

# Contents

Preface.....	xxi
--------------	-----

## ***PART I Fundamentals of Engineering Analysis and Management***

<b>Chapter 1</b> Fundamentals of Heat Transfer, Fluid Mechanics, and Thermodynamics in Food Processing.....	3
1.1 Introduction .....	3
1.2 Heat Transfer in Food Processing.....	4
1.2.1 Modes of Heat Transfer .....	4
1.2.2 Conductive Heat Transfer.....	4
1.2.3 Convective Heat Transfer.....	12
1.2.4 Radiative Heat Transfer .....	16
1.2.5 Phase Change Heat Transfer.....	17
1.2.6 Heat Transfer with Electromagnetic Waves.....	21
1.2.7 Unsteady-State Heat Transfer .....	22
1.3 Fluid Mechanics in Food Processing .....	25
1.3.1 Viscosity of Fluids .....	25
1.3.2 Laws of Fluid Dynamics.....	25
1.3.3 Energy Loss of Fluid Flow .....	27
1.3.4 Fluid Handling Equipment in Food Processing Facilities .....	33
1.4 Thermodynamics in Food Processing.....	34
1.4.1 System and Its States.....	34
1.4.2 Processes and State Changes .....	35
1.4.3 First Law of Thermodynamics .....	35
1.4.4 Second Law of Thermodynamics .....	37
1.4.5 Energy and Exergy .....	37
1.4.6 Loss of Work and Exergy .....	39
1.4.7 Energy and Exergy Efficiencies.....	40
1.5 Summary.....	42
References.....	43
 <b>Chapter 2</b> Fundamentals of Energy Auditing.....	 45
2.1 Introduction.....	45
2.2 Procedures for Energy Audit.....	45
2.2.1 Preparing for an Energy Audit.....	45
2.2.2 Normalizing Energy Consumption Data.....	47

2.2.3	Facility Inspection .....	48
2.2.4	Energy Analysis and Energy Action Plan .....	50
2.2.5	Energy Audit Report.....	51
2.3	Measurements, Instrumentation, and Data Collection .....	52
2.3.1	Dimension Measurement .....	52
2.3.2	Temperature Measurement .....	52
2.3.3	Pressure Measurement.....	53
2.3.4	Fluid and Fuel Flow Measurement .....	53
2.3.5	Combustion Gas Composition Measurement .....	54
2.3.6	Electrical Measurement .....	54
2.3.7	Light Measurement .....	55
2.4	Energy Audit in Food Processing Facilities .....	56
2.5	Summary.....	56
	References.....	56

### **Chapter 3** Energy Project Management in Food Processing

	Facilities.....	57
3.1	Introduction.....	57
3.2	Energy Analysis.....	57
3.2.1	Mass and Energy Flows in a Food Processing Facility .....	57
3.2.2	Energy Sources and Their Quality .....	58
3.2.3	Energy and Exergy Flow in a Food Processing Facility .....	60
3.2.4	Energy and Exergy Efficiencies in a Food Processing Facility.....	62
3.3	Sustainability in the Food Industry.....	65
3.3.1	Sustainable Food Industry.....	65
3.3.2	Improving Energy Efficiency for Sustainability.....	65
3.3.3	Combining Energy Efficiency and Renewables for Sustainability.....	66
3.4	Economic Analysis .....	66
3.4.1	Capital Investment Characteristics .....	66
3.4.2	Time Value of Money .....	67
3.4.3	Depreciation and Taxes.....	70
3.4.4	Cash Flow Diagrams.....	72
3.4.5	Economic Evaluation Methods.....	73
3.4.5.1	Simple Payback Period .....	74
3.4.5.2	Discounted Payback Method.....	74
3.4.5.3	Benefit to Cost Ratio Method.....	75
3.4.5.4	Net Benefits or Savings Method .....	75
3.4.5.5	Internal Rate of Return Method .....	75
3.4.5.6	Life Cycle Cost Method.....	76
3.5	Financial Analysis.....	77
3.6	Energy Management Project Planning, Implementation, and Evaluation.....	78

