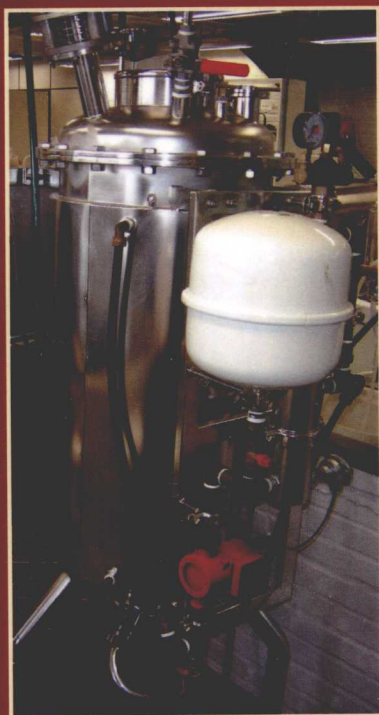
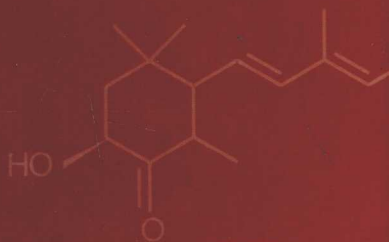


Contemporary Food
Engineering Series

Da-Wen Sun, Series Editor



Fermentation Processes Engineering in the Food Industry



Edited by

Carlos Ricardo Soccol

Ashok Pandey

Christian Larroche



CRC Press
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Fermentation Processes Engineering in the Food Industry

Contemporary Food Engineering

Series Editor

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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 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 continues to be a critical issue 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, efficient utilization of energy, and 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. The series covers advances in classical unit operations in engineering applied to food manufacturing 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 and electronic indicators in inventory management; 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 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 the contributions have been written by internationally renowned experts who have both academic and professional credentials. All the 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

Preface

Fermentation processes are some of the oldest technologies in food, having been developed with the aim of increasing the storage stability of foods and improving the organoleptic and textural properties of raw materials. Fermented foods remain very popular even today as a substantial percentage of daily consumed foods are fermented. Important examples include bread-making; dairy products, such as yogurts, cheeses, buttermilks, and sour milks; alcoholic drinks, such as wine, beer, and cider; fermented vegetables, such as sauerkraut and pickles; and fermented meats, such as sausages and salami. More recently, traditional products have started to include prebiotic and probiotic microorganisms and ingredients as a result of a better understanding of industrial microbiology and our physiology. With the advent of modern tools of molecular biology and genetic engineering and new skills in metabolic engineering and synthetic biology, the developments in fermentation technology for industrial applications have changed enormously.

This book comprises 17 chapters, providing state-of-the-art information concerning technological developments on engineering aspects of fermentation processes in the food industry. Chapter 1 by Dimitris Charalampopoulos and Colin Webb presents an overview about the lactic acid metabolism and the type of fermented foods that are produced using bacteria and yeast, including a presentation of the main processing steps for their manufacture; it also presents three examples of metabolic engineering of LAB with potential applications in the production of fermented foods and food ingredients. Chapter 2 by Syed G. Dastager describes the methods and techniques for isolation, improvement, and preservation of the microbial cultures used in the food fermentation industry. Chapter 3 by Vincenza Faraco and Antonella Amore discusses that fermentation processes are strongly affected by physical and chemical factors, such as temperature, pH, aeration, and medium composition. In this chapter, the authors present the effects of physical and chemical factors on fermentations in dairy and bakery products and alcoholic beverages.

