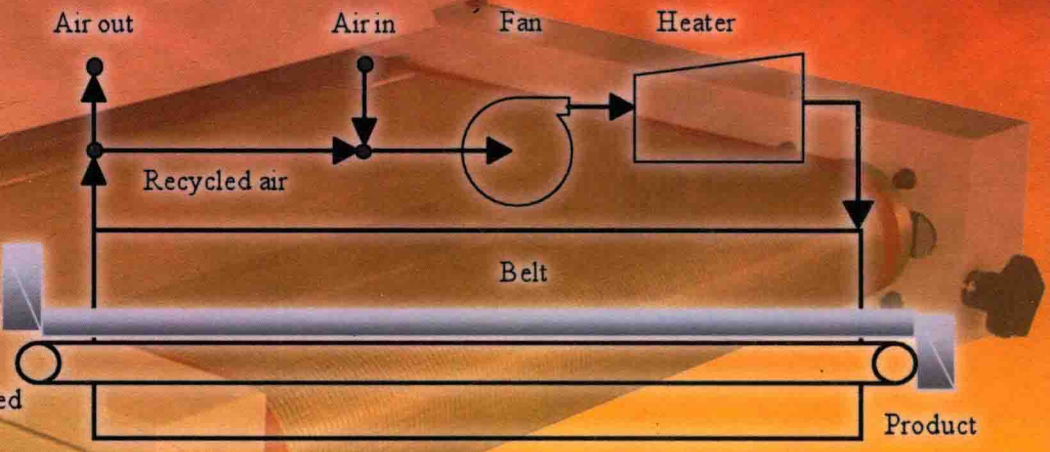
Contemporary Food Engineering Series

Da-Wen Sun, Series Editor

Food Process Engineering Operations



George D. Saravacos

Zacharias B. Maroulis

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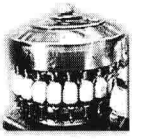

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CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the

Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number: 978-1-4200-8353-8 (Hardback)

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Contemporary Food Engineering

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To

Katie Saravacos

Sincerely yours,

George Emer

Professor George D. Saravacos

Series Preface

CONTEMPORARY FOOD ENGINEERING

Food engineering is the multidisciplinary field of applied physical sciences combined with the knowledge of product properties. Food engineers provide the technological knowledge transfer essential to the cost-effective production and commercialization of food products and services. In particular, food engineers develop and design processes and equipment in order to convert raw agricultural materials and ingredients into safe, convenient, and nutritious consumer food products. However, food engineering topics are continuously undergoing changes to meet diverse consumer demands, and the subject is being rapidly developed to reflect market needs.

In the development of food engineering, one of the many challenges is to employ modern tools and knowledge, such as computational materials science and nanotechnology, to develop new products and processes. Simultaneously, improving food quality, safety, and security continue to be critical issues in food engineering study. New packaging materials and techniques are being developed to provide more protection to foods, and novel preservation technologies are emerging to enhance food security and defense. Additionally, process control and automation regularly appear among the top priorities identified in food engineering. Advanced monitoring and control systems are developed to facilitate automation and flexible food manufacturing. Furthermore, energy saving and minimization of environmental problems continue to be important food engineering issues, and significant progress is being made in waste management, the efficient utilization of energy, and the reduction of effluents and emissions in food production.

The *Contemporary Food Engineering Series*, consisting of edited books, attempts to address some of the recent developments in food engineering. Advances in classical unit operations in engineering applied to food manufacturing are covered as well as such topics as progress in the transport and storage of liquid and solid foods; heating, chilling, and freezing of foods; mass transfer in foods; chemical and biochemical aspects of food engineering and the use of kinetic analysis; dehydration, thermal processing, nonthermal processing, extrusion, liquid food concentration, membrane processes, and applications of membranes in food processing; shelf life, electronic indicators in inventory management; sustainable technologies in food processing; and packaging, cleaning, and sanitation. The books are aimed at professional food scientists, academics researching food engineering problems, and graduate-level students.

