

Food Engineering Series

Series Editor

Gustavo V. Barbosa-Cánovas, Washington State University, USA

Advisory Board

José Miguel Aguilera, Catholic University, Chile

Kezban Candoğan, Ankara University, Turkey

Richard W. Hartel, University of Wisconsin, USA

Albert Ibarz, University of Lleida, Spain

Jozef Kokini, Purdue University, USA

Michael McCarthy, University of California, USA

Keshavan Niranjana, University of Reading, United Kingdom

Micha Peleg, University of Massachusetts, USA

Shafiur Rahman, Sultan Qaboos University, Oman

M. Anandha Rao, Cornell University, USA

Yrjö Roos, University College Cork, Ireland

Jorge Welti-Chanes, Monterrey Institute of Technology, Mexico.

Springer's *Food Engineering Series* is essential to the Food Engineering profession, providing exceptional texts in areas that are necessary for the understanding and development of this constantly evolving discipline. The titles are primarily reference-oriented, targeted to a wide audience including food, mechanical, chemical, and electrical engineers, as well as food scientists and technologists working in the food industry, academia, regulatory industry, or in the design of food manufacturing plants or specialized equipment.

More information about this series at <http://www.springer.com/series/5996>

George Saravacos • Athanasios E. Kostaropoulos

Handbook of Food Processing Equipment

Second Edition

 Springer

George Saravacos
21100 Nauplion, Greece

Athanasios E. Kostaropoulos
Athens, Greece

ISSN 1571-0297

Food Engineering Series

ISBN 978-3-319-25018-2

ISBN 978-3-319-25020-5 (eBook)

DOI 10.1007/978-3-319-25020-5

Library of Congress Control Number: 2015952650

Springer Cham Heidelberg New York Dordrecht London

© Springer International Publishing Switzerland 2016

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media
(www.springer.com)

Contents

1	Design of Food Processes and Food Processing Plants	1
1.1	Introduction	1
1.2	Overview of Chemical Process and Plant Design	2
1.2.1	Process Flow Sheets	3
1.2.2	Types of Process Designs	3
1.2.3	Material and Energy Balances	4
1.2.4	Design of Equipment	5
1.2.5	Plant Layout and Buildings	6
1.2.6	Economic Analysis in Process/Plant Design	7
1.2.7	Manufacturing Cost and Profitability	11
1.2.8	Computer-Aided Process/Plant Design	14
1.3	Design of Food Processes	15
1.3.1	Unit Operations in Food Processing	19
1.3.2	Food Process Flow Sheets	22
1.3.3	Material and Energy Balances	23
1.3.4	Computer-Aided Food Process Design	28
1.4	Food Plant Design	28
1.4.1	Elements of Food Plant Design	29
1.4.2	Good Manufacturing Practices	36
1.4.3	Food Plant Economics	38
	References	47
2	Design and Selection of Food Processing Equipment	51
2.1	Introduction	51
2.2	Sizing and Costing of Equipment	52
2.3	Materials of Construction	54
2.3.1	Metals	55
2.3.2	Plastics–Rubber	59
2.3.3	Glass–Ceramics	60
2.3.4	Wood	60

2.4	Fabrication of Equipment	61
2.4.1	Strength of Construction	61
2.4.2	Fabrication and Installation of Equipment	64
2.5	Hygienic Design of Food Processing Equipment	66
2.5.1	Hygienic Standards and Regulations	66
2.5.2	Cleaning of Food Equipment	69
2.6	Selection of Food Processing Equipment	72
2.6.1	Selection of Equipment	72
2.6.2	Testing of Equipment	78
2.6.3	Equipment Specifications	79
2.7	Directories of Equipment	82
2.7.1	Directories of Food Equipment	82
2.7.2	Exhibitions of Food Equipment	83
	References	83
3	Mechanical Transport and Storage Equipment	87
3.1	Introduction	87
3.2	Mechanical Transport Equipment	88
3.2.1	Fluid Food Transport Equipment	88
3.2.2	Pneumatic and Hydraulic Transport Equipment	108
3.2.3	Mechanical Conveyors	112
3.3	Food Storage Equipment	126
3.3.1	Introduction	126
3.3.2	Storage of Solids	126
3.3.3	Storage of Liquids	138
	References	146
4	Mechanical Processing Equipment	149
4.1	Introduction	149
4.2	Size Reduction	149
4.2.1	Introduction	149
4.2.2	Cutting	153
4.2.3	Crushing and Grinding Equipment	165
4.3	Size Enlargement	186
4.3.1	Introduction	186
4.3.2	Agglomeration Equipment	189
4.3.3	Selection of Agglomeration Equipment	207
4.4	Homogenization	207
4.4.1	Introduction	207
4.4.2	Homogenization Equipment	208
4.5	Mixing and Forming Equipment	214
4.5.1	Introduction	214
4.5.2	Fluid Mixing Equipment	214
4.5.3	Paste and Dough Mixing Equipment	219

