Food Engineering Series

José Miguel Aguilera
Gustavo V. Barbosa-Cánovas
Ricardo Simpson · Jorge Welti-Chanes
Daniela Bermúdez-Aguirre *Editors*

Food Engineering Interfaces

Springer

Food Engineering Series

For other titles published in this series, go to
www.springer.com/series/5996

José Miguel Aguilera • Gustavo V. Barbosa-Cánovas • Ricardo Simpson • Jorge Welti-Chanes • Daniela Bermúdez-Aguirre
Editors

Food Engineering Interfaces

Springer

Editors
Prof. José Miguel Aguilera
Pontificia Universidad Católica de Chile
Dept. de Ingeniería Química y
Bioproceso
Vicuña Mackenna 4860
Santiago
Chile
jmaguile@ing.puc.cl

Dr. Ricardo Simpson
Universidad Técnica Federico
Santa María
Depto. Procesos Químicos,
Biotecnológicos y Ambientales
Av. España 1680
Valparaíso
Chile
ricardo.simpson@usm.cl

Dr. Daniela Bermúdez-Aguirre
Washington State University
Dept. Biological Systems Engineering
213 LJ Smith Hall
99164-6120 Pullman
Washington
USA
daniela@wsu.edu

Dr. Gustavo V. Barbosa-Cánovas
Washington State University
Dept. Biological Systems
Engineering L.J. Smith Hall 220
Pullman, WA 99164-6120
USA
barbosa@wsu.edu

Dr. Jorge Welti-Chanes
Director de Post y Pregrado
División de Biotecnología y Alimentos
Instituto Tecnológico y de Estudios
Superiores de Monterrey
Av. Eugenio Garza Sada 2501 Sur
Col. Tecnológico
64849 Monterrey
N.L. México
jwelti@itesm.mx

ISSN 1571-0297
ISBN 978-1-4419-7474-7 e-ISBN 978-1-4419-7475-4
DOI 10.1007/978-1-4419-7475-4
Springer New York Heidelberg Dordrecht London

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

The articles included in *Food Engineering Interfaces* are based on the presentations made by invited speakers of the 10th International Congress on Engineering and Food (ICEF 10) held in Viña del Mar, Chile, in April 2008. All the chapters were significantly upgraded from the original presentations and were later peer-reviewed and copyedited. This book was conceived well ahead of the event in order to make sure that readers would have the opportunity to get a taste of the challenges that lie ahead. At the same time, efforts were made to cover, with a high degree of detail, specific topics that are very relevant at the present time. As a result, this book is an excellent addition to the literature as the topics are well blended and clearly expand old food engineering boundaries.

The book is divided into five parts: selected topics in food engineering, advances in food process engineering, water management in food, food microstructure, and food packaging. All the 28 chapters have been written by renowned professionals working in food engineering and related disciplines. The first chapter of the book deals with the history and future of food engineering, and the remaining chapters in Part I deal with topics such as microbial risk assessment using new engineering tools, the development of eco-indicators to monitor the environmental impact on selected food industries, the mathematical simulation of gastric digestion, the engineering challenges posed by incorporating fiber in selected foods, the applications of computational fluid dynamics (CFD) in food processing, food safety engineering, food engineering economics, and the systemic approach for curriculum development. Part II has two comprehensive overviews, one on advanced thermal processing and the other on nonthermal processing, as well as chapters dealing with the optimization of thermal processes, the sterilization of foodstuff by pressure-assisted thermal processing (PATS), and the extraction of essential oils and nutraceuticals by supercritical fluid extraction. Part III has a very good selection of chapters, including an update on glass transition in foods, caking in food powders, the rehydration modeling of food particulate systems, and the identification of drying zones in a laboratory spray-dryer. Part IV includes a chapter that envisions how food microstructure studies will help the development of healthy foods that promote well-being and pleasure, as well as a chapter that deals with the analysis of food microstructures by synchrotron X-ray-computed tomography. Finally, Part V covers, among other topics, the utilization of edible coatings as food safety and quality enhancers, physical properties of gel-based edible films, and packaging materials based on renewable resources.

We truly hope that this book, with its visionary approach, will be a valuable addition to the food engineering literature and will promote interest in food engineering research, development, and implementation.

José M. Aguilera
Gustavo V. Barbosa-Cánovas
Ricardo Simpson
Jorge Welti-Chanes
Daniela Bermúdez-Aguirre

Acknowledgments

The editors would like to express their gratitude and appreciation to Sharon Himsl, Publication Coordinator, Center for Nonthermal Processing of Food, Washington State University, for her professionalism and dedication in facilitating the steps needed to complete this challenging project. She kept track of all the manuscripts and had them copyedited and effectively interacted with the editors, authors, and the staff at Springer.