The books' editors are leading engineers and scientists from many parts of the world. All the editors were asked to present their books to address the market's need and pinpoint the cutting-edge technologies in food engineering.

All contributions are written by internationally renowned experts who have both academic and professional credentials. All authors have attempted to provide critical,

comprehensive, and readily accessible information on the art and science of a relevant topic in each chapter, with reference lists for further information. Therefore, each book can serve as an essential reference source to students and researchers in universities and research institutions.

Da-Wen Sun
Series Editor

Series Editor

Professor Da-Wen Sun, PhD, was born in Southern China and is a world authority on food engineering research and education. His main research activities include cooling, drying, and refrigeration processes and systems; quality and safety of food products; bioprocess simulation and optimization; and computer vision technology. His innovative studies on vacuum cooling of cooked meats, pizza quality inspection by computer vision, and edible films for shelf-life extension of fruits and vegetables have been widely reported in the national and international media.

Dr. Sun received first-class BSc honors and an MSc in mechanical engineering, and a PhD in chemical engineering in China before working at various universities in Europe. He became the first Chinese national to be permanently employed in an Irish university when he was appointed college lecturer at the National University of Ireland, Dublin (University College Dublin) in 1995, and was then continuously promoted in the shortest possible time to senior lecturer, associate professor, and full professor. Dr. Sun is now professor of food and biosystems engineering and director of the Food Refrigeration and Computerized Food Technology Research Group at the University College Dublin.

As a leading educator in food engineering, Dr. Sun has contributed significantly to the field of food engineering. He has trained many PhD students who have made their own contributions to the industry and academia. He has also, on a regular basis, given lectures on the advances in food engineering at academic institutions internationally and delivered keynote speeches at international conferences. As a recognized authority in food engineering, Dr. Sun has been conferred adjunct/visiting/consulting professorships from 10 top universities in China including Zhejiang University, Shanghai Jiaotong University, Harbin Institute of Technology, China Agricultural University, South China University of Technology, and Jiangnan University. In recognition of his significant contribution to food engineering worldwide and for his outstanding leadership in the field, the International Commission of Agricultural and Biosystems Engineering (CIGR) awarded him the CIGR Merit Award in 2000 and again in 2006; the Institution of Mechanical Engineers based in the United Kingdom named him Food Engineer of the Year 2004; in 2008 he was awarded the CIGR Recognition Award in recognition of his distinguished achievements as the top 1% of agricultural engineering scientists around the world; in 2007, Dr. Sun was presented with the AFST(I) Fellow Award by the Association of Food Scientists and Technologists (India); and in 2010, he was presented with the CIGR Fellow Award; the title of "Fellow" is the highest honor in CIGR, and is conferred to individuals who have made sustained, outstanding contributions worldwide.

Dr. Sun is a fellow of the Institution of Agricultural Engineers and a fellow of the Institution of Engineers of Ireland. He has also received numerous awards for teaching and research excellence, including the President's Research Fellowship, and has received the President's Research Award from the University College Dublin on two occasions. He is editor-in-chief of *Food and Bioprocess Technology—An International Journal* (Springer); series editor of the *Contemporary Food Engineering Series* (CRC Press/Taylor & Francis); former editor of the *Journal of Food Engineering* (Elsevier); and an editorial board member for the *Journal of Food Engineering* (Elsevier), the *Journal of Food Process Engineering* (Blackwell), *Sensing and Instrumentation for Food Quality and Safety* (Springer), and the *Czech Journal of Food Sciences*. Dr. Sun is also a chartered engineer.

On May 28, 2010, Dr. Sun was awarded membership to the Royal Irish Academy (RIA), which is the highest honor that can be attained by scholars and scientists working in Ireland. At the 51st CIGR General Assembly held during the CIGR World Congress in Quebec City, Canada, in June 2010, he was elected as incoming president of CIGR, and will become CIGR president in 2013–2014; the term of the presidency is six years, two years each for serving as incoming president, president, and past president.