3.6.1	Energy Management Programs.....	78
3.6.2	Commitment from Leadership.....	80
3.6.3	Training.....	81
3.6.4	Continuous Improvement.....	81
3.6.5	Communication.....	82
3.7	Summary.....	82
	References.....	83

## ***PART II Energy Conservation Technologies Applied to Food Processing Facilities***

<b>Chapter 4</b>	<b>Energy Conservation in Steam Generation and Consumption System.....</b>	<b>87</b>
4.1	Introduction.....	87
4.2	Components of a Steam Generation and Distribution System.....	87
4.3	Steam Generation System.....	88
4.3.1	Components of a Boiler System.....	88
4.3.2	Fuels Used in Boilers.....	89
4.3.3	Energy Analysis for a Steam Generation System.....	91
4.3.4	Heat Loss from a Boiler System.....	94
4.3.5	Energy Conservation Technologies for Steam Generation System.....	96
4.3.5.1	Energy Saving through Optimal Design and Operation.....	96
4.3.5.2	Energy Recovery from Flue Gas.....	97
4.3.5.3	Energy Recovery from Blowdown Water.....	97
4.3.5.4	Maintenance of Boiler.....	98
4.4	Steam Distribution System.....	98
4.4.1	Components of a Steam Distribution System.....	98
4.4.2	Heat Loss and Energy Efficiency of a Steam Distribution System.....	99
4.4.3	Energy Conservation Technologies for a Steam Distribution System.....	99
4.4.3.1	Steam Trap Maintenance and Condensate Recovery.....	99
4.4.3.2	Repairing of Steam Leaks.....	99
4.4.3.3	Insulation Improvement.....	100
4.5	Economic Analysis of Energy Efficiency Improvement for a Steam System.....	103
4.6	Cogeneration.....	103
4.7	Summary.....	104
	References.....	104

<b>Chapter 5</b>	<b>Energy Conservation in Compressed Air System</b> .....	107
5.1	Introduction .....	107
5.2	Main Components of Compressed Air Systems .....	107
5.3	Sources of Energy Losses from a Compressed Air System.....	108
5.4	Energy Conservation Technologies for Compressed Air Systems.....	109
5.4.1	Energy Conservation in Compressed Air Systems.....	109
5.4.2	High-Efficiency Motors.....	109
5.4.3	Repairing of Air Leaks .....	110
5.4.4	Reduced Air Pressure.....	112
5.4.5	Reduced Air Inlet Temperature.....	113
5.4.6	Waste-Heat Recovery .....	114
5.5	Localized Air Delivery System .....	114
5.6	Summary.....	115
	References .....	115
<b>Chapter 6</b>	<b>Energy Conservation in Power and Electrical Systems</b> .....	117
6.1	Introduction .....	117
6.2	Typical Electrical Equipment.....	117
6.2.1	Types of Electrical Loads.....	117
6.2.2	Electric Motors.....	118
6.3	Electricity Bill Structure.....	119
6.4	Sources of Energy Losses in Power and Electrical Systems .....	119
6.4.1	Low Power Factor.....	119
6.4.2	Improper Motor Load.....	120
6.4.3	Poor Control .....	121
6.5	Energy Conservation Technologies for Power and Electrical Systems.....	122
6.5.1	Power Management for Demand Control.....	122
6.5.2	Power Factor Improvement .....	124
6.5.3	Replacement with High-Efficiency Motors.....	125
6.5.4	Replacement with Electronic Adjustable Speed Motors .....	125
6.6	Summary.....	127
	References.....	128
<b>Chapter 7</b>	<b>Energy Conservation in Heat Exchangers</b> .....	129
7.1	Introduction .....	129
7.2	Typical Heat Exchangers.....	129
7.2.1	Double-Pipe Heat Exchanger and Shell and Tube Heat Exchanger.....	129
7.2.2	Plate Heat Exchanger.....	129
7.2.3	Scraped-Surface Heat Exchanger.....	131
7.3	Analysis of Heat Exchangers .....	132
7.3.1	Heat Transfer Coefficient.....	132
7.3.2	Temperature Difference.....	137