Contents

Contributors

Alik Abakarov Departamento de Ingeniería Química y Ambiental, Universidad Técnica Federico Santa María, P.O. Box 110-V, Valparaíso, Chile

José Miguel Aguilera Department of Chemical and Bioprocess Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile

Liliana Alamilla-Beltrán Departamento de Graduados e Investigación en Alimentos, Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional, Carpio y Plan de Ayala, s/n CP, 11340 México, DF, Mexico

Yves Arcand Agriculture and Agri-Food Canada's Food Research and Development Centre, 3600 Casavant Blud West, St. Hyacinthe, Quebec, Canada

Gustavo V. Barbosa-Cánovas Center for Nonthermal Processing of Food, Washington State University, Pullman, WA, USA

Daniela Bermúdez-Aguirre Center for Nonthermal Processing of Food, Washington State University, Pullman, WA, USA

Gerd Brunner Thermische Verfahrenstechnik, Technische Universität Hamburg-Harburg (TUHH), Harburg, Germany

Roman Buckow CSIRO Food and Nutritional Sciences, 671 Sneydes Road, VIC-3030 Werribee, Australia

Branko Bugarski Department of Chemical Engineering, University of Belgrade, Karnegijeva 4, 11000 Belgrade, Serbia

Osvaldo Campanella Agricultural and Biological Engineering Department, Purdue University, 47907 West Lafayette, IN, USA

Rosemary A. Carvalho Department of Food Engineering, University of São Paulo, Pirassununga (SP), Brazil

Jose Jorge Chanona-Pérez Departamento de Graduados e Investigación en Alimentos, Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional, Carpio y Plan de Ayala, s/n CP, 11340 México, DF, Mexico

Peter Cloetens European Synchrotron Radiation Facility, 6 Rue Jules Horowitz, BP 220, 38043 Grenoble Cedex, France

Valerie Davidson School of Engineering, University of Guelph, N1G 2W1 Guelph, Ontario, Canada

Juan C. de la Fuente Departamento de Procesos Químicos, Biotecnológicos y Ambientales, Universidad Técnica Federico Santa María, Valparaíso, Chile

Adriana Delgado FRCFT Group, Biosystems Engineering, UCD Agriculture & Food Science Centre, University College Dublin, Belfield, Dublin 4, Ireland

José M. del Valle Departamento de Ingeniería Química y Bioprocesos, Pontificia Universidad Católica (PUC) de Chile, Santiago, Chile

Carlos Daza Donoso School of Engineering, University of Guelph, N1G 2W1 Guelph, Ontario, Canada

Inés Ecima Ingeniería de Producción Agroindustrial, La Sabana University, Bogotá, Colombia

Carmen S. Fávaro-Trindade Department of Food Engineering, University of São Paulo, Pirassununga (SP), Brazil

Nathalie Gontard Joint Research Unit, Agropolymers Engineering and Emerging Technologies, Montpellier SupAgro, INRA, UM II, CIRAD, 34060 Montpellier, France

Gloria González-Mariño Biosciences Doctoral Program, La Sabana University, Bogotá, Colombia

Stéphane Guilbert Joint Research Unit, Agropolymers Engineering and Emerging Technologies, Montpellier SupAgro, INRA, UM II, CIRAD, 34060 Montpellier, France

Carole Guillaume Joint Research Unit, Agropolymers Engineering and Emerging Technologies, Montpellier SupAgro, INRA, UM II, CIRAD, 34060 Montpellier, France

Gustavo Fidel Gutiérrez-López Departamento de Graduados e Investigación en Alimentos, Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional, Carpio y Plan de Ayala, s/n CP, 11340 México, DF, Mexico

Bruce Hamaker Department of Food Science, Purdue University, 47907 West Lafayette, IN, USA

Volker Heinz German Institute of Food Technology, Prof.-von-Klitzing-Str. 7, D-49601 Quakenbrueck, Germany

Dennis Heldman Heldman Associates, 5224 Kings Mills Rd; #314, 45040 Mason, OH, USA

Humberto Hernández-Sánchez Departamento de Graduados e Investigación en Alimentos, Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional, Carpio y Plan de Ayala, s/n CP, 11340 México, DF, Mexico

Els Herremans Division BIOSYST-MeBioS, K.U.Leuven, W. de Croylaan 42, Box 2428, BE-3001 Leuven, Belgium

Quang Tri Ho Division BIOSYST-MeBioS, K.U.Leuven, W. de Croylaan 42, Box 2428, BE-3001 Leuven, Belgium

Antonio Ruperto Jiménez-Aparicio Centro de Desarrollo de Productos Bióticos del Instituto Politécnico Nacional, CEPROBI-IPN, Yautepec, Morelos, Mexico

Madhuvanti Kale Department of Food Science, Purdue University, 47907 West Lafayette, IN, USA