Preface

Food engineering is an interdisciplinary field of major concern to university departments of food science, and chemical and biological engineering. It is an applied area of importance to engineers and scientists working in various food processing industries.

Food Process Engineering Operations deals with the application of chemical engineering unit operations to the handling, processing, packaging, and distribution of food products. In addition to basic process engineering considerations, such as material and energy balances, food processing should meet the special requirements of food acceptance, human nutrition, and food safety.

This book is concerned with the applications of process engineering fundamentals to food processing technology. It can be used primarily as a textbook for one or two semesters for food science students. It can also serve as an important reference for students of chemical and biological engineering interested in food engineering, and for scientists, engineers, and technologists working in food processing industries.

Chapters 1 through 5 review the fundamentals of process engineering and food processing technology, with typical examples of food process applications. Chapters 6 through 15 (the main part of the book) cover food process engineering operations in detail, including theory, process equipment, engineering operations, and application examples and problems.

Chapter 1 provides an introduction to food process engineering with brief discussions on process diagrams, material and energy balances, and engineering calculations. It also presents typical flow sheets of food preservation, food manufacturing, and food ingredient processes.

Chapter 2 deals with the transport phenomena in process engineering, including steady- and unsteady-state transport of heat, mass, and momentum. It presents the simplified solutions of the generalized diffusion equation and introduces interface transfer, transfer coefficients, and dimensionless numbers.

Chapter 3 presents an outline of thermodynamics and kinetics in relation to food processing. It introduces the laws of thermodynamics and covers several thermodynamic processes. It also discusses phase equilibria, with an emphasis on water equilibria, and introduces food kinetics, with an emphasis on microbial growth and inactivation.

Chapter 4 presents a brief overview of food processing technology with typical examples from the food preservation, food manufacturing, and food ingredient industries.

Chapter 5 reviews the engineering properties of foods, including thermophysical, mechanical, and transport properties. It also presents realistic engineering property data, which can be used in food engineering calculations and in food process designs.

Chapter 6 covers the fluid transport operations of foods, including rheology, mechanical balances, piping systems, and pumping equipment.

Chapter 7 describes the several mechanical processing operations used in the preservation and manufacturing of food products. It also discusses particle characteristics, size reduction and enlargement, mixing and forming, mechanical separations, and removal of food parts.

Chapters 8 and 9 discuss the heat transfer operations used in food processing. The heat transfer coefficients are defined and applied to the design of various heat exchangers. Thermal preservation processes (sterilization and pasteurization) are discussed in detail and thermal treatment processes (baking, roasting, and frying) are outlined.

Chapters 10 and 11 deal with the evaporation and drying operations of food processing. The design of evaporators and dryers is based on heat and mass transfer and on water activity. Energy savings are important for economic design. These chapters describe several types of drying equipment.

Chapter 12 covers refrigeration and freezing operations applied to food systems.

Chapter 13 discusses the food applications of mass transfer, including distillation, extraction, and crystallization.

Chapter 14 reviews novel food process operations, such as membrane processing, supercritical fluid extraction, and high-pressure processing.

Chapter 15 provides an overview of food packaging engineering, including packaging materials, packaging equipment, and package processing operations.

Chapter 16 introduces spreadsheet software in food process engineering. It presents examples of Excel® and Visual Basic® applications for heat exchanger, psychrometric, and rheological calculations.

Simple diagrams are used to illustrate the mechanism of each operation and the main components of the process equipment. Simplified calculations, based on elementary calculus, are used in the book. Realistic values of food engineering properties are taken from the literature and the authors' experience. Detailed data and pictures of process equipment can be obtained from suppliers of equipment. The appendix contains useful engineering data for process calculations, such as steam tables, engineering properties, engineering diagrams, and suppliers of process equipment. The book is based on our long teaching and research experiences both in the United States and in Greece.

