Contemporary Food Engineering Series

Da-Wen Sun, Series Editor

Innovation in Food Engineering

New Techniques and Products

Edited by
Maria Laura Passos
Claudio P. Ribeiro

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Contemporary Food Engineering

Series Editor

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Dedicated
with respect and love
to my family and
to all my students (ex and new)

Maria Laura Passos

To my beloved parents,
Cláudio and Irenice,
for their constant support.

Cláudio P. Ribeiro, Jr.

Series Preface

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 quality, safety, and security remain critical issues in the study of food engineering. 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 issues in food engineering, and significant progress is being made in waste management, efficient utilization of energy, and reduction of effluents and emissions in food production.

The *Contemporary Food Engineering* book series, which consists of edited books, attempts to address some of the recent developments in food engineering. Advances in classical unit operations in engineering related 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, and sustainable technologies in food processing; and packaging, cleaning, and sanitation. These books are aimed at professional food scientists, academics researching food engineering problems, and graduate-level students.

The editors of these books are leading engineers and scientists from all parts of the world. All of them were asked to present their books in such a manner as to address the market needs and pinpoint the cutting-edge technologies in food engineering. Furthermore, 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

Born in southern China, Professor Da-Wen Sun 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; bio-process simulation and optimization; and computer vision technology. Especially, 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 national and international media. The results of his work have been published in over 200 peer-reviewed journal papers and more than 200 conference papers.

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

Sun has contributed significantly to the field of food engineering as a leading educator in this field. He has trained many PhD students who have made their own contributions to the industry and academia. He has also regularly given lectures on advances in food engineering in international academic institutions and delivered keynote speeches at international conferences. As a recognized authority in food engineering, he 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 this field, the International Commission of Agricultural Engineering (CIGR) awarded him the CIGR Merit Award in 2000 and again in 2006. The Institution of Mechanical Engineers (IMechE) based in the United Kingdom named him Food Engineer of the Year 2004. In 2008, he was awarded the CIGR Recognition Award in honor of his distinguished achievements in the top 1% of agricultural engineering scientists in the world.

Sun is a fellow of the Institution of Agricultural Engineers and a Fellow of Engineers Ireland. He has received numerous awards for teaching and research excellence, including the President's Research Fellowship and the President's Research Award of University College Dublin on two occasions. He is a member of the CIGR Executive Board and an honorary vice-president of CIGR; the editor in chief of *Food*

and Bioprocess Technology—An International Journal (Springer); the 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 *Czech Journal of Food Sciences*. He is also a chartered engineer.

Preface

Food engineering has seen many developments since its establishment as an individual research area in the 1970s, but the food industry of the twenty-first century faces new challenges. Energy-related concerns are more important than ever, consumers have become much more quality conscious, nutritional aspects have acquired significant, if not dominant, importance, and the once-accepted compromise between convenience and quality for food products is no longer an option. In this book, we present an overview of the different routes that researchers are pursuing to provide solutions for these challenges. Without the presumption of being able to cover everything in a single volume but, at the same time, driven by the desire to contribute something new, we chose to address not only new or alternative techniques, but also new products, materials, and additives that have emerged as a response to the challenges faced by the food industry.