Greet Kerckhofs Research group of Materials Performance and Non-destructive Evaluation, Katholieke Universiteit Leuven, Kasteelpark Arenberg 44, BE-3001 Leuven, Belgium

Dietrich Knorr Department of Food Biotechnology and Food Process Engineering, Berlin University of Technology, Koenigin-Luise-Str. 22, D-14195 Berlin, Germany

Jozef L. Kokini Department of Food Science and Human Nutrition 2 College of ACES, University of Illinois at Urbana Champaign, 61801 Urbana, IL, USA

Denyse Landry Agriculture and Agri-Food Canada Head Quarter, 1341 Baseline Road, Tower 5, Floor 2, Room 126, Ottawa, ON, K1A OC5, Canada

Daryl B. Lund Department of Food Science, University of Wisconsin-Madison. 1605 Linden Dr., 53706 Madison, WI, USA

Verica Manojlović Department of Chemical Engineering, University of Belgrade, Karnegijeva 4, 11000 Belgrade, Serbia

Alejandro Marabí Institute of Biochemistry, Food Science and Nutrition, Robert H. Smith Faculty of Agricultural, Food and Environment, The Hebrew University of Jerusalem, P.O. Box 12, 76100 Rehovot, Israel

Michèle Marcotte Agriculture and Agri-Food Canada's Eastern Cereal and Oilseed Research Centre, 960 Carling Avenue, KW Neatby, Room 1093, Ottawa, ON, k1A OC6, Canada

Zacharias Maroulis School of Chemical Engineering, National Technical University of Athens, 15780 Athens, Greece

Alexander Mathys Department of Food Biotechnology and Food Process Engineering, Berlin University of Technology, Koenigin-Luise-Str. 22, D-14195 Berlin, Germany

Dominique Maxime Agriculture and Agri-Food Canada's Food Research and Development Centre, 3600 Casavant Blud West, St. Hyacinthe, Quebec, Canada

Hibru Kelemu Mebatsion Division BIOSYST-MeBioS, K.U.Leuven, W. de Croylaan 42, Box 2428, BE-3001 Leuven, Belgium

Fernando Mendoza FRCFT Group, Biosystems Engineering, UCD Agriculture & Food Science Centre, University College Dublin, D4 Belfield, Dublin, Ireland

Ulises Ramón Morales-Durán Departamento de Graduados e Investigación en Alimentos, Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional, Carpio y Plan de Ayala, s/n CP, 11340 México, DF, Mexico

Viktor A. Nedović Department of Food Technology and Biochemistry, University of Belgrade, Nemanjina 6, P.O. Box 127, 11081 Belgrade-Zemun, Serbia

Bart Nicolaï Division BIOSYST-MeBioS, K.U.Leuven, W. de Croylaan 42, Box 2428, BE-3001 Leuven, Belgium

Tomás Norton Food Refrigeration and Computerised Food Technology (FRCFT), University College Dublin, National University of Ireland, Agriculture & Food Science Centre, Belfield, Dublin 4, Ireland

Dhananjay Pai Whistler Center for Carbohydrate Research, Purdue University, 47907 West Lafayette, IN, USA

Stefan Palzer Nestlé Research Centre Lausanne, Vers-Chez-Les-Blanc, 1000 Lausanne 26, Switzerland

Maurcio Pardo Ingeniería de Producción Agroindustrial, La Sabana University, Bogotá, Colombia

María del Pilar Buera Departamentos de Industrias y de Química Orgánica, Facultad de Ciencias Exactas y Naturales, 1428 Ciudad de Buenos Aires, Argentina

Hosahalli Ramaswamy Department of Food Science, McGill University, Ste Anne de Bellevue, Montreal, Quebec, Canada

Kai Reineke Department of Food Biotechnology and Food Process Engineering, Berlin University of Technology, Koenigin-Luise-Str. 22, D-14195 Berlin, Germany

Yrjö H. Roos Department of Food and Nutritional Sciences, University College Cork, Cork, Ireland

Juliana Ruzante Joint Institute for Food Safety and Applied Nutrition, University of Maryland, 20742 College Park, MD, USA

I. Sam Saguy Institute of Biochemistry, Food Science and Nutrition, Robert H. Smith Faculty of Agricultural, Food and Environment, The Hebrew University of Jerusalem, POB 12, 76100 Rehovot, Israel

George Saravacos School of Chemical Engineering, National Technical University of Athens, 15780 Athens, Greece

Bernhard Seifried Department of Agricultural, Food and Nutritional Science, University of Alberta, T6G 2P5 Edmonton, Alberta, Canada

Nattiga Silalai Department of Food and Nutritional Sciences, University College Cork, Cork, Ireland

Ricardo Simpson Departamento de Ingeniería Química y Ambiental, Universidad Técnica Federico Santa María, P.O. Box 110-V, Valparaíso, Chile