4.5.4	Extrusion and Forming Equipment	220
4.5.5	Butter and Cheese Processing Equipment	226
4.5.6	Solid Mixing and Encrusting Equipment	227
	References	230
5	Mechanical Separation Equipment	233
5.1	Introduction	233
5.2	Classification Operations	235
5.2.1	Grading	236
5.2.2	Sorting	237
5.3	Solid/Solid Separations	241
5.3.1	Screening	241
5.3.2	Fluid Classification	247
5.4	Solid/Liquid Separators	251
5.4.1	Screens	251
5.4.2	Sedimentation Equipment	251
5.4.3	Industrial Filters	252
5.4.4	Centrifuges	258
5.4.5	Mechanical Expression	263
5.5	Solid/Air Separators	270
5.5.1	Cyclone Separators	270
5.5.2	Bag Filters	272
5.5.3	Air Filters	274
5.5.4	Electrical Filters	275
5.5.5	Wet Scrubbers	276
5.6	Removal of Food-Related Parts	276
5.6.1	General Aspects	276
5.6.2	Removal of Undesired Own Parts	277
5.6.3	Removal of Desired Parts	287
5.6.4	Food Cleaning Operations	287
	References	290
6	Heat Transfer Equipment	293
6.1	Introduction	293
6.2	Heat Transfer Coefficients	293
6.3	Empirical Correlations of (<i>h</i>)	296
6.3.1	General Correlations	296
6.3.2	Simplified Equations for Air and Water	298
6.3.3	Heat Transfer Factor	299
6.4	Heat Exchangers	300
6.4.1	Overall Heat Transfer Coefficients	300
6.4.2	Fouling of Heat Exchangers	302
6.4.3	Residence Time Distribution	303
6.4.4	Tubular Heat Exchangers	304
6.4.5	Plate Heat Exchangers	306

6.4.6	Agitated Kettles	310
6.4.7	Scraped Surface Heat Exchangers	312
6.4.8	Direct Heat Exchangers	314
6.4.9	Baking and Roasting Ovens	315
6.4.10	Fryers	318
6.4.11	Radiation Heaters	319
6.4.12	Heat Generation Processes	321
6.4.13	Hygienic Considerations	324
	References	329
7	Food Evaporation Equipment	331
7.1	Introduction	331
7.2	Heat Transfer in Evaporation	332
7.2.1	Physical Properties	332
7.2.2	Heat Transfer Coefficients	333
7.2.3	Fouling in Evaporators	333
7.2.4	Heat Transfer in Film Evaporators	334
7.2.5	Falling Film Evaporation of Fruit Juices	338
7.3	Food Quality Considerations	340
7.4	Food Evaporators	340
7.4.1	Material and Energy Balances	340
7.4.2	Long Residence-Time Evaporators	341
7.4.3	Short Residence-Time Evaporators	344
7.5	Energy-Saving Evaporation Systems	348
7.5.1	Multiple-Effect Evaporators	348
7.5.2	Vapor Recompression Evaporators	351
7.5.3	Heat Pump Evaporators	353
7.5.4	Combined Reverse Osmosis/Evaporation	355
7.5.5	Water Desalination	355
7.5.6	Waste-Heat Evaporators	355
7.6	Evaporator Components	356
7.6.1	Evaporator Bodies	356
7.6.2	Vapor/Liquid Separators	357
7.6.3	Condensers	358
7.6.4	Vacuum Systems	359
7.6.5	Evaporator Control	360
7.6.6	Testing of Evaporators	360
7.6.7	Hygienic Considerations	361
	References	364
8	Food Dehydration Equipment	367
8.1	Introduction	367
8.2	Principles of Drying	368
8.2.1	Psychrometric Calculations	368
8.2.2	Drying Rates	370
8.2.3	Food Dehydration Technology	374

8.3	Design and Selection of Food Dryers	375
8.3.1	Heat and Mass Transfer	376
8.3.2	Modeling and Simulation of Dryers	379
8.3.3	Design of Industrial Dryers	381
8.3.4	Selection of Industrial Dryers	382
8.3.5	Commercial Food Drying Equipment	383
8.3.6	Special Food Dryers	405
8.3.7	Hygienic and Safety Considerations	409
8.4	Energy and Cost Considerations of Drying	410
8.4.1	Heat Sources for Drying	410
8.4.2	Heat Recovery	411
8.4.3	Energy-Efficient Dryers	412
8.4.4	Cost Considerations	413
	References	415
9	Refrigeration and Freezing Equipment	421
9.1	Introduction	421
9.2	Refrigeration Equipment	422
9.2.1	Refrigeration Cycles	422
9.2.2	Compressors	427
9.2.3	Evaporators	433
9.2.4	Condensers	443
9.2.5	Capacity Control	445
9.3	Refrigerants	446
9.3.1	Introduction	446
9.3.2	Natural Refrigerants	452
9.3.3	Fluorocarbon and Blend Refrigerants	453
9.4	Lubricants	455
9.4.1	Main Types of Lubricants	455
9.4.2	Function of Lubrication	456
9.4.3	Requirements for Good Lubrication	456
9.4.4	Choice of Refrigerant Lubricants	458
9.4.5	Additives	459
9.5	Cooling of Foods	459
9.5.1	Chilling	459
9.5.2	Cooling Equipment	462
9.6	Freezing of Food	468
9.6.1	Freezing	468
9.6.2	Freezing Equipment	474
9.6.3	Thawing Equipment	482
9.7	Cold Storage	485
9.7.1	General Aspects	485
9.7.2	Reduction of Weight Loss	489
9.8	Ice Manufacturing	493
	References	499

