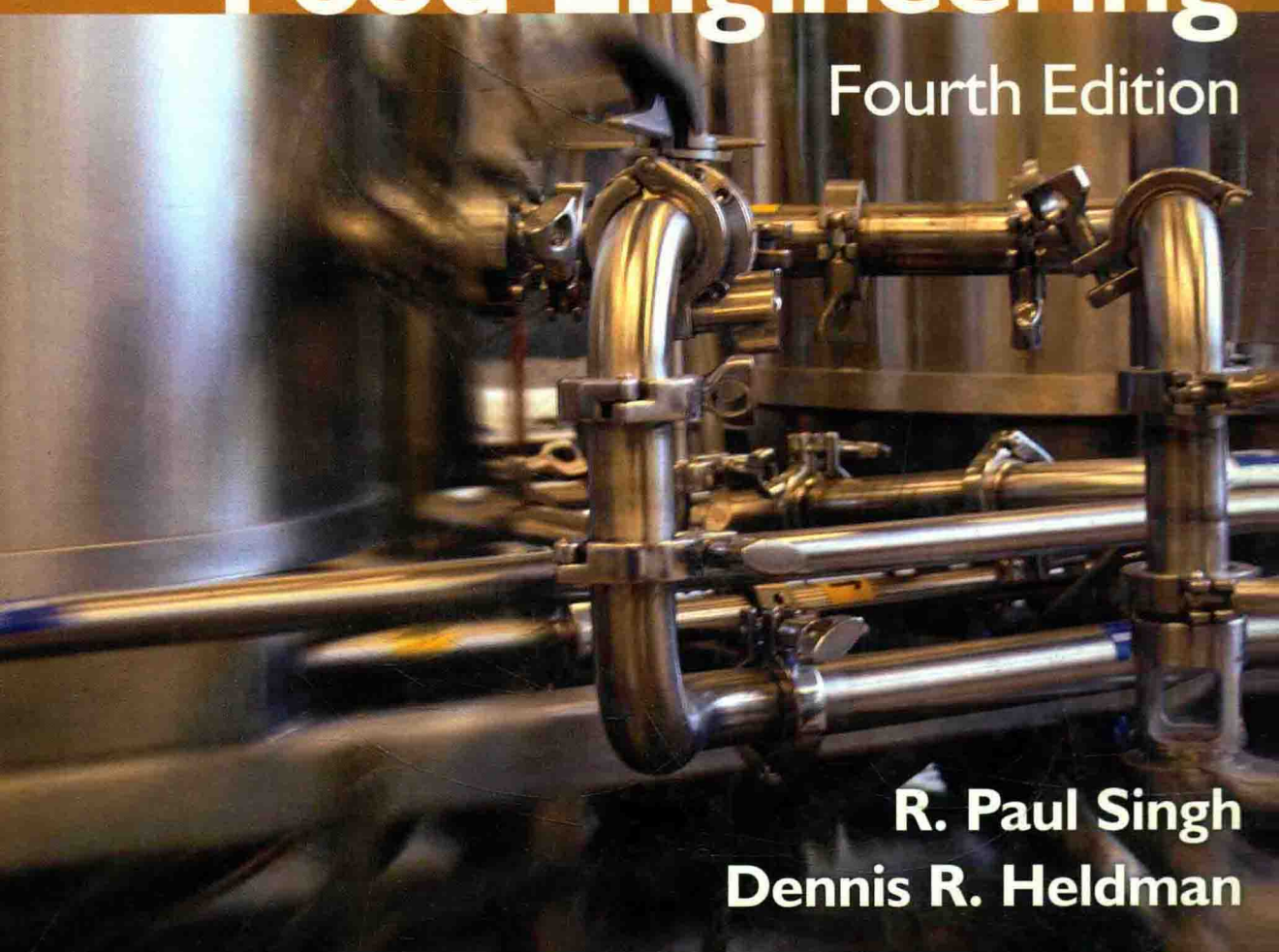
Introduction to Food Engineering

Fourth Edition



R. Paul Singh
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Food Science and Technology, International Series

Introduction to Food Engineering

Fourth Edition

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30 Corporate Drive, Suite 400, Burlington, MA 01803, USA
525 B Street, Suite 1900, San Diego, California 92101-4495, USA
84 Theobald's Road, London WC1X 8RR, UK

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Library of Congress Cataloging-in-Publication Data

APPLICATION SUBMITTED

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

ISBN: 978-0-12-370900-4

For information on all Academic Press publications visit our Web site at www.elsevierdirect.com

Printed in China

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Fourth Edition

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About the Authors

R. Paul Singh and Dennis R. Heldman have teamed up here once again, to produce the fourth edition of Introduction to Food Engineering; a book that has had continuing success since its first publication in 1984. Together, Drs. Singh and Heldman have many years of experience in teaching food engineering courses to students, both undergraduates and graduates; along with Dr. Heldman's experience in the food processing industry, is once again apparent in their approach within this book. The authors' criteria for the careful selection of topics, and the way in which this material is presented, will enable students and faculty to reap the full benefits of this combined wealth of knowledge.

