.14 Mechanical Vapor Recompression 336
11.15 Quality Changes During Evaporation 338
11.16 Conclusion 338
References 339

12 Food Freezing Technology 341
Kasiviswanathan Muthukumarappan, Chenchaiah Marella

12.1 Introduction 341
12.2 Freezing Point Depression 342

12.3 Freezing Process 342
12.4 Phase Change and Ice Crystals Formation 345
12.5 Product Heat Load 346
12.6 Freezing Time Estimations 347
12.6.1 Plank's equation 348
12.6.2 Factors affecting the freezing time 348
12.6.3 Modified Plank's equation 349
12.7 Freezing Equipment 351
12.7.1 Direct contact freezers using cold surface 351
12.7.2 Freezers using air as cooling medium 353
12.7.3 Freezers using liquids as cooling media 357
12.8 Effects of Freezing and Frozen Storage on Foods 359
12.8.1 Effect freezing on physical characteristics 359
12.8.2 Effects of freezing on food constituents 360
12.8.3 Effects of freezing on thermal properties of foods 360
12.9 Developments in Freezing Techniques 362
12.9.1 High pressure freezing 362
12.9.2 Dehydrofreezing 362
12.10 Energy Conservation in Freezing 363
12.11 Scope for Future Focus 363
References 364

13 Heat and Mass Transfer in Food Processing 367
Mohammed Mehdi Farid

13.1 Basic Concepts of Heat and Mass Transfer 367
13.1.1 Conduction heat transfer 368
13.1.2 Forced convection heat transfer 370
13.1.3 Free convection heat transfer 370
13.1.4 Radiation heat transfer 371
13.1.5 Mass diffusion 371
13.1.6 Mass transfer by convection 372
13.2 Case Study 1: Thermal Sterilization Using Computational Fluid Dynamics 372
13.2.1 Simulations of thermal sterilization in a vertical can 374
13.2.2 Simulation of bacteria deactivation during sterilization 375
13.2.3 Simulation of vitamins destruction during sterilizaion 376
13.2.4 Simulation of a horizontal can during sterilization 377
13.2.5 Simulation of a 3-D pouch during sterilization 377
13.3 Case Study 2: New Approach to the Analysis of Heat and Mass Transfer in Drying and Frying 378

13.4 Case Study 3: Microwave Thawing of Frozen Meat 381
13.4.1 Theoretical analysis 383
13.4.2 Discussion of results 386
13.4.3 Nomenclature 386
13.4.4 Greek symbols 389
References 389

14 Food Rheology 391
Qixin Zhong

14.1 Introduction 391
14.2 Basic Concepts in Rheology 391
14.2.1 Stress and strain 391
14.2.2 Constitutive relations and classification of materials 393
14.2.3 The importance of time, Deborah number 395
14.3 Rheology of Fluids 395
14.3.1 Shear strain rates in a laminar flow 395
14.3.2 Apparent viscosity and yield stress 396
14.3.3 Rheological models for fluids 397
14.3.4 Rheometry 400
14.4 Rheology of Semi-Solid Materials 403
14.4.1 Small amplitude oscillatory shear tests 404
14.4.2 Stress relaxation tests 409
14.4.3 Creep tests 410
14.5 Interfacial Rheology 411
14.5.1 Interfacial dilatational rheology 412
14.5.2 Interfacial shear rheology 413
14.6 Conclusions 413
References 414

15 Thermal Processing for Food Sterilization and Preservation 415
Arthur A. Teixeira

15.1 Introduction 415
15.2 Scientific Principles: Food Microbiology Considerations 415
15.2.1 An overview 415
15.2.2 Sterilizing value 416
15.2.3 Process lethality 417
15.2.4 Specification of process lethality 419
15.3 Scientific Principles: (Engineering Heat Transfer Considerations) 420
15.3.1 Steady state (isothermal) heat transfer 420
15.3.2 Unsteady (non-isothermal) heat transfer 420

15.3.3 Heat transfer mechanisms 421
15.3.4 Heat penetration measurement 422
15.4 Process Calculation 423
15.5 Commercial Retort Sterilization Equipment Systems 426
15.5.1 Batch retorts 426
15.5.2 Continuous retort systems 428
15.6 Commercial Aseptic Process Equipment Systems 438
15.7 Low-Acid Canned Food Regulations 443
15.7.1 Plant registration 443
15.7.2 Process filing 444
15.7.3 Personnel training 444
15.7.4 Equipment and procedure 444
15.7.5 Product preparation 445
15.7.6 Establishing scheduled processes 445
15.7.7 Thermal process operations 446
15.7.8 Process deviations 446
15.7.9 Container closure and coding 447
15.7.10 Records and storage 447
15.7.11 Recall planning 448
References 448