R. Paul Singh Department of Biological and Agricultural Engineering, University of California, 95616 Davis, CA, USA

Samrendra Singh Department of Biological and Agricultural Engineering, University of California, 95616 Davis, CA, USA

Paulo J.A. Sobral Department of Food Engineering, University of São Paulo, Pirassununga (SP), Brazil

Karl Sommer Department of Process Engineering of Disperse Systems, Technical University of Munich, Am Forum 2, 85354 Freising, Germany

Da-Wen Sun Food Refrigeration and Computerised Food Technology (FRCFT), University College Dublin, National University of Ireland, Agriculture & Food Science Centre, Belfield, Dublin 4, Ireland

Arthur Teixeira Agricultural and Biological Engineering Department, University of Florida, 32611-0570 Gainesville, FL, USA

Feral Temelli Department of Agricultural, Food and Nutritional Science, University of Alberta, T6G 2P5 Edmonton, Alberta, Canada

Oranit Troygot Institute of Biochemistry, Food Science and Nutrition, Robert H. Smith Faculty of Agricultural, Food and Environment, The Hebrew University of Jerusalem, P.O. Box 12, 76100 Rehovot, Israel

Edgar Uquiche Departamento de Ingeniería Química, Universidad de La Frontera, Temuco, Chile

Nektarios Valous FRCFT Group, Biosystems Engineering, UCD Agriculture & Food Science Centre, University College Dublin, Belfield, Dublin 4, Ireland

Pieter Verboven Division BIOSYST-MeBioS, K.U.Leuven, W. de Croylaan 42, Box 2428, BE-3001 Leuven, Belgium

Kiran V. Vyakaranam Department of Food Science, Rutgers University, 08901 New Brunswick, NJ, USA

Rony Wallach Department of Soil and Water Sciences, Robert H. Smith Faculty of Agricultural, Food and Environment, The Hebrew University of Jerusalem, P.O. Box 12, 76100 Rehovot, Israel

Martine Wevers Research group of Materials Performance and Non-destructive Evaluation, Katholieke Universiteit Leuven, Kasteelpark Arenberg 44, BE-3001 Leuven, Belgium

Ronnie Willaert Structural Biology Brussels, Vrije Universiteit Brussel, Flanders Institute for Biotechnology, Pleinlaan 2, B-1050 Brussels, Belgium

Noemí Zaritzky Centro de Investigación y Desarrollo en Criotecnología de Alimentos (CIDCA), Universidad Nacional de La Plata (UNLP) – CONICET La Plata and Depto de Ingeniería Química, UNLP, La Plata, Argentina

Carsten Zetzl Thermische Verfahrenstechnik, Technische Universität Hamburg-Harburg (TUHH), Harburg, Germany

Part I
Selected Topics in Food Engineering

Chapter 1
The Beginning, Current, and Future of Food Engineering: A Perspective

Dennis R. Heldman and Daryl B. Lund

1.1 Introduction

Food engineering is a field of study that has emerged in rather recent history, but is based on concepts that have evolved over a significant period of time. In general, food engineering is the interpretation and application of engineering principles and concepts to any aspect of food manufacturing and operations, including the construction of the facilities for these operations. With this broad interpretation, almost any of the more traditional fields of engineering (electrical, mechanical, civil, chemical, industrial, and agricultural) would contribute to the successful operation of the facilities and processes dealing with food. Recent focus in food engineering has been on processes occurring within manufacturing operations, specifically on the influence of unique characteristics and properties of foods and ingredients in these processes.

The purpose of this paper is to review the history and current status of food engineering, and to provide a framework for discussion about its future. In addition to identifying some of the founding fathers and giants in food engineering, this review will include the development of educational programs and the role of food engineering within those programs. Attention will be given to evolution of research and the potential of food engineering research in the future. Finally, there will be an attempt to evaluate the impact of public sector research on research conducted within the food industry, as well as applications of research within the industrial sector.

D.R. Heldman (✉)
Heldman Associates, 5224 Kings Mills Rd; #314, 45040 Mason, OH, USA
e-mail: drheldman@earthlink.net

D.B. Lund
Department of Food Science, University of Wisconsin-Madison. 1605 Linden Dr., 53706 Madison, WI, USA
e-mail: dlund@cals.wisc.edu

J.M. Aguilera et al. (eds.), *Food Engineering Interfaces*, Food Engineering Series,
DOI 10.1007/978-1-4419-7475-4_1, © Springer Science+Business Media, LLC 2011

1.2 Scope of Food Engineering

As suggested, the term "food engineering" has many interpretations and the scope of this term has evolved over time. In addition, there are varied interpretations and meanings in different regions of the world. It is likely our attempt at a definition will fall short and not capture all of the various interpretations. However, the broadest interpretation of food engineering occurs in the industrial sector, where it is generally accepted on a global basis. This general interpretation includes applications of engineering in any aspect of production, handling, storage, processing, packaging, and distribution of food. This is certainly the interpretation accepted by the founding fathers of the International Congress of Engineering and Food (ICEF), who did not use "food engineering" in the title of the congress. Obviously, this broad interpretation is inclusive of the expertise associated with most of the engineering fields.