Part I deals with innovative or reformulated technologies applied to food processing. Considering the importance of thermal processing in the food industry, it seemed almost natural for us to start this first part with a chapter on nonthermal processes for food preservation. Thus, in Chapter 1, the theories, potential applications, and challenges of high-pressure processing, pulsed electric fields, and ultrasound are discussed. Chapter 2 focuses on innovation in one of the fastest-growing segments in the food industry—bakery products—in which low-temperature technology has been intensively investigated as a means to meet consumers' demands of convenience, health, and quality. Chapter 3 discusses biotechnology as an alternative to extraction for producing natural flavors, as well as analytical tools that can be used to distinguish between natural and synthetic products. Chapter 4 covers further applications of biotechnology in the food industry and focuses specifically on solid-state fermentation, which is an attractive option for efficient utilization and value addition of agro-industrial solid wastes. Chapter 5 addresses a similar philosophy of efficient utilization but applied to liquid residues and process streams. It provides the basic principles and potential applications of three membrane-based unit operations (pervaporation, nanofiltration, and electrodialysis) for the recovery, concentration, and purification of compounds with target bioactivity. Three other membrane-based unit operations (reverse osmosis, membrane distillation, and osmotic distillation), as well as some advanced thermal techniques are discussed in Chapter 6 as alternative techniques for fruit-juice concentration. Chapters 7 and 8 cover encapsulation technology. The former provides the basic theoretical aspects and a review of the current research on four types of delivery systems (gelled microparticles, spray-dried microparticles, emulsions, and liposomes), whereas the latter focuses on fluidized bed coating as an encapsulation method.

Water removal has long been adopted as a means of food preservation, and the importance of drying as a unit operation in the food industry is well recognized. Chapters 9 through 12 discuss drying-related innovations. Chapter 9 deals with recent developments in spray drying, the most traditional drying techniques, while

Chapter 10 provides an overview of superheated steam drying along with its advantages and potential applications to foods. Chapter 11 focuses on the use of spouted bed dryers to process tropical fruit pulps, while Chapter 12 presents some promising results concerning the use of microwave radiation to assist not only in the process of drying but also that of extraction. Chapter 13, in turn, is devoted to a different approach to water removal, that is, vacuum frying, which has emerged as a viable option for the production of snacks from fruits and vegetables.

Packaging is an important topic for the food industry and this book would not be complete without a discussion on some of the advances in this area. Chapter 14 reviews the state of the art in aseptic packaging, including the application of plasma decontamination. Chapter 15 discusses controlled- and modified-atmosphere packaging, with a special emphasis on applications in fresh-cut produce—a particularly difficult yet dynamic sector for these technologies due to several technical and food-safety challenges. Chapter 16 concludes Part I, and provides a critical review of the latest trends in the use of polymeric packages for food applications, including the use of nanocomposites, active packaging, and antimicrobial packaging.

Part II is dedicated to new materials, products, and additives. It starts with an in-depth analysis, in Chapter 17, of the development of biodegradable films for packaging materials that can be used as a substitute for petrochemical polymers. Chapter 18 illustrates the complex process involved in the establishment of a new product line through a case study related to the production of goat-milk powder in small agro-cooperatives. Functional foods have been successfully introduced into the market as a response to the consumers' demands for healthier products, and research in this area has been very active. This topic is covered in three chapters: Chapter 19 deals with meat products, Chapter 20 analyzes the inclusion of probiotic bacteria and prebiotic substrates into dairy foods, and, finally, Chapter 21 addresses the potential of cereals for the development of functional foods. Low-fat products, like functional foods, reflect the consumers' awareness of nutritional and health benefits, and Chapter 22 reviews the recent advances in this area. Last but not least, Chapter 23 discusses potential applications of biosurfactants in the food industry, as well as new approaches for their production and scale-up.

It has been a long journey from the conception to the realization of this book, and we could never have accomplished this without the dedicated work and commitment of all our contributors, to whom we are most grateful. The book, ultimately, is a result of their combined efforts. We would also like to thank Prof. Da-Wen Sun for inviting us to contribute this volume to the *Contemporary Food Engineering* series, an invitation that was the genesis of this entire project. In addition, we would like to thank our project coordinator at CRC Press, Patricia Roberson, who was always very efficient and helpful.

Maria Laura Passos
Cláudio P. Ribeiro, Jr.