16 Food Process Modeling, Simulation and Optimization 449
Gauri Shankar Mittal

16.1 Introduction 449
16.1.1 Modeling 449
16.1.2 Simulation 451
16.2 Modeling Based on Mass and Energy Balances 452
16.2.1 Mass balance 452
16.2.2 Energy balance 454
16.2.3 Reaction kinetics 455
16.2.4 Heat and mass transport equations 456
16.2.5 Initial and boundary conditions 458
16.3 Finite Difference Techniques 459
16.3.1 Finite differences 459
16.3.2 Grid system 461
16.4 Process Modeling and Simulation 461
16.4.1 Example 1: Pasteurization of a beverage in a can—based on energy balance 461
16.4.2 Example 2: Temperature profiles of particulate solids in liquid in a can during pasteurization—energy balances 462

16.4.3 Example 3: Cooking of a spherical product—modeling and simulation, based on heat and mass transfer equations and finite differences 467
16.4.4 Quality kinetics modeling during meatballs frying—based on reaction kinetics 472
16.5 Process Optimization 476
16.5.1 Linear programming 476
16.5.2 Dynamic programming 479
References 482

17 Design of Food Process Controls Systems 485
Mark T. Morgan, Timothy A. Haley

17.1 Introduction 485
17.1.1 Design of food process controls 485
17.2 Benefits of Automation 485
17.3 Computer Integrated Manufacturing 486
17.4 Automation Components and Terminology 488
17.5 Control System Objectives 490
17.5.1 Discrete control 491
17.5.2 Continuous control 494
17.5.3 Block diagrams 494
17.5.4 Closed loop systems 495
17.5.5 PID control algorithm 497
17.5.6 Open loop control systems 501
17.5.7 Predictive control 502
17.5.8 Feed-forward control 503
17.6 Controllers 504
17.6.1 Processor 505
17.6.2 Memory 505
17.6.3 Power supply 505
17.6.4 Input/output terminals (I/O) 506
17.6.5 Chassis 506
17.6.6 Programming device 507
17.6.7 Controller programming 507
17.6.8 HMI—human-machine-interface 510
17.7 Sensor Fundamentals 512
17.7.1 Range and resolution 513
17.7.2 Accuracy and precision 513
17.7.3 Sensor dynamics 514
17.7.4 Rangeability and turndown 516

17.7.5 Sensitivity/gain 516
17.7.6 Linearity 516
17.7.7 Maintenance 516
17.7.8 Specification of sensors 517
17.7.9 Common sensor technologies 518
17.7.10 Transmitters and transducers 539
17.8 Actuators 543
17.8.1 Motors 543
17.8.2 Pumps 544
17.8.3 Control valves 544
17.8.4 Control valve actuators and positioners 546
References 552

18 Ohmic Pasteurization of Meat and Meat Products 553
James Lyng, Brian M. McKenna

18.1 Introduction 553
18.2 Conventional Thermal Methods for the Preservation of Meats 555
18.3 Basic Principle of Ohmic Heating 556
18.3.1 Fundamentals of electrical circuitry 556
18.3.2 Mechanism of ohmic heating 556
18.3.3 Factors influencing heat generation rate 558
18.4 Microbial Inactivation during Ohmic Heating 565
18.5 Quality of Ohmically Heated Meat Products 565
18.6 Economics of Ohmic Processing 568
18.7 Ohmic Heating for Commercial Scale Production of Cooked Meats 568
18.7.1 Ohmic heater control options 568
18.7.2 Packaging for ohmic processing 570
18.7.3 Possible methods for commercial application of ohmic heating to meat 570
18.8 Conclusion and Future Work 572
18.9 Acknowledgements 572
18.10 Abbreviations 572
References 573

19 Food Processing Facility Design 579
Timothy J. Bowser

19.1 Introduction 579
19.2 Background 580
19.3 Key Facility Issues 581

19.3.1 Cross-cutting issues 582
19.3.2 Interacting issues 585
19.3.3 Individual issues 586
19.4 Project Phases 587
19.4.1 Drawings 588
19.4.2 Planning 594
19.4.3 Conceptual design 602
19.4.4 Preliminary design 603
19.4.5 Final design 603
19.4.6 Construction 604
19.4.7 Startup 605
19.5 Conclusion 605
References 605