In development of food engineering curricula, a more narrow interpretation of food engineering has been applied within education institutions, so as to define the uniqueness of the discipline in teaching and research. As might be expected, these interpretations focus more on basic concepts and principles, and the impact of the product being handled on the application of engineering principles, with special emphasis on the word "food."

Undergraduate food engineering teaching programs incorporate both basic engineering principles and the unique chemical and microbiological characteristics of foods. These programs tend to integrate basic engineering, chemistry, and microbiology into process designs. It is clear that in most regions of the world, these programs have evolved at the interface between science and engineering. In the United States, two types of programs have developed in parallel: some with a clear alignment with engineering curricula (usually in chemical or agricultural engineering), and many with food science programs (associated with colleges of agricultural sciences). Graduate programs and research in food engineering have evolved with an evident focus on basic principles, mathematical models, and process simulations.

In summary, food engineering provides an essential link between engineering and the food sciences. The dimensions of this interface present unique challenges in education, research, and applications, and will continue to provide professionals associated with food engineering with opportunities in the future and a continuing evolution of scope.

1.3 Definitions of Food Engineering

There are many definitions of food engineering, and not one is universally accepted. One of the early definitions appears in the preface of the book *Elements of Food Engineering* (1952) by Parker, Harvey, and Stateler. Parker proposed that "Food Engineering is concerned with the design, construction, and operation of industrial processes and plants in which intentional and controlled changes in food materials are performed with due consideration to all economic aspects considered." Later in 1963, Charm suggested that the purpose of food engineering is "to illustrate the common relationship between basic engineering principles and the fundamentals of food processing." Finally, in 1966, Earle defined food engineering as "the study of the processes that transform raw materials into finished products, or preserves foods so they can be kept for longer periods." There are obvious similarities and differences in these early definitions. All three indicate that food engineering is the application of engineering to manufacturing and preservation of foods, but there are distinct differences, from more emphasis on basic principles to greater emphasis on applications of engineering in practice.

A more current definition of food engineering has been posted online (Wikipedia 2010; http://en.wikipedia.org/wiki/Food_engineering) as follows: "Food engineering refers to the engineering aspects of food production and processing. Food engineering includes, but is not limited to, the application of agricultural engineering and chemical engineering principles to food materials." However, given the evolution of research and industrial applications, the following definition should also apply, now and in the near future: Food engineering is both the identification and creation of the physical principles associated with foods and ingredients, and the applications of the principles to the handling, storage, processing, packaging and distribution of consumer food products. This definition attempts to include both the interests associated with engineering research and the applications of outcomes from research to ultimate applications in processes associated with the food industry. Undoubtedly, a better appreciation of the diversity of this unique field of study solicits more discussion of the subject.

1.4 Origins of Food Engineering

There are clear relationships between the origins of food engineering and food preservation processes. Design and prediction of the effect of preservation properties on food requires quantification and modeling. One of the most visible applications can be found in the book *Sterilization in Food Technology* by Ball and Olson (1957). This book provides numerous examples of applications of mathematics to heat transfer to foods in containers and the description of the kinetics of microbial destruction. Historically, food preservation evolved from an art to a science. Early preservation techniques (drying, salting, fermentation, and cooling) were based on "trial and error." Later, technologies such as canning and freezing were based on observations that provided the basis for science-based improvements in the processes. Many of these early scientific findings occurred in the basic sciences of chemistry, biology, and physics. One of the more significant outcomes from Louis Pasteur (1860) in response to food spoilage challenges was to provide the foundation for bacteriology and microbiology. Other contributions from basic science and mathematics were significant, such as the influence of temperature on reactions (Arrhenius 1889) and modeling heat and mass transfer (Carslaw and Jaeger 1946; Crank 1956).

There are several other early and significant contributions that have become the foundation of food engineering. The role of Nicholas Appert in demonstrating thermal processing of foods in the early 1800s is recognized as the basis for many current shelf-stable foods. The invention and development of mechanical refrigeration by von Linde (1896) was significant, followed by Birdseye (1930) who established the basis of the modern frozen food industry. Although dehydration has been recognized as a food preservation process for centuries, the contributions of von Loesecke (1943) advanced the process in a quantitative manner. These three processes (thermal processing, food cooling and freezing, and food dehydration) continue to be the most visible processes in the research literature on food engineering.