7.3.3	Energy Balances in Heat Exchangers.....	138
7.3.4	Effectiveness of Heat Exchangers .....	140
7.3.5	Exergy Analysis of a Heat Exchanger .....	140
7.4	Energy Conservation Technologies for Heat Exchangers .....	142
7.4.1	Energy Conservation through Heat Transfer Enhancement Techniques .....	142
7.4.2	Energy Conservation through Cleaning of Fouling Layer .....	146
7.4.3	Energy Conservation through Optimization of Heat Exchanger Design .....	149
7.4.4	Energy Conservation through Heat Exchanger Network Retrofit .....	149
7.5	Summary.....	149
	References.....	150

## **Chapter 8** Waste-Heat Recovery and Thermal Energy Storage in Food Processing Facilities .....

8.1	Introduction.....	153
8.2	Recovery of Waste Heat in Food Processing Facilities .....	153
8.2.1	Quantity and Quality of Waste Heat in Food Processing Facilities.....	153
8.2.2	Waste-Heat Utilization.....	157
8.2.3	Heat Exchangers for Waste-Heat Recovery .....	158
8.2.4	Heat Pumps for Waste-Heat Recovery.....	159
8.3	Thermal Energy Storage.....	161
8.3.1	Thermal Energy Storage System.....	161
8.3.2	Thermal Energy Storage Materials.....	161
8.3.4	Hot Thermal Energy Storage .....	163
8.3.5	Cooling Energy Storage .....	164
8.4	Summary.....	165
	References.....	165

## **Chapter 9** Novel Thermodynamic Cycles Applied to the Food Industry for Improved Energy Efficiency .....

9.1	Introduction .....	167
9.2	Novel Refrigeration Cycles .....	167
9.2.1	Refrigeration Phenomena .....	167
9.2.2	Coefficient of Performance in a Mechanical Energy-Driving Refrigeration Cycle.....	168
9.2.3	Coefficient of Performance in a Thermal Energy-Driving Refrigeration Cycle.....	170
9.2.4	Mechanical Compression Cycle .....	172
9.2.5	Air Cycle Refrigeration.....	173
9.2.6	Absorption Refrigeration Cycle.....	174
9.2.7	Ejector-Refrigeration Cycle .....	176

9.2.8	Adsorption Refrigeration Cycle.....	177
9.2.9	Combined Refrigeration Cycles .....	180
9.3	Heat Pumps .....	182
9.3.1	Working Principle of Heat Pumps.....	182
9.3.2	Efficiency of Heat Pumps.....	183
9.3.3	Applications of Heat Pumps.....	183
9.4	Heat Pipes.....	186
9.4.1	Working Principle of Heat Pipes .....	186
9.4.2	Efficiency of Heat Pipes .....	188
9.4.3	Applications of Heat Pipes .....	188
9.5	Heat and Power Cogeneration Cycles .....	189
9.5.1	Cogeneration Cycles and Working Principles .....	189
9.5.2	Cogeneration Cycles with Internal Combustion Engines as the Mover .....	190
9.5.3	Cogeneration Cycles with Gas Turbines as the Mover.....	191
9.5.4	Cogeneration Cycles with Steam Turbines as the Mover.....	192
9.5.5	Cogeneration Cycles with Both Gas Turbine and Steam Turbines as the Mover .....	193
9.5.6	Polices and Applications of Combined Heat and Power Generation.....	194
9.5.7	Applications of Combined Heat and Power Generation in the Food Industry .....	195
9.6	Summary.....	195
	References.....	196