10	Thermal Processing Equipment	503
10.1	Introduction	503
10.2	Kinetics of Thermal Inactivation	504
10.2.1	Inactivation of Microorganisms and Enzymes	504
10.2.2	Thermal Damage to Food Components	507
10.3	Heat Transfer Considerations	507
10.3.1	General Aspects	507
10.3.2	Unsteady-State Heat Transfer	508
10.4	Thermal Process Calculations	511
10.4.1	In-container Sterilization	511
10.4.2	Continuous Flow Thermal Processes	514
10.5	Thermal Processing Equipment	517
10.5.1	General Aspects	517
10.5.2	In-container Sterilizers	517
10.5.3	Continuous Flow (UHT) Sterilizers	535
10.5.4	Thermal Pasteurizers	539
10.5.5	Thermal Blanchers	543
10.5.6	Hygienic Considerations	544
	References	546
11	Mass Transfer Equipment	549
11.1	Introduction	549
11.2	Distillation Equipment	551
11.2.1	Vapor/Liquid Equilibria	551
11.2.2	Determination of Equilibrium Stages	557
11.2.3	Food Distillation Equipment	564
11.3	Solvent Extraction/Leaching Equipment	570
11.3.1	Liquid/Liquid and Liquid/Solid Equilibria	570
11.3.2	Determination of Equilibrium Stages	573
11.3.3	Mass Transfer Considerations	574
11.3.4	Food Extraction and Leaching Equipment	576
11.3.5	Curing	579
11.4	Gas/Liquid Absorption Equipment	585
11.4.1	Gas/Liquid Equilibria	586
11.4.2	Determination of Equilibrium Stages	587
11.4.3	Gas Absorption and Stripping Equipment	590
11.5	Adsorption and Ion Exchange Equipment	591
11.5.1	Adsorption Equilibria and Mass Transfer	592
11.5.2	Adsorption Equipment	593
11.5.3	Ion Exchange Equipment	594
11.5.4	Food Applications	595
11.6	Crystallization from Solution Equipment	597
11.6.1	Solubility Considerations	597
11.6.2	Nucleation and Mass Transfer	598
11.6.3	Industrial Crystallizers	599
	References	602

12	Equipment for Novel Food Processes	605
12.1	Introduction	605
12.2	Membrane Separation Equipment	606
12.2.1	Mass Transfer Considerations	606
12.2.2	Membranes and Membrane Modules	608
12.2.3	Membrane Separation Systems	609
12.2.4	Reverse Osmosis and Nanofiltration	611
12.2.5	Ultrafiltration	613
12.2.6	Microfiltration	616
12.2.7	Pervaporation	618
12.2.8	Electrodialysis	620
12.3	SCF Extraction	621
12.3.1	Supercritical Fluids	621
12.3.2	SCF Extraction Processes and Equipment	622
12.3.3	SCF Extraction in Food Processing	623
12.4	Crystallization from Melt	624
12.4.1	Freeze Concentration	624
12.4.2	Fat Fractionation	626
12.5	Nonthermal Food Preservation	627
12.5.1	Food Irradiation	628
12.5.2	High-Pressure Processing	634
12.5.3	Pulsed Electric Field Processing	635
12.5.4	Nanotechnology	636
12.6	Robotics	637
	References	641
13	Food Packaging Equipment	645
13.1	Introduction	645
13.1.1	General Aspects	645
13.1.2	Packaging Characteristics	647
13.1.3	Packages and Packaging Materials	651
13.2	Preparation of Food Containers	657
13.2.1	Unscrambling	657
13.2.2	Fabrication and Forming of Packages	658
13.3	Filling Equipment	666
13.3.1	General Characteristics	666
13.3.2	Dosing	670
13.3.3	Product Transfer Systems	672
13.3.4	Valves	674
13.3.5	Weighing	676
13.4	Closing Equipment	679
13.4.1	Closing of Food Packages	679
13.4.2	Glass Closures	680
13.4.3	Closing of Metallic Containers	681
13.4.4	Closing of Plastic Packages	682
13.4.5	Closing of Cartons and Cardboard	683

13.5	Aseptic Packaging	683
13.6	Group Packaging	688
13.6.1	Grouping of Packages	688
13.6.2	Wrapping	688
13.6.3	Palletizing	691
13.7	Cleaning of Packaging Media	693
	References	694
Appendix A: Notation and Conversion of Units		697
Appendix B: Selected Thermophysical Properties		703
Appendix C: Control of Food Processing Equipment		709
Appendix D: Food Plant Utilities		711
Appendix E: Manufacturers and Suppliers of Food Equipment		717
Index		757