1.5 Evolution of Food Engineering

In general, food engineering was started by engineers who happened to have some acquaintance with the food industry. However, there were other engineers and scientists who appreciated the application of engineering principles to something as complex as food. At the risk of omission, here are some of the giants in food engineering and others who have made significant contributions to food engineering (in no particular order): Bird, Stewart and Lightfoot, Kessler, Thijssen, Leniger, Cheftel, King, Karel, Plank, Kuprianoff, Diendorfer, Humphrey, Hallstrom, Heldman, Labuza, Berk, Mizrahi, Morgan, Pflug, Earle, Goldblith, Proctor, Hayakawa, Ball, Zahradnick, Saravacos, Brody, Duckworth, Cheftel (J.C.), Loncin, Saguy, Ohlsson, Pham, Teixeira, Sastry, Hall, Farrall, Harper (J.C.), Nickerson, Mannheim, Harper (J.M.), Merson, Lund, Knorr, Singh (R.P.), Schluender, Schwartzberg, Bimbenet, and Lovric.

In addition to people, there are several events and developments that have contributed to the evolution of food engineering in the past 50 years. For professionals involved in teaching, there are several textbooks, including the following key books:

1952 – *Elements of Food Engineering* by Milton E. Parker, Ellery H. Harvey, and E. S. Stateler
1963 – *Fundamentals of Food Engineering* by Stanley E. Charm
1966 – *Unit Operations in Food Processing* by Richard Earle
1975 – *Food Process Engineering* by H.A. Leniger and W.A. Beverloo
1975 – *Food Process Engineering* by Dennis R. Heldman
1976 – *Elements of Food Engineering* by John C. Harper
1979 – *Food Engineering; Principles and Selected Applications* by Marcel Loncin and Larry Merson
1980 – *Fundamentals of Food Process Engineering* by Romeo Toledo
1984 – *Introduction to Food Engineering* by R. Paul Singh and Dennis R. Heldman

Although other textbooks have been published in this recent time period, these nine demonstrate the evolution of food engineering as a field of study. Parker et al.

(1952) placed significant emphasis on the description of manufacturing operations and the role of engineering in all aspects of the manufacturing facility. Charm (1963) introduced mathematics and an emphasis on process design and unit operations. Earle's book (1966) was ideal for undergraduate students pursuing a degree in food science, and the objectives in Harper's book (1976) were similar. Books by Leninger and Beverloo (1975) and Heldman (1975) were designed for students with a significant background in engineering concepts, and emphasized advanced analysis of unit operations. The book by Loncin and Merson (1979) provided even more emphasis on mathematical analysis of unit operations, and was suited to introductory graduate students in some dimension of food engineering. Both Toledo (1980) and Singh and Heldman (1984) developed textbooks for undergraduate students in food science with specific attention to topics identified in guidelines for food science curricula recommended by the Institute of Food Technologists.

During the past 25 years, several of these pioneering textbooks have been published in later editions. In most cases, emphasis has been on new information and technologies, as well as on advancement in tools available for conducting analysis. There has been a continuous trend toward more mathematical description of processes, and computer simulation of operations within the food industry. Further, there has been an obvious emphasis on the impact of processes on product quality attributes, including nutrients, as well as changes in process design to enhance the efficiency of processes.

Another measure of the evolution and development of food engineering as a field of study and research is the holding of national and international meetings that focus on food engineering. Some of the key meetings and events that have occurred during the last 50 years include:

1972 – *Food Engineering Conference*; organized by H.A. Leninger and Hans Thijssen, hosted at Agricultural University, Wageningen, The Netherlands.

1976 – *International Congress on Engineering and Food (ICEF1)*; 1st Congress was chaired by Dr. Joe Clayton, held in Boston, Massachusetts. The 11th Congress will be hosted in Athens, Greece on May 22–26, 2011.

1976 – *Food Engineering Division of IFT*; a petition signed by several food engineering members of IFT was approved by the Executive Committee; the Division continues to organize symposia and research programming at annual IFT meetings.

1981 – *International Conference in Fouling and Cleaning*; conference was organized by Bengt Hallstom, Lund University, and Daryl Lund, University of Wisconsin; subsequent conferences were held in 1985 (USA) and 1989 (Germany); now part of ICEF.

1991 – *Conference of Food Engineering (CoFE)*; first of nine conferences organized by Dr. Martin Okos, held in Chicago. The 11th conference is being planned for 2011.

1996 – *CIBIA*; 1st Congreso IberoAmericano de Ingenieria de Alimentos (CIBIA) was hosted in Campinas, Brazil. The 6th Congreso was hosted in Bogata, Columbia, in 2009.

2007 – *European Workshop on Food Engineering and Technology*; first of series of workshops held with focus on applications of food engineering research.

Although many other meetings related to food engineering have occurred, the above list illustrates the continuing development of research programs in the past 35 years.