## ***PART III Energy Consumption and Saving Opportunities in Existing Food Processing Facilities***

<b>Chapter 10</b>	<b>Energy Consumption in the Food Processing Industry.....</b>	<b>201</b>
10.1	Introduction.....	201
10.2	Overview of Energy Consumption in the Food Industry.....	202
10.2.1	Energy Consumption in the Food Manufacturing Industry .....	202
10.2.2	Energy Indicators in the Food Manufacturing Industry .....	203
10.2.3	Energy Sources in the Food Manufacturing Industry.....	203
10.2.4	Energy Use in Different Food Manufacturing Sectors .....	206
10.2.5	Energy Use for Production of Different Food Products.....	208
10.2.6	Energy Use in Different Unit Operations.....	208
10.3	Energy Efficiency and Conservation in the Food Industry.....	210
10.3.1	Energy and Exergy Efficiencies in Food Processing Facilities .....	210
10.3.2	Energy Conservation in Food Processing Facilities.....	211

10.3.3	Renewable Energy in Food Processing Facilities.....	213
10.4	Energy Conservation in Unit Operations .....	215
10.4.1	Pasteurization and Sterilization.....	215
10.4.1.1	Maintenance and Optimization of Existing Systems.....	215
10.4.1.2	Application of Heat Pumps.....	215
10.4.1.3	Applications of Nonthermal Processes.....	216
10.4.1.4	Concentration, Dehydration, and Drying .....	218
10.4.1.5	Chilling and Freezing.....	219
10.5	Summary.....	223
	References.....	223

<b>Chapter 11</b>	<b>Energy Conservation in Grains and Oilseeds Milling Facilities .....</b>	<b>227</b>
11.1	Introduction .....	227
11.2	Energy Consumption in the Grain and Oilseed Milling Sector.....	228
11.3	Corn Wet Milling Process.....	228
11.3.1	Wet Milling Process and Energy Consumption .....	228
11.3.2	Energy Conservation in Steeping .....	230
11.3.3	Energy Conservation in Dewatering.....	230
11.3.4	Applications of Membrane Separation .....	231
11.4	Oilseed Milling .....	231
11.4.1	Oilseed Process and Energy Consumption .....	231
11.4.2	Energy Conservation in Mechanical Oil Extraction Process .....	232
11.4.3	Energy Conservation in Oil Extraction Process with Solvents.....	233
11.4.4	Energy Conservation in Supercritical CO <sub>2</sub> Oil Extraction Process.....	234
11.5	Drying of Grains and Oilseeds .....	235
11.5.1	Energy Conservation in In-Bin Drying of Grains and Oilseeds .....	235
11.5.2	Use of More Efficient Dryers.....	236
11.5.3	Energy Conservation in Fluidized Bed Drying of Grains and Oilseeds.....	236
11.5.4	Application of Heat Pumps in Drying of Grains and Oilseeds .....	236
11.5.5	Novel Drying Processes for Grains and Oilseeds.....	236
11.6	Energy Utilization of By-Products in Grain and Oilseed Processing.....	237
11.6.1	By-Products in Grain and Oilseed Processing Facilities .....	237
11.6.2	Biological Conversion of By-Products .....	238
11.6.3	Thermochemical Conversion of By-Products .....	238
11.7	Summary .....	239
	References.....	240