We wish to acknowledge the contributions of our colleagues, associates, and students at the National Technical University of Athens, Rutgers University, and Cornell University. We appreciate the useful information provided by technical people in the food processing industry and the suppliers of processing equipment.

Special thanks are due to Magda Krokida for her help in preparing the numerical examples in this book. We also appreciate the help of N. Oikonomou, V. Oikonomopoulou, C. Boukouvalas, P. Eleni, I. Katsavou, A. Lazou, K. Kavvadias, and P. Michailidis for preparing the various diagrams in the book.

We hope that this book will contribute to the advancement of teaching and applications of food process engineering operations worldwide. We welcome any comments, criticisms, and corrections by the readers of this book.

George D. Saravacos
Zacharias B. Maroulis

Authors

George D. Saravacos is currently an emeritus professor at the National Technical University of Athens (NTUA), Athens, Greece. He has been a professor of chemical engineering at the NTUA, and a professor of food engineering at Cornell and Rutgers Universities. He has taught courses on unit operations and food engineering both in the United States and in Greece.

Dr. Saravacos received his diploma engineering degree in chemical engineering from NTU, his MS degree in food science from the University of California, and his ScD degree from MIT. He was awarded an honorary doctorate by the Agricultural University of Athens.

Professor Saravacos' research interests include transport properties of foods, heat and mass transfer, evaporation, dehydration, and distillation. He has participated in several fundamental and applied research projects in food engineering in Greece and in the United States, cooperating with the NYSAES (Cornell) and CAFT (Rutgers). He has published more than 150 papers in technical journals and proceedings of national and international meetings, and has authored 10 books/book chapters and 5 textbooks (in Greek). He is also the recipient of the P&G Award for Excellence in Drying Research.

Dr. Saravacos is a member of the IFT, the AIChE, and the Engineering Society of Greece. He is on the editorial board of the *Journal of Food Engineering.* Currently (2008–2011), he is serving as the president of the International Association of Engineering and Food (IAEF).

Zacharias B. Maroulis is currently a professor of chemical engineering at the National Technical University of Athens (NTUA), Athens, Greece, where he teaches and does research on unit operations and process design.

He received his diploma engineering degree and his doctorate from the NTUA and pursued his postdoctoral research at Rutgers University. He is the author or coauthor of more than 120 journal articles, 7 books and book chapters, and professional publications, including *Food Plant Economics* (CRC, 2007), *Food Process Design* (Dekker, 2003), and *Transport Properties of Foods* (Dekker, 2001).

Dr. Maroulis also serves on the editorial board of the journal *Drying Technology*; his research interests include transport properties of foods, drying science and technology, and process economics.

Contents

Series Preface xxi
Series Editor xxiii
Preface xxv
Authors xxvii

Chapter 1 Introduction 1

1.1 Introduction 1
1.2 Process Diagrams 2
1.3 Material and Energy Balances 2
1.3.1 Material Balances 3
1.3.2 Energy Balances 5
1.4 Engineering Units 6
1.5 Engineering Calculations 7
1.5.1 Engineering Symbols 7
1.5.2 Dimensions and Dimensionless Numbers 8
1.5.3 Notation of Numbers 8
1.5.4 Engineering Calculations 9
Application Examples 9
Material Balance 14
Energy Balances 14
Total Energy Requirements 16
Actual Energy Requirements 16
Problems 16
List of Symbols 17
References 18

Chapter 2 Transport Phenomena 19

2.1 Introduction 19
2.2 Steady-State Transport 20
2.2.1 Transport Rate Equations 20
2.2.1.1 Heat Transport 20
2.2.1.2 Mass Transport 21
2.2.1.3 Momentum Transport 21
2.3 Unsteady-State Transport 22
2.3.1 Mathematical Modeling 22
2.3.1.1 Analytical Solution 22
2.3.1.2 Generalized Chart Solution 25
2.3.1.3 Numerical/Computer Solution 28