The historical evolution of food engineering can also be illustrated by the publication of research literature. Specific journals for publication of current food engineering research have been created with some of the more visible journals and reference books, such as:

1970 – *Journal of Food Science*; first issue published, which included a section titled "Applied Science and Engineering by the Institute of Food Technologists."
1976 – *Journal of Food Process Engineering*; first issue published by Food & Nutrition, Press.
1982 – *Journal of Food Engineering*; first issue published by Academic Press, Inc.
1992 – *Handbook of Food Engineering*; first edition published by Marcel Dekker, Inc.
1997 – *Handbook of Food Engineering Practice*; published by Academic Press, Inc.
2003 – *Encyclopedia of Agriculture, Food and Biological Engineering*; first edition published by Marcel Dekker, Inc.

Information about food engineering has been published in many other journals and references, but the above list illustrates the evolution within a relatively short time period.

All of the developments described have occurred during a period of significant change in the food industry and related industries. Bruin and Jongen (2001) suggested the following categories of significant change:

1. Mergers and acquisitions of companies in the food and related industries. These changes have caused significant reorganization within all companies, impacting the role of food engineers in the industry.
2. Expectations for innovation. Changes in consumer expectations have increased in frequency, forcing the identification and implementation of new, innovative processes.
3. Changes in industry expectations. Previously, expectations of the food industry were to deliver an abundant and safe supply of food to consumers. These expectations have evolved to include not only more abundant and safe foods but also foods with greater convenience, and eventually, foods with enhanced influence on health and wellness.
4. Advances in computer technology. These advances have provided the tools to accelerate the responsiveness of engineers to all types of challenges.

These changes have influenced the environment of food engineering activities, and have had an impact on the expectations of food engineers in the industry. Many of these changes also will be incorporated into future educational programs for food engineers. Thus, a challenge to educators will be to incorporate these changes into food engineering programs.

1.6 Evolution in Food Engineering Research

There have been significant advancements in food engineering research over the past 50 years. Although the research has been conducted over a broad range of applications, the unique focus of research that has evolved is the integration of reaction kinetics with transport phenomenon to accomplish process design. The research model concept is illustrated in Fig. 1.1.

The concept described by the model encourages research in three distinct areas: kinetic parameters, transport phenomenon, and process design. Research on kinetic models has expanded the availability of kinetic parameters and enhanced the investigation of appropriate models used for food products. Transport phenomenon research has improved our understanding of heat and mass transfer in foods, with specific attention to the unique properties of food products and the mathematic models needed to describe the phenomenon in a food system. Process design research integrates the kinetic models with appropriate transport phenomenon models to allow prediction of a parameter to quantify the quality of the food product. In general, the concept is ideal for optimization of the process through maximizing the product quality attributes, while identifying the best combination of process parameters.

1.6.1 Kinetic Models

The development of kinetic models for food systems is still evolving. A typical model used to describe changes in a food component or attribute is expressed as:

$$\mathrm{d}A/\mathrm{d}t = -kA \tag{1.1}$$

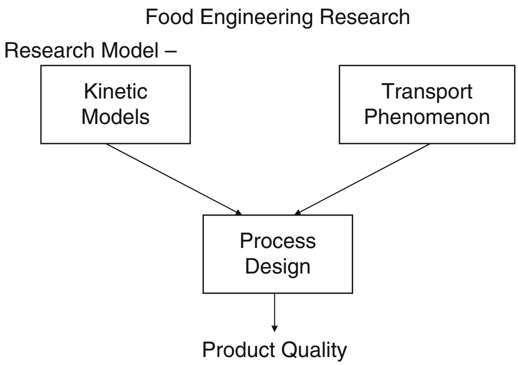

Fig. 1.1 A food process engineering research model

where A = the concentration or intensity of component, and k = the first-order rate constant.

There has been a significant increase in the measurement and publication of rate constants for an array of product component changes as a function of process or storage parameters, as illustrated by Villota and Hawkes (2007). Traditionally, the same model has been used to describe changes in microbial populations during preservation processes; the rate constants have been assembled in several locations, including the IFT Task Force Report (2000). These rate constants are evaluated and expressed as a function of parameters such as temperature, water activity, pressure, pH, etc. The evolution of more complex models has been explored by von Bockel (2008), with specific attention to variations from first-order kinetics.

1.6.2 Transport Phenomenon

Significant attention has been given to the development of models to describe heat, mass, and momentum transfer in food systems, expressed as follows:

$$\partial N/\partial t = \alpha \blacktriangledown^2 N \tag{1.2}$$

where N = intensity of a process parameter, and α = appropriate property of food structure.

Expressions of this type are used to predict distribution histories of the preservation process parameter. Typical parameters include temperature, moisture content, pressure, and other parameters used to accomplish reductions in microbial populations. Over the past 30–40 years, the availability of quantitative physical properties data has increased significantly (Rao et al. 2005). In addition, there has been increased emphasis on the development of prediction models for properties based on product composition.