<b>Chapter 12</b>	<b>Energy Conservation in Sugar and Confectionary Processing Facilities .....</b>	<b>243</b>
12.1	Introduction .....	243
12.2	Overview of Main Processes .....	244
12.3	Energy Consumption in the Sugar and Confectionary Product Manufacturing Sector .....	245
12.4	Energy Conservation in Main Unit Operations .....	245
12.4.1	Energy Conservation in Dewater and Drying .....	245
12.4.2	Energy Conservation in Evaporator .....	245
12.4.3	Energy Conservation in Crystallization .....	246
12.5	Cogeneration of Heat and Power.....	247
12.6	Using Processing Waste for Production of Renewable Energy.....	247
12.7	Summary .....	248
	References .....	249
<b>Chapter 13</b>	<b>Energy Conservation in Fruit and Vegetable Processing Facilities .....</b>	<b>251</b>
13.1	Introduction .....	251
13.2	Main Products and Processes.....	251
13.2.1	Material and Energy Flow in Canned Fruit and Vegetable Processing Facilities .....	251
13.2.2	Freezing and Dehydrating Fruits and Vegetables .....	252
13.3	Energy Use in Fruit and Vegetable Processing Facilities .....	254
13.4	Energy Conservation in Fruit and Vegetable Processing.....	255
13.4.1	Energy Conservation in Blanching.....	255
13.4.2	Energy Conservation in Pasteurization and Sterilization.....	255
13.4.3	Applications of Nonthermal Pasteurization .....	256
13.4.4	Energy Conservation in Freezing of Fruits and Vegetables .....	257
13.4.5	Energy Conservation in Concentration and Drying.....	258
13.5	Energy Utilization of Vegetable and Fruit Processing Wastes .....	261
13.5.1	Vegetable and Fruits Processing Wastes .....	261
13.5.2	Anaerobic Digestion of Vegetable and Fruit Wastes.....	261
13.5.3	Production of Fermentable Sugars from Vegetable and Fruit Processing Wastes .....	262
	Summary.....	263
	References .....	263
<b>Chapter 14</b>	<b>Energy Conservation in Dairy Processing Facilities .....</b>	<b>267</b>
14.1	Introduction .....	267
14.2	Main Products and Unit Operations in the Dairy Processing Sector.....	267
14.2.1	Fluid Milk and Its Process.....	269



14.2.2	Ice Cream, Butter, and Cheese and Their Processes.....	269
14.2.3	Dry Milk Products and Processes.....	269
14.3	Energy Use in the Dairy Sector.....	270
14.4	Potential Energy Conservation Measures.....	271
14.4.1	Energy Conservation in Pasteurization and Cooling.....	271
14.4.2	Energy Conservation in Concentration and Drying.....	272
14.4.3	Energy Conservation through Cleaning of Fouling Layers.....	273
14.5	Energy Utilization of Dairy By-Products.....	274
14.6	Summary.....	274
	References.....	274

## **Chapter 15** Energy Conservation in Meat Processing Facilities..... 277

15.1	Introduction.....	277
15.2	Overview of Main Processes.....	278
15.3	Energy Use in the Meat Manufacturing Sector.....	278
15.4	Potential Energy Conservation Measures.....	278
15.4.1	Optimization of Heat Exchange Network.....	278
15.4.2	Energy Conservation in Direct Fuel Use.....	281
15.4.3	Energy Conservation in Refrigeration.....	282
15.4.3.1	Energy Conservation in Refrigeration through Maintenance and Optimization.....	282
15.4.3.2	Energy Conservation in Refrigeration through Reduced Weight Loss.....	282
15.4.3.3	Energy Conservation in Refrigeration through Reduced Cooling Load.....	283
15.4.3.4	Applications of a Novel Waste-Heat-Powered Refrigeration System.....	283
15.4.4	Nonthermal Processing of Meat Products.....	284
15.5	Energy Utilization of Meat Processing Wastes.....	284
15.5.1	Meat Processing Wastes.....	284
15.5.2	Anaerobic Digestion of Slaughterhouse Wastes.....	284
15.5.3	Biodiesel Production from Animal Fats.....	285
15.6	Summary.....	286
	References.....	286

## **Chapter 16** Energy Conservation in Bakery Processing Facilities..... 289

16.1	Introduction.....	289
16.2	Overview of Main Products and Processes.....	289
16.3	Energy Consumption in the Bakery Processing Sector.....	291
16.4	Potential Energy Conservation Measures.....	292

16.4.1	Operation of Bake Ovens on Their Full Load.....	292
16.4.2	Recovery of Waste Heat from Bake Ovens.....	292
16.4.3	Applications of Microwave Baking Technology.....	292
16.4.4	Energy Conservation in Drying of Pasta.....	293
16.4.5	Application of Combined Heat and Power Generation.....	293
16.5	Summary.....	294
	References.....	294