Chapter 4 by Binod et al. presents the fundamentals of fermentation processes, modes of fermentation, and the principle operations of upstream processes that include the screening and selection of suitable organisms for a particular product, development of a suitable medium, and finally, the mass culturing of the organism for the product. The upstream processing costs make up approximately 20%–50% of the total; whereas the downstream processing costs about 50%–80%. Upstream processing is very crucial for getting the desired end products. The techniques of fermentation and fermentation parameters affect the product yield, and proper quality control measures should be taken during upstream operations for getting the desired product quality. Chapter 5 by Andre Lebert covers the use of mathematical models for analyzing the evolution of the pH and a_w of a process, and their relationship with the increase in the nutritional and safety qualities of the fermented products. Chapter 6 by Christophe Vial and Yussef Stirriba focuses on the effective use of computational methods for bioreactors, mainly using commercial solutions. These

are now considered to be standard numerical tools, widely used within the industry although they are yet to be fully integrated into the design methodology. Conversely, the details of computational fluid dynamics (CFD) algorithm development remain beyond the scope of the discussion. The first section of this chapter describes briefly what can be expected from the characterization of bioreactors using CFD. The second section describes the main steps of CFD analysis. The third and the fourth parts address the physical modeling and numerical issues of CFD, focusing on the specificity of bioreactors. The last section analyzes the recent progresses and limitations of CFD, using the example of bubble column and airlift reactors so as to illustrate the steps and issues developed previously on bioreactors.

Chapter 7 by Talasi Satynarayana et al. provides an overview of various types of fermenters and bioreactors employed in submerged fermentations with special reference to their utility in food industries. Chapter 8 by José Angel Rodríguez-León et al. describes the evolution of the fermentation theory of solid-state fermentation that can be characterized by kinetic concepts. Several commonly employed SSF reactors are also described. Chapter 9 by Júlio Cesar de Carvalho et al. describes the most important operations for solid-liquid separation, concentration, and drying of fermented foods. Chapter 10 by Wilerson Sturm et al. describes automation systems, such as sensors, actuators, and controls, specifically in the food industry. Chapter 11 by Juliano De Dea Lindener et al. documents different aspects related to meat and vegetable fermentations, emphasizing the advantages of the fermentation processes and the benefits to health. Also, it presents some characteristics of fermented functional foods, including probiotics and prebiotics, and new trends for the fermentation of foods. Chapter 12 by Satinder Kaur Brar provides a brief outline on different varieties of alcoholic beverages, technical aspects of their production processes, and recent advances in this field. Chapter 13 by Luciana Porto de Souza Vandenberghe et al. presents general aspects about the manufacturing of dairy fermented products as well as technological challenges of the fermentative process and economic and functional importance of these products. Chapter 14 by Jean-Luc Tholozan and Jean-Luc Cayol describes new tendencies of dairy and nondairy probiotic products, including soy milk, fruits, vegetables, juices, and others beverages. Chapter 15 by Juliano Lemos Bicas et al. provides an insight about the main aspects involving the properties and biotechnological production methods of food additives, focusing on bio-aromas, bio-colorants, nondigestible oligosaccharides, and biosurfactants. Chapter 16 by Jorge Alberto Vieira Costa and Michele Greque de Moraes presents several applications of microalgae in the food sector, including supplementation of the products from biomass, specific biocompounds, polymers with potential for developing packaging, and the treatment of industrial effluents. Chapter 17 by Carlos Ricardo Soccol et al. presents the potentials of the application of a biorefinery concept to add value to the solid and liquid wastes from the food industries. Some results are presented about a case study on an integrated project in which the concept was applied for the integral exploitation of residues of the soybean industry for the production of bioethanol, xanthan gum, alpha-galactosidase, and lactic acid on laboratory- and pilot-scales.

Series Editor



Professor Da-Wen Sun, PhD, is a world authority on food engineering research and education; he is a member of the Royal Irish Academy, which is the highest academic honor in Ireland; he is also a member of Academia Europaea (The Academy of Europe) and a Fellow of International Academy of Food Science and Technology. 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.

In particular, especially, his many scholarly works have become standard reference materials for researchers in the areas of computer vision, computational fluid dynamics modelling, vacuum cooling, etc. Results of his work have been published in more than 600 papers, including over 250 peer-reviewed journal papers (Web of Science *h*-index = 40; Google Scholar *h*-index = 47). He has also edited 13 authoritative books. According to Thomson Reuters's *Essential Science Indicators*SM updated as of July 1, 2010, based on data derived over a period of ten years and four months (January 1, 2000–April 30, 2010) from the ISI Web of Science, a total of 2554 scientists are among the top 1% of the most cited scientists in the category of agriculture sciences, and Professor Sun is listed at the top with a ranking of 31.