Singh is a distinguished professor of food engineering at the University of California, Davis, where he has been teaching courses on topics in food engineering since 1975. The American Society of Agricultural Engineers (ASAE) awarded him the Young Educator Award in 1986. The Institute of Food Technologists (IFT) awarded him the Samuel Cate Prescott Award for Research in 1982. In 1988, he received the International Award from the IFT, reserved for a member of the Institute who "has made outstanding efforts to promote the international exchange of ideas in the field of food technology." In 1997, he received the Distinguished Food Engineering Award from the Dairy and Food Industry Suppliers Association and ASAE, with a citation recognizing him as a "world class scientist and educator with outstanding scholarly distinction and international service in food engineering." In 2007, ASAE awarded him the Kishida International Award for his worldwide contributions in food engineering education. He was elected a fellow of both IFT and ASAE in 2000 and the International Academy of Food Science and Technology in 2001. He has helped establish food engineering programs in Portugal, Indonesia, Argentina, and India and has lectured extensively on food engineering topics in 40 different nations around the world. Singh has authored, or co-authored, fourteen books and published more than two hundred technical papers. His research program at Davis addresses study of heat and mass transfer in foods during processing using mathematical simulations and seeking sustainability in the food supply chain. In 2008, Singh was elected to the National Academy of Engineers "for innovation and leadership in food engineering research and education." The honor is one of the highest professional distinctions for engineers in the United States.

Currently, Heldman is the Principal of Heldman Associates, a consulting business dedicated to applications of engineering concepts to food processing for educational institutions, industry and government. He is an Adjunct Professor at the University of California-Davis and Professor Emeritus at the University of Missouri. His research interests focus on use of models to predict thermophysical properties of foods and the development of simulation models for processes used in food manufacturing. He has been author or co-author of over 150 research papers and is Co-Editor of the

Handbook of Food Engineering, and Editor of the **Encyclopedia of Agricultural, Food and Biological Engineering** and an **Encyclopedia of Biotechnology in Agriculture and Food** to be published in 2009. Heldman has taught undergraduate and graduate food engineering courses at Michigan State University, University of Missouri and Rutgers, The State University of New Jersey. He has held technical administration positions at the Campbell Soup Company, the National Food Processors Association, and the Weinberg Consulting Group, Inc. He has been recognized for contributions, such as the DFISA-ASAE Food Engineering Award in 1981, the Distinguished Alumni Award from The Ohio State University in 1978, the Young Researcher Award from ASAE in 1974, and served as President of the Institute of food Technologists (IFT) in 2006–07. In addition, Heldman is Fellow in the IFT (1981), the American Society of Agricultural Engineers (1984), and the International Academy of Food Science & Technology (2006).

Foreword

Nine out of ten Food Science students would probably claim the Food Engineering course as the most difficult one in their undergraduate curriculum. Although part of the difficulty may be related to how food engineering is taught, much of the difficulty with food engineering stems from the nature of the material. It's not necessarily that food engineering concepts are more difficult than other food science concepts, but food engineering is based on derivations of equations, and the quantitative manipulation of those equations to solve problems.

From word problems to integral calculus, the skills required to master food engineering concepts are difficult for many Food Science students. However, these concepts are integral to the required competencies for an IFT-approved Food Science program, and are the cornerstone for all of food processing and manufacturing. It is critical that Food Science graduates have a good understanding of engineering principles, both because they are likely to need the concepts during the course of their career but also because they will most certainly need to interact with engineers in an educated manner. Food Science graduates who can use quantitative engineering approaches will stand out from their co-workers in the field.

Fortunately, two of the leading food engineers, Paul Singh and Dennis Heldman, have teamed up to write a textbook that clearly and simply presents the complex engineering material that Food Scientists need to know to be successful. In this fourth edition of a classic Food Engineering textbook, Singh and Heldman have once again improved the book even further. New chapters on process control, food packaging, and process operations like filtration, centrifugation and mixing now supplement the classic chapters on mass and energy balances, thermodynamics, heat transfer and fluid flow. Furthermore, numerous problems have now been solved with MATLAB, an engineering mathematical problem solver, to enhance student's math skills.