## ***PART IV Energy Efficiency and Conservation in Emerging Food Processing Systems***

<b>Chapter 17</b>	<b>Membrane Processing of Foods.....</b>	<b>297</b>
17.1	Introduction.....	297
17.2	Overview of a Membrane Process.....	297
17.3	Energy Consumption in Membrane Processing.....	299
17.4	Application of Membrane Technology in Food Processing Facilities.....	299
17.4.1	Applications of Membrane Separation in Wet Grain Milling.....	299
17.4.2	Applications of Membrane Separation in Vegetable Oil Extraction with Solvents.....	300
17.4.3	Applications of Membrane Separation in Concentration of Liquid Foods.....	300
17.4.4	Applications of Membrane Separation in Recovery of Sugars from Fruit and Vegetable Processing Wastewater.....	301
17.4.5	Applications of Membrane Separation in Pasteurization of Liquid Foods.....	301
17.5	Summary.....	301
	References.....	301
<b>Chapter 18</b>	<b>Energy Efficiency and Conservation in Food Irradiation.....</b>	<b>303</b>
18.1	Introduction.....	303
18.2	Overview of Main Food Irradiation Processes.....	303
18.2.1	Irradiation Mechanism.....	303
18.2.2	Irradiation Process.....	304
18.2.3	Applications of Food Irradiation.....	307
18.3	Energy Use, Efficiency, and Conservation.....	308
18.3.1	Efficiency of Food Irradiation.....	308
18.3.2	Irradiation Dose and Energy Consumption.....	309
18.3.3	Temperature Increase during Food Irradiation.....	310
18.4	Summary.....	310
	References.....	311

<b>Chapter 19</b>	<b>Energy Efficiency and Conservation in Pulsed Electric Fields Treatment</b> .....	313
19.1	Introduction .....	313
19.2	Process Overview .....	313
19.2.1	Pulsed Electric Fields Treatment Mechanism .....	313
19.2.2	Pulsed Electric Fields Treatment Process .....	314
19.2.3	Pulsed Electric Fields Treatment Applications .....	315
19.3	Energy Efficiency and Consumption.....	316
19.3.1	Energy Efficiency.....	316
19.3.2	Energy Consumption .....	317
19.3.3	Temperature Increase during PEF Treatment.....	318
19.3.4	Energy Conservation .....	319
19.4	Summary .....	319
	References.....	320
<b>Chapter 20</b>	<b>Energy Efficiency and Conservation in High-Pressure Food Processing</b> .....	323
20.1	Introduction .....	323
20.2	Process Overview.....	323
20.2.1	Process Mechanism of High-Pressure Sterilization/Pasteurization .....	323
20.2.2	Process Mechanism of High-Pressure Freezing/Thawing.....	324
20.2.3	High-Pressure Generation and System Design.....	325
20.2.4	Applications of High-Pressure Processes .....	325
20.2.4.1	High-Pressure Pasteurization and Sterilization.....	325
20.2.4.2	High-Pressure Freezing and Thawing .....	327
20.3	Energy Use, Efficiency, and Conservation.....	327
20.3.1	Energy Use for High-Pressure Generation.....	327
20.3.2	Temperature Increase during High-Pressure processing .....	328
20.3.3	Energy Savings with High-Pressure Processes.....	329
20.4	Summary.....	330
	References.....	331
<b>Chapter 21</b>	<b>Energy Efficiency and Conservation in Microwave Heating</b> .....	333
21.1	Introduction .....	333
21.2	Process Overview .....	333
21.2.1	Microwave Heating Mechanism.....	333
21.2.2	Microwave Heating Systems .....	334
21.3	Factors Affecting Microwave Heating .....	335
21.3.1	Dielectric Properties .....	335
21.3.2	Temperature and Frequency .....	337
21.3.3	Shape and Size of Food Items .....	337

21.4	Applications of Microwave Heating in the Food Industry .....	338
21.4.1	Microwave Dehydration .....	338
21.4.2	Microwave Pasteurization .....	339
21.4.3	Microwave Thawing .....	339
21.4.4	Microwave Cooking .....	340
21.4.5	Microwave Baking .....	340
21.4.6	Microwave-Assisted Extraction .....	340
21.5	Energy Efficiency, Consumption, and Conservation during Microwave Heating .....	343
21.5.1	Energy Efficiency .....	343
21.5.2	Energy Consumption .....	344
21.5.3	Potential Energy Conservation Measures .....	346
21.6	Summary .....	347
	References .....	347