2.4 Interface Transfer 28
2.4.1 Transfer Coefficients 28
2.4.2 Dimensionless Numbers 29
2.4.2.1 Momentum Transport (*Re*, *Fr*, *f*) 29
2.4.2.2 Heat Transfer (*Bi*, *Fo*, *Gr*, *Gz*, *Le*, *Nu*, *Pe*, *Pr*, *St*) 29
2.4.2.3 Mass Transfer (*Bi*, *Fi*, *Le*, *Pe*, *Sc*, *Sh*) 30
Application Examples 30
Problems 34
List of Symbols 34
References 36

Chapter 3 Thermodynamics and Kinetics 37

3.1 Introduction 37
3.2 Principles of Thermodynamics 37
3.2.1 Definitions 37
3.2.2 First Law 38
3.2.3 Second Law 39
3.2.4 Calculation of Entropy Change 40
3.2.5 Thermodynamic Flow Processes 40
3.2.5.1 Compression Processes 41
3.2.5.2 Expansion Processes 41
3.2.5.3 Steam Power Cycle 42
3.2.5.4 Carnot Cycle 44
3.2.5.5 Refrigeration and Heat Pumps 44
3.2.6 Gas Compression 45
3.3 Phase Equilibria 46
3.3.1 Vapor–Liquid Equilibria 47
3.3.2 Vapor–Solid Equilibria 47
3.3.3 Water Phase Equilibria 49
3.4 Food Kinetics 50
3.4.1 Chemical Reactions 50
3.4.2 Microbial Kinetics 54
3.4.2.1 Microbial Growth 54
3.4.2.2 Microbial Inactivation 55
Application Examples 55
Problems 58
List of Symbols 58
References 59

Chapter 4 Overview of Food Process Technology 61

4.1 Introduction 61
4.2 Food Preservation 62
4.2.1 Minimal Processing and Hurdle Technology 62
4.2.2 Refrigeration 62

4.2.3 Freezing 63
4.2.4 Thermal Processing 65
4.2.5 Concentration and Dehydration 66
4.2.6 Novel Food Processes 69
4.3 Food Manufacturing 70
4.4 Food Ingredients 74
4.5 Food Product Engineering 77
Problems 77
References 78

Chapter 5 Engineering Properties of Foods 79

5.1 Introduction 79
5.2 Physical Properties 79
5.2.1 Density and Porosity 79
5.2.2 Thermal Properties 83
5.2.2.1 Nonfrozen Foods 83
5.2.2.2 Frozen Foods 84
5.2.3 Mechanical Properties 85
5.2.3.1 Static Tests 85
5.2.3.2 Dynamic Tests 86
5.2.3.3 Empirical Tests 87
5.2.4 Electrical Properties 87
5.2.5 Acoustic Properties 88
5.2.5.1 Sound Propagation 88
5.2.5.2 Food Applications 88
5.2.5.3 Doppler Velocimetry 89
5.2.6 Colorimetric Properties 89
5.2.7 Surface Properties 90
5.2.7.1 Introduction 90
5.2.7.2 The Gibbs Equation 90
5.2.7.3 Liquids 91
5.2.7.4 Solids 91
5.3 Transport Properties 92
5.3.1 Transport Properties of Gases and Liquids 92
5.3.2 Rheological Properties 95
5.3.3 Thermal Transport Properties 98
5.3.4 Mass Transport Properties 99
5.3.4.1 Mass Diffusivity 99
5.3.4.2 Permeability 101
Application Examples 102
Problems 107
List of Symbols 108
References 110

