Contemporary Food Engineering Series

Da-Wen Sun, Series Editor

ENGINEERING ASPECTS OF THERMAL FOOD PROCESSING

Edited by

RICARDO SIMPSON

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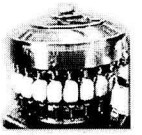

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This book is dedicated to my wife, Anita; family,
José Ignacio, María Jesús, Enrique; my beloved mother,
Carmen; and to the memory of my father, Jorge.

Series Preface

Food engineering is a multidisciplinary field of applied physical sciences combined with a knowledge of product properties. Food engineers provide technological knowledge 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 the market needs.

For the development of the field 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 remain critical issues in food engineering study. New packaging materials and techniques are being developed to provide a higher level of protection to foods and novel preservation technologies are emerging to enhance food security and defense. Additionally, process control and automation are among the top priorities identified in food engineering. Advanced monitoring and control systems have been 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, efficient utilization of energy, and the reduction of effluents and emissions in food production.

The *Contemporary Food Engineering* series consists of edited books and 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, and sustainable technologies in food processing; and packaging, cleaning, and sanitation. These books are intended for use by professional food scientists, academics researching food engineering problems, and graduate level students.

These books have been edited by leading engineers and scientists from many parts of the world. All the editors were asked to present their books so as to address market needs and pinpoint cutting-edge technologies in food engineering. Furthermore, all contributions have been written by internationally renowned experts who have both academic and professional credentials. All authors have attempted to

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

Da-Wen Sun
Series Editor

Preface

In the last 10 years, there has been a remarkable growth in research in the field of thermal processing, which indicates that the process is thriving and expanding all over the world. This book has been written with the intention of revising and updating the physical and engineering aspects of thermal processing of packaged foods.

Each chapter has been contributed by a renowned authority on a particular process and in this way the book covers all aspects of thermal processing. The book consists of four parts: (I) Fundamentals and New Processes, (II) Modeling and Simulation, (III) Optimization, and (IV) Online Control and Automation.

Part I consists of six chapters. Dr. Donald Holdsworth has written an outstanding introduction emphasizing the increased use of new packaging materials, including retortable pouches, and the use of containers made from other plastic composite materials. Dr. Silva and Dr. Gibbs have contributed the most complete and up-to-date chapter on pasteurization including a detailed account of the importance of *sous vide* processing. Chapter 3 has been written by top researchers from Unilever and deals with aseptic processing, a field which has expanded and developed in the last decade due to customer demand for better quality products. Chapter 4 is devoted to new and emerging technologies. This chapter is the result of collaboration among selected authors from academia and the industry. Traditional methods have been successful; however, limitations in heat transfer mean that this technology is not capable of providing convenient and high quality products. To overcome these limitations, methods using electromagnetism have been investigated and developed. The first part concludes with two excellent chapters on high-pressure processing by Dr. Gustavo Barbosa-Cánovas and coworkers. Chapter 5 discusses the principles behind four modeling approaches—analytical, numerical, macroscopic, and artificial neural networks—that can be used to predict temperatures in a high-pressure system. Chapter 6 highlights some applications of each modeling approach to high-pressure/low-temperature systems and high-pressure/high-temperature conditions reported in the literature.

Part II also consists of six chapters. Starting with this part, we have included two viewpoints on the crucial topic of thermal inactivation of microbial cells and bacterial spores. Due to the relevance of this subject in thermal food processing, we have asked the most prominent authors to collaborate on this work. Chapter 7 was written by Dr. Micha Peleg and coworkers and Chapter 8 was written by Dr. Arthur Teixeira and Dr. Alfredo Rodriguez. As the processing of heat-preserved foods in flexible pouches has gained considerable commercial relevance worldwide in recent years, Dr. Amézquita from Unilever and Dr. Almonacid from Chile cover the most important aspects of retortable pouch processing and mathematical modeling in Chapter 9. Although thermal processing, or canning, has proven to be one of the most effective methods of preserving foods while ensuring the product remains safe from harmful bacteria, it also has strong effects on the sensory characteristics of the product, such as color, texture, and nutritional value. In Chapter 10, Dr. Ramaswamy

and Dr. Dwivedi discuss rotary processing and how it can be used to overcome this difficulty. The last two chapters of this part deal with mathematical modeling. Chapter 11 has been written by Dr. Michele Chiumenti and coworkers and focuses on the mathematical modeling of ohmic heating as an emerging food preservation technology currently used by the food industry. Chapter 12 includes a comprehensive review of computational fluid dynamics and has been written by the well-known professor Da-Wen Sun and coworkers.