## **Chapter 22** Energy Efficiency and Conservation in Supercritical Fluid Processing .....

22.1	Introduction .....	351
22.2	Overview of Supercritical Fluid Processes .....	351
22.2.1	Supercritical Fluids .....	351
22.2.2	Supercritical Fluid Process .....	352
22.2.3	Practical Issues of a Supercritical Fluid Process .....	353
22.3	Applications of Supercritical Fluid Processes in the Food Industry .....	354
22.3.1	Supercritical Fluid Extraction .....	354
22.3.2	Supercritical Fluid Drying .....	355
22.3.3	Supercritical Fluid for Particle Formulation .....	356
22.4	Energy Use and Efficiency .....	356
22.5	Potential Energy Conservation Measures .....	358
22.6	Summary .....	359
	References .....	359

## ***PART V Conversion of Food Processing Wastes into Energy***

### **Chapter 23** Food Processing Wastes and Utilizations .....

23.1	Introduction .....	363
23.2	Fruit and Vegetable Processing Wastes .....	364
23.2.1	Availability and Quality .....	364
23.2.2	Current Utilization .....	366
23.2.3	Energy Utilization .....	367
23.3	Oilseed Processing Wastes .....	368
23.3.1	Availability and Quality .....	368
23.3.2	Current Utilization .....	369
23.3.3	Energy Utilization .....	369

<b>23.4</b>	Grain Processing Wastes.....	370
23.4.1	Availability and Quality .....	370
23.4.2	Current Utilization .....	372
23.4.3	Energy Utilization .....	372
<b>23.5</b>	Meat Processing Wastes.....	373
23.5.1	Availability and Quality .....	373
23.5.2	Current Utilization .....	374
23.5.3	Energy Utilization .....	375
<b>23.6</b>	Waste Oils and Fats.....	375
23.6.1	Availability and Quality .....	375
23.6.2	Current Utilization .....	378
23.6.3	Energy Utilization.....	378
<b>23.7</b>	Energy Conversion Technologies for Food Processing Wastes .....	378
<b>23.8</b>	Summary.....	380
	References.....	381

## **Chapter 24** Anaerobic Digestion of Food Processing Wastes..... 385

<b>24.1</b>	Introduction.....	385
<b>24.2</b>	Overview of Anaerobic Digestion Technologies .....	386
24.2.1	Anaerobic Digestion Pathways.....	386
24.2.2	Effects of Feedstocks on Anaerobic Digestion .....	387
24.2.3	Effects of Operating Conditions on Anaerobic Digestion .....	388
24.2.4	Anaerobic Digester Design .....	389
<b>24.3</b>	Anaerobic Digestion of Food Processing Wastes .....	389
24.3.1	Anaerobic Digestion of Fish Wastes.....	391
24.3.2	Anaerobic Digestion of Slaughterhouse Wastes.....	391
24.3.3	Anaerobic Digestion of Fruit and Vegetable Solid Waste.....	391
24.3.4	Anaerobic Digestion of Food Processing Wastewater .....	392
24.3.5	Co-Digestion .....	392
<b>24.4</b>	Economic and Environmental Impacts of Anaerobic Digestion of Food Processing Wastes .....	393
<b>24.5</b>	Summary.....	394
	References.....	394

## **Chapter 25** Fermentation of Food Processing Wastes into Transportation Alcohols..... 397

<b>25.1</b>	Introduction.....	397
<b>25.2</b>	Feedstock for Fermentable Sugar.....	397
25.2.1	Sucrose .....	398
25.2.2	Starch.....	398
25.2.3	Lignocelluloses.....	398
25.2.4	Fermentable Carbon Sources from Food Processing Wastes .....	399
<b>25.3</b>	Microorganisms for Ethanol Production.....	400
25.3.1	Microorganisms.....	400
25.3.2	Nutritional Needs .....	401
25.3.3	Environmental Needs.....	401