Chapter 6 Fluid Flow Operations 111

6.1 Introduction 111
6.2 Food Rheology 111
6.2.1 Capillary Tube Viscometry 111
6.2.2 Rotational Viscometry 112
6.2.3 Velocity Distribution 113
6.2.4 Reynolds Number 115
6.3 Mechanical Energy Balances 116
6.3.1 Mechanical Flow Systems 116
6.3.2 Friction in Piping Systems 119
6.3.3 Friction in Non-Newtonian Fluids 121
6.3.4 Rabinowitsch–Mooney Equation 121
6.4 Piping Systems 122
6.4.1 Pipes and Tubes 122
6.4.2 Pipe Fittings 126
6.5 Film and Oren Channel Flows 126
6.5.1 Film Flow 126
6.5.2 Open Channel Flow 127
6.6 Flow Measurement 128
6.6.1 Differential Pressure Flow Meters 128
6.6.1.1 U-Tube Manometer 129
6.6.1.2 Orifice Meter 130
6.6.1.3 Venturi Meter 131
6.6.1.4 Pitot Tube 131
6.6.2 Mechanical Flow Meters 133
6.6.2.1 Rotameters 133
6.6.2.2 Positive Displacement Flow Meters 133
6.6.3 Electrical and Magnetic Flow Meters 133
6.6.3.1 Hot Wire Anemometer 133
6.6.3.2 Magnetic and Acoustic Flow Meters 134
6.6.4 Weir Flow Meters 134
6.7 Pumping Equipment 135
6.7.1 Pumps 135
6.7.1.1 Centrifugal Pumps 136
6.7.1.2 Positive Displacement Pumps 136
6.7.1.3 Rotary Pumps 137
6.7.2 Pump Characteristics 139
6.7.2.1 Pump Curves 139
6.7.2.2 Net Positive Suction Head 142
6.7.2.3 Pump Selection 143
6.7.3 Fans and Blowers 144
6.7.4 Vacuum Pumps 145
Application Examples 147
Problems 158
List of Symbols 159
References 160

Chapter 7 Mechanical Processing Operations 161

7.1 Introduction 161
7.2 Particle Characteristics 161
7.2.1 Particle Size and Shape 161
7.2.2 Particle Size Distribution 163
7.2.3 Particle Size Analysis 164
7.2.3.1 Methods of Measurement 164
7.2.3.2 Sieve Analysis 165
7.3 Size Reduction 166
7.3.1 Introduction 166
7.3.2 Cutting 168
7.3.2.1 Introduction 168
7.3.2.2 Cutting Tools 169
7.3.2.3 Portable Cutting Tools 170
7.3.2.4 Cutting Equipment 170
7.3.3 Crushing and Grinding Operations 172
7.3.3.1 Introduction 172
7.3.3.2 Crushers 172
7.3.3.3 Grinders 173
7.3.4 Droplet Formation 179
7.3.4.1 Pressure Nozzles 179
7.3.4.2 Rotary Nozzles 180
7.3.4.3 Two-Fluid Nozzles 180
7.4 Size Enlargement 180
7.4.1 Introduction 180
7.4.2 Free Structuring Agglomeration 181
7.4.3 Pressure Agglomeration 183
7.5 Mixing and Forming 184
7.5.1 Fluid Mixing 184
7.5.1.1 Agitated Tanks 184
7.5.1.2 Industrial Mixers 187
7.5.2 Food Mixing 187
7.5.3 Homogenization 188
7.5.4 Solids Mixing 188
7.5.5 Forming Operations 189
7.5.6 Extrusion 190
7.6 Conveying of Solids 191
7.6.1 Pneumatic Conveying 192
7.6.2 Hydraulic Conveying 193
7.6.3 Mechanical Conveying 194
7.6.3.1 Belt Conveyors 194
7.6.3.2 Roll and Skate Wheel Conveyors 195
7.6.3.3 Chain Conveyors 195
7.6.3.4 Bucket Elevators 196
7.6.3.5 Screw Conveyors 196
7.6.4 Hygienic Considerations 197