Dr. Sun received his first class BSc honors and his MSc in mechanical engineering, and his 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 a college lecturer at the National University of Ireland, Dublin (University College Dublin [UCD]), in 1995. He was then continuously promoted in the shortest possible time to the position of senior lecturer, associate professor, and full professor. Dr. Sun is now a professor of food and biosystems engineering and director of the Food Refrigeration and Computerized Food Technology Research Group at UCD.

As a leading educator in food engineering, Dr. Sun has contributed significantly to the field of food engineering. He has guided 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 international academic institutions and delivered keynote speeches at international conferences. As a recognized authority in food engineering, Dr. Sun has been conferred adjunct/visiting/consulting professorships by over ten 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 U.K.-based Institution of Mechanical Engineers 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, he was presented with the only AFST(I) Fellow Award in that year 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 upon individuals who have made sustained, outstanding contributions worldwide).

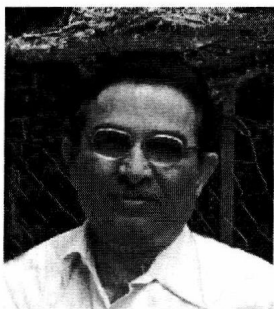
Dr. Sun is a fellow of the Institution of Agricultural Engineers and a fellow of Engineers Ireland (the Institution of Engineers of Ireland). He has also received numerous awards for teaching and research excellence, including the President’s Research Fellowship, and has received the President’s Research Award from UCD on two occasions. He is also the editor in chief of *Food and Bioprocess Technology—An International Journal* (Springer) (2011 Impact Factor = 3.703, ranked at the fourth position among 128 ISI-listed food science and technology journals); series editor of the Contemporary Food Engineering Series (CRC Press/Taylor & Francis Group); former editor of *Journal of Food Engineering* (Elsevier); and an editorial board member of *Journal of Food Engineering* (Elsevier), *Journal of Food Process Engineering* (Blackwell), *Sensing and Instrumentation for Food Quality and Safety* (Springer), and *Journal of Ocean University of China*. Dr. Sun is also a chartered engineer.

On May 28, 2010, he 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 to 2014. The term of the presidency is six years—two years each for serving as incoming president, president, and past president. On September 20, 2011, he was elected to Academia Europaea (The Academy of Europe), which is functioning as European Academy of Humanities, Letters and Sciences and is one of the most prestigious academies in the world; election to the Academia Europaea represents the highest academic distinction.

Editors



Carlos Ricardo Soccol is the research group leader of the **Department of Bioprocess Engineering and Biotechnology (DEBB)** at the Federal University of Paraná, Brazil, with 20 years of experience in biotechnological research and development of bioprocesses with industrial application. He received the bachelor's degree in chemical engineering from UFPR (1979), the master's degree in food technology from UFPR (1986), and the Ph.D. degree in *Genie Enzymatique, Microbiologie et Bioconversion* from the *Université de Technologie de Compiègne*, France (1992). He received his postdoctoral degree from the Institut ORSTOM/IRD (Montpellier, 1994 and 1997) and the *Université de Provence et de la Méditerranée* (Marseille, 2000). He is an HDR professor at the *Ecole d'Ingénieurs Supérieure de Luminy*, Marseille, France. He has experience in the area of science and food technology, with emphasis on agroindustrial and agroalimentary biotechnology, acting in the following areas: bioprocess engineering and solid state fermentation, submerged fermentation, bioseparations, industrial bioprocesses, enzyme technology, tissue culture, bioindustrial projects, and bioproduction. He is currently a Coordinator of Master BIODEV-UNESCO, an Associate Editor of five international journals, and the Editor in Chief of the *Brazilian Archives of Biology and Technology Journal*. Professor Soccol received several national and international awards, including the Science and Technology award of the Government of Paraná (1996), the Scopus/Elsevier Award (2009), Dr. Honoris Causa, University Blaise Pascal-France (2010), and Outstanding Scientist—5th International Conference on Industrial Bioprocesses, Taipei, Taiwan (2012). He is a technical and scientific consultant of several companies, agencies, and scientific journals in Brazil and abroad. He has supervised and molded 88 master of science students, 35 Ph.D. students, and 12 postdoctorate students. He has 931 publications/communications that include 14 books, 87 book chapters, 250 original research papers, and 543 research communications in international and national conferences, and he has registered 37 patents. His research articles have so far been cited 4150 times (Scopus database) and 3950 times (Web of Science—ISI) with Index $h = 32$.