25.4	Ethanol Fermentation Process .....	401
25.4.1	Overview of Ethanol Production Process.....	401
25.4.2	Starch Hydrolysis .....	402
25.4.3	Pretreatment and Hydrolysis of Lignocellulosic Biomass.....	403
25.4.4	Ethanol Fermentation .....	404
25.5	Advanced Concepts in Ethanol Fermentation .....	404
25.5.1	Simultaneous Saccharification and Fermentation .....	404
25.5.2	Solid-State Fermentation.....	404
25.6	Examples of Ethanol Fermentation from Food Processing Wastes.....	405
25.6.1	Ethanol Fermentation from Grain Milling By-Products.....	405
25.6.2	Ethanol Fermentation from Vegetable and Fruit Processing Wastes.....	406
25.6.3	Ethanol Fermentation from Sugar Processing Wastes .....	407
25.6.4	Ethanol Fermentation from Cheese Whey .....	407
25.7	Summary .....	407
	References .....	407
<b>Chapter 26 Biodiesel Production from Waste Oils and Fats .....</b>		<b>411</b>
26.1	Introduction.....	411
26.2	Biodiesel Fuels .....	412
26.3	Traditional Biodiesel Production .....	415
26.3.1	Traditional Biodiesel Production Process .....	415
26.3.2	Transesterification Reaction.....	416
26.3.3	Recovery and Purification of Biodiesel.....	417
26.4	Catalysts for Biodiesel Production.....	418
26.4.1	Alkaline Catalysts .....	418
26.4.2	Acid Catalysts.....	419
26.4.3	Biocatalysts .....	420
26.4.4	Heterogeneous Catalysts .....	420
26.5	Biodiesel Production from Waste Oils and Fats .....	421
26.5.1	Technical Challenges for Biodiesel Production from Waste Oils and Fats.....	421
26.5.2	Alkaline Catalytic Process for Biodiesel Production from Waste Oils and Animal Fats.....	421
26.5.3	Acid Catalytic Process for Biodiesel Production from Waste Oils and Fats.....	422
26.5.3.1	Acid Pretreatment of Waste Oils and Fats .....	422
26.5.3.2	Acid Posttreatment of Soap in Crude Biodiesel .....	422
26.5.3.3	Acid-Catalyzed Transesterification Reaction .....	422
26.5.4	Biodiesel Production from Waste Oils and Fats in Supercritical Alcohols.....	423
26.6	Summary.....	425
	References .....	426

<b>Chapter 27</b>	<b>Thermochemical Conversion of Food Processing Wastes for Energy Utilization .....</b>	<b>429</b>
<b>27.1</b>	<b>Introduction .....</b>	<b>429</b>
<b>27.2</b>	<b>Combustion .....</b>	<b>430</b>
27.2.1	Combustion Process .....	430
27.2.2	Combustion of Food Processing Wastes .....	430
<b>27.3</b>	<b>Pyrolysis .....</b>	<b>431</b>
27.3.1	Pyrolysis Process .....	431
27.3.2	Pyrolysis Products and Utilization .....	431
27.3.3	Pyrolysis of Food Processing Wastes .....	432
<b>27.4</b>	<b>Gasification.....</b>	<b>432</b>
27.4.1	Gasification Process.....	432
27.4.2	Gasification Products and Utilization.....	434
27.4.3	Gasification of Food Processing Wastes.....	435
<b>27.5</b>	<b>Thermochemical Liquefaction .....</b>	<b>436</b>
27.5.1	Liquefaction Process.....	436
27.5.2	Liquefaction Products.....	436
27.5.2.1	Fermentable Sugars Production by Super- or Near-Critical Water.....	436
27.5.2.2	Organic Acids Production by Super- or Near-Critical Water .....	437
27.5.2.3	Bio-Oil Production by Thermochemical Liquefaction .....	437
<b>27.6</b>	<b>Summary .....</b>	<b>438</b>
<b>References</b> .....		<b>438</b>
<b>Index</b> .....		<b>445</b>