Part III consists of four chapters. The whole concept is to understand that mathematical optimization is the key ingredient for computing optimal operating policies and building advanced decision support systems. Chapter 13 on optimization has been contributed by Dr. Julio Banga and his outstanding team. This chapter deals not only with global optimization in thermal processing, but several food processes such as thermal sterilization, contact cooking, and microwave processing that can also be analyzed to find optimal operating procedures computed via global optimization methods. Chapter 14 proposes a new economic evaluation procedure to optimize the system design and operation of multiple effect evaporators compared to the traditional chemical engineering approach based on total cost minimization. Chapter 15 describes the optimization of in-line aseptic processing and demonstrates that it is essential for successful commercial exploitation. Chapter 16 analyzes plant production productivity, although an important problem in food processing, it has received little attention in thermal processing. This type of optimization, scheduling to maximize efficiency of batch processing plants, has become well known and it is commonly practiced in many processing industries.

Part IV consists of two chapters. Chapter 17 describes a practical and efficient (nearly precise, yet safe) strategy for online correction of thermal process deviations during retort sterilization of canned foods. In Chapter 18, authors from academia (Dr. Osvaldo Campanella) and industry (Dr. Clara Rovedo, Dr. Jacques Bichier, and Dr. Frank Pandelaers) analyze and discuss manufacturers' businesses in today's competitive marketplace. For such purposes, manufacturers must face challenges of increasing productivity and product quality, while reducing operating costs and safety risks. Traditionally, plant automation has been the main tool to assist the manufacturer in meeting those challenges.

Series Editor

Professor Da-Wen Sun 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 national and international media. Results of his work have been published in over 180 peer-reviewed journal papers and in more than 200 conference papers.

Professor Sun received his first class BSc honors and 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 college lecturer at the National University of Ireland, Dublin (University College Dublin), Ireland, in 1995, and was then continuously promoted in the shortest possible time to senior lecturer, associate professor, and full professor. Sun is now Professor of Food and Biosystems Engineering and the director of the Food Refrigeration and Computerized Food Technology Research Group at University College Dublin.

As a leading educator in food engineering, 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 given lectures on advances in food engineering on a regular basis at academic institutions internationally 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 the 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 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 one percent of agricultural engineering scientists in the world.

Professor Sun is a fellow of the Institution of Agricultural Engineers and a fellow of Engineers 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 University College Dublin on two occasions. He is a member of the CIGR executive board and honorary vice president of CIGR; editor-in-chief of *Food and Bioprocess Technology*—an international journal (Springer); former editor of *Journal of Food Engineering* (Elsevier); series editor of the *Contemporary Food Engineering* book series (CRC Press/Taylor & Francis); and an editorial board member for the *Journal of Food Engineering* (Elsevier), *Journal of Food Process Engineering* (Blackwell), *Sensing and Instrumentation for Food Quality and Safety* (Springer), and the *Czech Journal of Food Sciences*. He is also a chartered engineer.

Editor

Ricardo Simpson is currently working as a full professor at the Chemical and Environmental Engineering Department, Universidad Técnica Federico Santa María, Chile. He holds a biochemical engineering degree from the P. Universidad Católica de Valparaíso (PUCV, 1980), an MS in food science and technology (1990) and a doctorate in food science (1993) from Oregon State University, and a diploma in economics from the Universidad de Chile (1981). He lectured at PUCV from 1984 to 1999 and became a full professor in 1998. He was also a member of the Food Technology Study Group of CONICYT (equivalent to NSF).

Ever since Dr. Simpson obtained his PhD in 1993, he has been a prolific contributor to the food industry, not only in Chile, but also internationally (e.g., Unilever). His contributions have been summarized in more than 140 conference presentations and more than 50 refereed publications (as author or coauthor), thus advancing the understanding of many aspects of food engineering. He has also done extensive collaborative work with the Chilean food processing industry. He is one of the leading experts in the world in thermal processing of foods, having helped establish and improve food engineering programs at universities in Chile, Peru, and Argentina. He has presented short courses for the food industry in Costa Rica, Chile, Peru, and Argentina on energy conservation, thermal processing, and mathematical modeling applied to the food industry and also on project management. He has coplanned and codirected an international congress, the IV Ibero-American Congress in Food Engineering, and a national congress on food science and technology, both held in Valparaíso, Chile, in 1995 and 2003, respectively. He also planned and directed the national congress on mass and heat transfer held in Valparaíso, Chile, in 1996. He was vice president of the organizing committee of ICEF 10 (International Congress on Engineering and Food) held in Viña del Mar in April 2008. In recent years, he has published an average of eight refereed articles per year and has delivered several invited talks to international audiences. He has made outstanding contributions to engineering programs in education, research, development, consulting, and technology transfer that have resulted in improved food production, quality of life, and education for people living in Chile and Latin America. Recently, he completed a 4-month stay at Unilever's Food Research Center in Vlaardingen, and he was appreciated by the management for his work at its laboratory.

Dr. Simpson has consolidated his expertise as one of the leading experts in Latin America in thermal processing research (commercial sterilization of low-acid canned foods) in the last 3 years, and has been widely recognized in the international arena. Since 2002, he has published several manuscripts, patents, and book chapters on this field.

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PART II Modeling and Simulation

PART III Optimization

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