Ashok Pandey obtained his master's degree in chemistry in 1976 and his Ph.D. in 1979 in microbiology from the University of Allahabad. Professor Pandey was a scientist at the National Sugar Institute, Kanpur, during 1982 and 1985. During 1985 and 1986, he worked as a research scientist in Suddeutsche Zucker AG in Germany. In 1987, he joined the CSIR's National Institute for Interdisciplinary Science and Technology at Trivandrum as a scientist

and since then continuing there. Currently, he is deputy director and head of the Center for Biofuels and Biotechnology Division there.

Professor Pandey's current main research focus is on bioprocesses and product development, mainly focused on agro-industrial solid waste utilization for the production of biofuels, biopolymers, industrial enzymes, etc. He has developed and transferred technologies on industrial enzymes to the industries and has completed several industrial consultancy projects. He has 900 publications/communications, which include 12 patents, 29 books, 23 special issues of journals as guest/special issue editor, 25 technical reports, 95 chapters in the books, 354 original and review papers, and 362 research communications in international and national conferences.

Professor Pandey is the recipient of many national and international awards and fellowships, which include Fellow of International Organization of Biotechnology and Bioengineering, Biotech Research Society of India and Association of Microbiologists of India; honorary doctorate degree from Univesite Blaise Pascal, France; Thomson Scientific India Citation Laureate Award; Lupin Visiting Fellowship, Visiting Professor in the University Blaise Pascal, France, Federal University of Parana, Brazil and EPFL, Switzerland; Best Scientific Work Achievement award, Government of Cuba; UNESCO Professor; Raman Research Fellowship Award, CSIR; GBF, Germany and CNRS, France Fellowship; Young Scientist Award, etc. He was chairman of the International Society of Food, Agriculture and Environment, Finland (Food and Health) during 2003 and 2004. He is founder president of Biotech Research Society of India and international coordinator of International Forum on Industrial Bioprocesses. He is editor-in-chief of *Bioresource Technology*, the Elsevier journal, and editorial board member of several international and Indian journals.



Christian Larroche is a graduate in biochemical engineering from the INSA, Toulouse (1979); docteur-ingénieur in organic chemistry from Paul Sabatier Toulouse 3 University (1982); and docteur ès sciences (Ph.D.) in biochemical engineering from Blaise Pascal University (1990). Professor Larroche has strong research interests in the areas of applied microbiology and biochemical engineering. His skills are related to the study and development of special processes for the use of microorganisms. This includes fungal spores produced by solid-state cultivation and their use as protein (enzyme) reservoirs in biotransformations. A special interest in phase-transfer phenomena coupled with metabolic engineering has to be noticed. It is applied to the design and optimization of biotransformations involving hydrophobic compounds and carried out in biphasic liquid-liquid media. These processes are related both to the food and environment (bioremediation) areas. His interests have recently been extended to bioenergy, and he is presently coordinator of two French research programs on biohydrogen production by nonphotosynthetic anaerobic microorganisms grown on complex media.

He is author of approximately 70 articles, two patents, and 12 book chapters. He has supervised 10 Ph.D. students and 20 MSc lab works. He is a member of the SFGP (French Society for Process Engineering) and chief international coordinator of the ICBF Forum, an international network entitled Food Bioprocessing: A

Global Approach for Advancing Sustainable Production of Value-Added Food. He is head of the department of the study and development of processes involving micro-organisms of the platform for technological development biotechnology—material engineering of Blaise Pascal University and is in charge the research on solid-state fermentations—biotransformations of the team GePEB (process engineering, energetics, and biosystems) of the Institut Pascal in the same university. He has been vice president of the university in charge of research valorization and technology transfer (2008–2012) and is currently director of Polytech Clermont-Ferrand, a school of engineering of Blaise Pascal University.

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