1.6.3 Process Design

Integration of the appropriate kinetic model with transport phenomenon expressions leads to process design. In general, the outcomes are product quality attributes, predicted as follows:

$$A = \int k(N)\ \mathrm{d}t \tag{1.3}$$

where A = the intensity or concentration of a quality attribute.

The focus of process design is on the product, with impact of the process on reduction of the microbial population and/or the retention of a sensitive product quality attribute. Process design provides the opportunity to consider multiple attributes as long as the kinetic parameters and models are available. An even more important dimension of this approach is the potential for process optimization, which is the identification of the process parameters to achieve maximum retention of product quality attributes, while ensuring the desired reduction in microbial population for safety or shelf-life extension.

1.7 Contributions of Food Engineering Research

The process design approach has contributed to many positive products manufactured by the food industry. These contributions can be expressed in several different ways. In general, process design facilitates the quantitative prediction of process outcomes, while evaluating a range of process parameters without conducting time-consuming and costly experimental trials.

1.7.1 Safe and Wholesome Foods

Process design has had significant impact on the safety and wholesomeness of food products. The development of food canning by Nicholas Appert (1750–1841) took 14 years. Using the current process design approaches, processes can be developed within hours. These approaches ensure microbiological safety of products, along with the capability to maximize the retention of product quality attributes.

A current example of process design is illustrated in Fig. 1.2. Knorr (2006) has demonstrated that through measuring and understanding the kinetics of *Escherichia coli* population reductions at high pressures, the retention of product quality attributes in sausage are evident. These same approaches have been used to ensure maximum retention of nutrients in a food product using high temperatures to ensure microbiological safety and shelf-life of the product.

1.7.2 Affordable Food Supply

Food engineering research has contributed to keeping quantities of food available at a modest cost to the consumer. These contributions have been accomplished through overall improvements in the efficiency of food manufacturing. These improvements have occurred through a focus on specific processes, as well as an analysis of processing operations. Many of the improvements in efficiency have occurred through increased capacity of individual pieces of equipment and

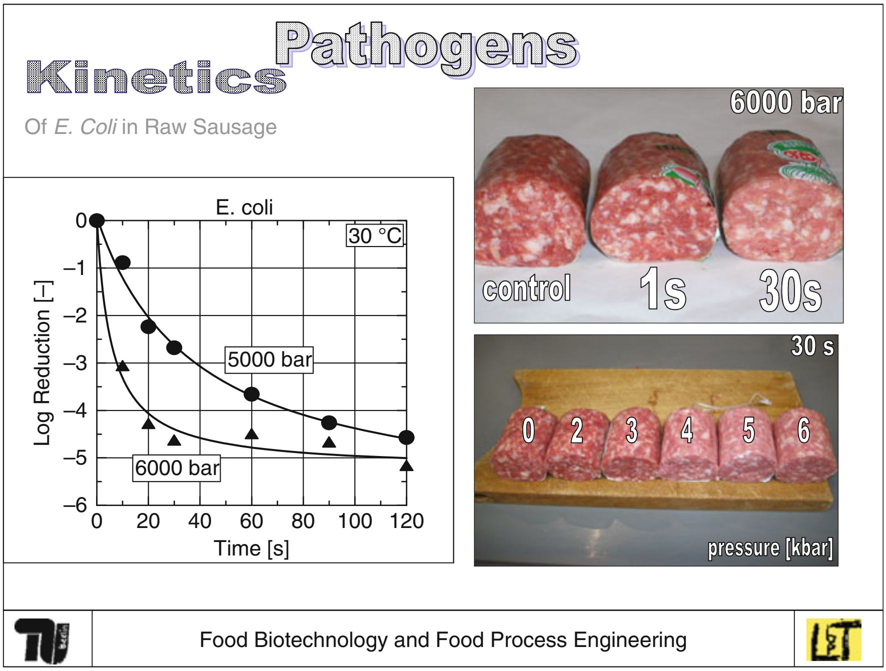

Fig. 1.2 Process design for pathogen reduction of *Escherichia coli* in sausage while retaining product quality attributes (Knorr 2006)

throughput of processing lines. Another contributor to a low-cost food supply has been the development of processes that allow foods to be transported for long distances without noticeable reductions in product quality attributes.

An example of process improvements for shelf-stable foods has been aseptic processing and packaging. This continuous process has been demonstrated as an excellent alternative to the more traditional batch retort process. As illustrated in Fig. 1.3, the process involves continuous processing of both product and packaging, before filling the product into the package. As illustrated by Bruin and Jongen (2001), improvements in the process have continued with capabilities to accomplish thermal processing of food particles within the carrier liquid.

1.7.3 Convenient Food Products

Process design has contributed to the development of convenient foods in a significant way. Examples include products with reduced preparation times, products with improved quality attributes, products with extended shelf-life, and a variety of shelf-stable products.