20 Agricultural Waste Management in Food Processing 609
Conly L. Hansen, Dae-Yeol Cheong

20.1 Introduction 609
20.2 Common Unit Processes Employed in Food Waste Treatment 611
20.2.1 Land application of untreated or partially treated waste 611
20.2.2 Sedimentation, settling and chemical precipitation 611
20.2.3 Dissolved air flotation (DAF) 611
20.2.4 Stabilization ponds 611
20.2.5 Aerated lagoons 612
20.2.6 Anerobic lagoons 612
20.2.7 Other anaerobic processes 612
20.2.8 Activated sludge process 612
20.2.9 Membrane processes 613
20.2.10 Chemical methods 613
20.2.11 Trickling filters 613
20.2.12 Rotating biological discs 613
20.2.13 Disinfection 613
20.3 Characteristics of Wastes and Treatment Types 614
20.3.1 Dairy processing waste 615
20.3.2 Meat, poultry, seafood processing waste 616
20.3.3 Fruit and vegetable processing waste 617
20.3.4 Brewery and distillery waste 618
20.4 Physical-Chemical Treatment Process 619
20.4.1 Screening 619
20.4.2 Sedimentation (settling) 620
20.4.3 Flotation 622

20.4.4 Filtration 623
20.4.5 Coagulation and flocculation 624
20.4.6 Chemical precipitation 626
20.4.7 Disinfection 626
20.4.8 Carbon adsorption 629
20.4.9 Ion exchange 630
20.4.10 Membrane process 630
20.5 Biological Treatment Process 631
20.5.1 Aerobic processes 632
20.5.2 Anaerobic processes 634
20.5.3 Composting processes 642
20.6 Land Treatment of Waste 643
20.6.1 Land application 643
20.6.2 Landfilling 644
20.7 Bioprocess Technology from Waste 646
20.7.1 Reuse of effluent as resource 646
20.7.2 Bio-energy recovery 647
20.7.3 Fuel-ethanol production 649
20.7.4 Chemical production 651
20.7.5 Single-cell protein and biomass 652
20.7.6 Immobilized cells 653
20.8 Conclusions 653
References 656

PART 4 FOOD PACKAGING SYSTEMS AND MACHINERY DESIGN 663

21 Damage Reduction to Food Products during Transportation and Handling ... 665
Jay Singh, Paul Singh

21.1 Introduction 665
21.2 Functions of Packaging 665
21.2.1 Containment 666
21.2.2 Protection 667
21.2.3 Communication 668
21.2.4 Utility 668
21.3 Food Product Categories 670
21.3.1 Meats 670
21.3.2 Seafood 671
21.3.3 Vegetables and fruits 672
21.3.4 Processed versus non-processed 675

21.4 Food Product Distribution Environment 675
21.4.1 Harvesting 675
21.4.2 Packing 675
21.4.3 Shipping 677
21.4.4 Storage and shelf life 677
21.5 Major Causes of Food Spoilage/Damage in Supply Chain 677
21.5.1 Microbiological spoilage 678
21.5.2 Biochemical 678
21.5.3 Chemical 678
21.5.4 Macrobiological spoilage 678
21.5.5 Physical 679
21.6 Packaging Materials 679
21.6.1 Paper 680
21.6.2 Plastic 681
21.6.3 Metal 683
21.6.4 Glass 684
21.7 "Smart" Packaging 684
21.7.1 Active packaging 685
21.7.2 Modified Atmosphere Packaging (MAP) 685
21.7.3 Controlled Atmosphere Packaging (CAP) 686
21.7.4 Intelligent packaging 686
21.8 Trends in Protective Food Packaging of 2000 and Beyond 686
21.8.1 Food packaging trends 686
21.8.2 Damage reduction trends 690
References 692

22 Food Packaging Machinery 695
Harold A. Hughes

22.1 Introduction 695
22.1.1 Containment 695
22.1.2 Protection 695
22.1.3 Communication 695
22.1.4 Utility 696
22.2 Filling Machines 696
22.3 Volumetric Fillers 698
22.3.1 Piston fillers 698
22.3.2 Diaphragm fillers 699
22.3.3 Timed flow fillers 700
22.3.4 Auger filler 700

22.4 Weight Filling 701
22.4.1 Net weight fillers 702
22.4.2 Gross weight fillers 702
22.5 In-Line or Rotary Filling Machines 703
22.5.1 In-line fillers 703
22.5.2 Rotary fillers 704
22.6 Cap Application Machines 705
22.6.1 Chucks and clutches 707
22.6.2 Chuck type press-on cappers 708
22.6.3 Roller type press-on cappers 708
22.7 Induction Capsealing 708
22.8 Flexible Packaging 710
22.9 Form-Fill-Seal Equipment 710
22.9.1 Vertical form-fill-seal machines 711
22.9.2 Horizontal-form-fill-seal 712
22.9.3 Thermo-form-fill-seal 712
22.10 Canning Machinery 713
22.11 Carton Filling and Closing Machinery 715
22.11.1 Carton filling 715
22.12 Metal Detectors 717
22.12.1 Typical metal detector 717

Index 719