Editors

Maria Laura Passos is currently a consultant in fluid-particle systems and drying technology. She acts as an associate researcher in the Chemical Engineering Drying Center of the Federal University of São Carlos and as a co-advisor at the Chemical Engineering Graduate Program of the Federal University of Rio Grande do Norte, as well as at the Technology Center of Minas Gerais (CETEC-MG). She was a full-time professor at the Engineering School of the Federal University of Minas Gerais (UFMG) in Belo Horizonte, Brazil. She received her BSc (with honors) in chemical engineering from UFMG, her MSc in chemical engineering from the Federal University of Rio de Janeiro, and her PhD from the chemical engineering department of McGill University, Montreal, Canada. She has participated, as a member, in official committees from governmental agencies to evaluate chemical engineering graduate and undergraduate education in Brazil. She has written over 180 scientific publications on fluid-particle systems and drying, and over 50 technical and educational reports on chemical engineering. She is a member of the editorial board of *Drying Technology*. She has participated as a reviewer in many international journals on chemical and food engineering, and has a large experience as an ad hoc consultant in several research agencies. She has worked as a member of organization and scientific committees of many symposiums, conferences, and congresses.

Cláudio P. Ribeiro, Jr. received his BSc (with honors) and MSc from the Federal University of Minas Gerais (UFMG), and his doctoral degree from the Federal University of Rio de Janeiro in 2005, all in chemical engineering. In the same year, he was awarded a fellowship from the Alexander von Humboldt Foundation to work as a visiting scholar at the University of Hannover, Germany. He returned to Brazil in 2006 and worked as a lecturer at the Federal University of Rio de Janeiro. In 2007, he moved to his current position as a postdoctoral researcher at the laboratory of Membrane Science and Technology from the Center of Energy and Environmental Resources at the University of Texas at Austin. He has published a total of 27 papers in peer-reviewed journals and 20 contributions to academic conferences. His research on an alternative route for fruit-juice concentration was chosen as the best Brazilian PhD thesis on engineering and exact sciences in 2005 by CAPES, the governmental agency responsible for evaluating graduate courses in Brazil. He has already participated as a reviewer in many international journals on chemical engineering.

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Nomenclature

a	activity (—)
a^*	redness (—)
A	area (L^2)
A^*	water permeability constant of a reverse osmosis membrane (tL^{-1})
A_i or a_i	constant (i = number)
b^*	yellowness (—)
B	geometric factor in the Laplace–Young equation (—)
B_i^*	permeability constant of solute i in a reserve osmosis membrane (Lt^{-1})
c_i	mass concentration of component i (ML^{-3})
c_p	specific isobaric heat capacity ($L^2t^{-2}T^{-1}$)
$c_{R\text{-}ab}$	absorbed radiant heat capacity ($L^2t^{-2}T^{-1}$)
C_i	content (mass fraction) of component i (M/M)
C_i^w	content of component i per water content (w/w) (—)
C_D	drag coefficient (between fluid and particle) (—)
d	diameter (L)
d_{32}	mean particle Sauter diameter (L)
d_{eq}	equivalent (or hydraulic) diameter of a noncircular channel (L)
d_p	particle diameter (L)
d_p^*	pore diameter (L)
D_m	diffusion coefficient or mass diffusivity (L^2t^{-1})
E	electric field strength or electrical potential ($ML^2t^{-3}A^{-1}$)
fr	frequency (Cycles t^{-1})
F	force (MLt^{-2})
$\mathfrak{F}$	Faraday constant (At mol^{-1})
g	gravitational acceleration (Lt^{-2})
h	convective heat-transfer coefficient ($Mt^{-3}T^{-1}$)
H	height (L)
Id	dispersion index span (—)
j	complex operator (—)
J^m	mass flux ($ML^{-2}t^{-1}$)
J^V	volumetric flux (Lt^{-1})
J^E	electrical charge flux (AL^{-2})
k	convective mass-transfer coefficient (Lt^{-1})
K or K^{OV}	overall mass-transfer coefficient ($M^{-1}L^2t$)
kT	energy unit = Boltzman constant × absolute temperature (ML^2t^{-2})
l	thickness (L)
L	length (L)
L_p	permeability coefficient ($M^{-1}L^3t$)
L^*	lightness (—)
m	moisture content (expressed in d.b. or in w.b. when specified) (—)
M	mass (M)