A good textbook should clearly and concisely present material needed by the students and at a level appropriate to their backgrounds. With chapters that are broken down into short, manageable sections that promote learning, the easy-to-follow explanations in the 4th Edition of Singh and Heldman are aimed at the perfect level for Food Scientists. Numerous example problems, followed by practice problems, help students test their understanding of the concepts. With fifteen chapters that cover the fundamental aspects of engineering and their practical application to foods, this book is an ideal text for courses in both food engineering and food processing. It will also serve as a useful reference for Food Science graduates throughout their career.

Richard W. Hartel
Professor of Food Engineering
University of Wisconsin-Madison

Preface

The typical curriculum for an undergraduate food science major in the United States and Canada requires an understanding of food engineering concepts. The stated content of this portion of the curriculum is "Engineering principles including mass and energy balances, thermodynamics, fluid flow, and heat and mass transfer". The expectations include an application of these principles to several areas of food processing. Presenting these concepts to students with limited background in mathematics and engineering science presents a significant challenge. Our goal, in this text book, is to provide students, planning to become food science professionals, with sufficient background in engineering concepts to be comfortable when communicating with engineering professionals.

This text book has been developed specifically for use in undergraduate food engineering courses taken by students pursuing a four-year degree program in food science. The topics presented have been selected to illustrate applications of engineering during the handling, processing, storage, packaging and distribution of food products. Most of the topics include some descriptive background about a process, fundamental engineering concepts and example problems. The approach is intended to assist the student in appreciating the applications of the concepts, while gaining an understanding of problem-solving approaches as well as gaining confidence with the concepts.

The scope of the book ranges from basic engineering principles, based on fundamental physics, to several applications in food processing. Within the first four chapters, the concepts of mass and energy balance, thermodynamics, fluid flow and heat transfer are introduced. A significant addition to this section of the fourth edition is an introduction to the concepts of process control. The next four chapters include applications of thermodynamics and heat transfer to preservation processes, refrigeration, freezing processes and evaporation processes used in concentration of liquid foods. Following the chapters devoted to the concepts of psychrometrics and mass transfer, several chapters are used to present applications of these concepts to membrane separation processes, dehydration processes, extrusion processes and packaging. Finally, a new chapter in this edition is devoted to supplemental processes, including filtration, centrifugation and mixing.

Most features of the first three editions of this book are included in this fourth edition. Chapters include modest amounts of descriptive material to assist the student in appreciating the process applications. Although equations are developed from fundamental concepts, the equations are used to illustrate the solution to practical problems. Most chapters contain many example problems to illustrate various concepts and applications, and several examples are presented in spreadsheet program format. At the end of most chapters, lists of problems are provided for the student to use in gaining confidence with problem-solving skills, and the more difficult problems are identified.

The focus of additions to the fourth edition has been on evolving processes and related information. Chapter 2 has been expanded to include information on properties of dry food powders and applications during handling of these products. The new material on process controls in Chapter 3 will assist students in understanding the systems used to operate and control food manufacturing operations. Numerous revisions and additions in the preservation process chapter provide information on applications of evolving technologies for food preservation. Completely new chapters have been included on the subjects of supplemental processes (filtration, centrifugation, mixing) and extrusion processes. Finally, a separate chapter has been devoted to food packaging, to emphasize applications of engineering concepts in selection of packaging materials and prediction of product shelf-life.

The primary users of this book are the faculty involved in teaching students pursuing an undergraduate degree in Food Science. The approaches used to present the concepts and applications are based on our own combined teaching experiences. Faculty members are encouraged to select chapters and associated materials to meet the specific objectives of the course being taught. The descriptive information, concepts and problems have been organized to provide maximum flexibility in teaching. The organization of the information in the book does serve as a study guide for students. Some students may be able to solve the problems at the end of chapters after independent study of the concepts presented within a given chapter. For the purposes to enhance learning, many illustrations in the book are available in animated form at www.rpaulsingh.com. This website also contains most of the solved examples in an electronic form that allow "what-if" analysis.

The topics presented in this book can be easily organized into a two-course sequence. The focus of the first course would be on engineering concepts and include information from Chapters 1 through 4, and the second course would focus on applications using Chapters 5 to 8. Alternatively, Chapters 9 and 10 could be added to the course on fundamentals, and the applications from Chapters 11 through 15 would be used in the second course. The chapters on applications provide an ideal basis for a process-based capstone course.

A new feature in this edition is the inclusion of several problems that require the use of MATLAB®. We are indebted to Professor Thomas R. Rumsey for generously sharing several of these problems that he has used in his own teaching. We thank Ms. Barbara Meierhenry for her valuable assistance in editing the original manuscript.

We appreciate the many recommendations from colleagues, and the encouragement from students, as received over a period of nearly 25 years. All of these comments and suggestions have been valuable, and have made the continuous development of this book a rewarding experience. We will continue to respond to communications from faculty members and students as the concepts and applications of food engineering continue to evolve.

R. Paul Singh
Dennis R. Heldman

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