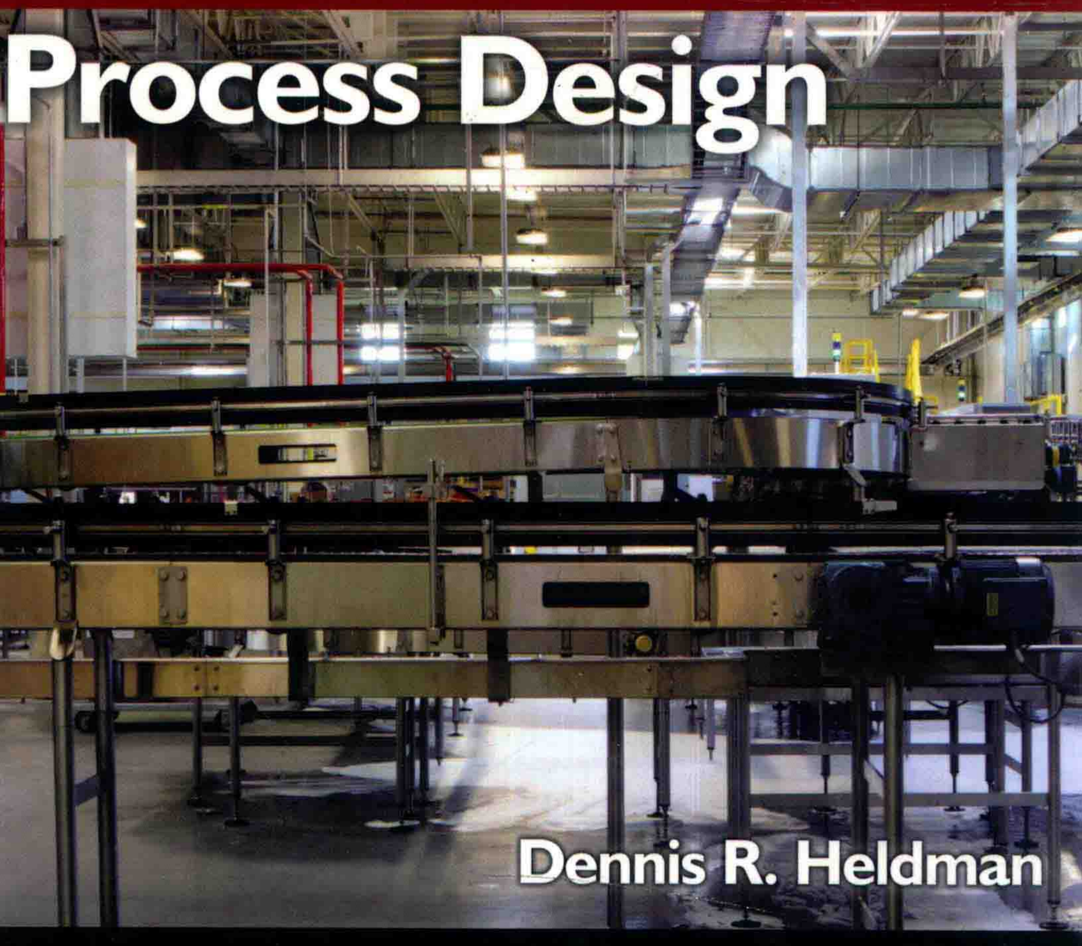
# Food Preservation Process Design



Dennis R. Heldman

Food Science and Technology, International Series

# Food Preservation Process Design

**Dennis R. Heldman**
Heldman Associates
Mason, Ohio



ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO
Academic Press is an imprint of Elsevier

Academic Press is an imprint of Elsevier
30 Corporate Drive, Suite 400, Burlington, MA 01803, USA
525 B Street, Suite 1800, San Diego, California 92101-4495, USA
84 Theobald's Road, London WC1X 8RR, UK



**Library of Congress Cataloging-in-Publication Data**

Heldman, Dennis R.
Food preservation process design / Dennis R. Heldman.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-12-372486-1 (hardback)
1. Food—Preservation. I. Title.
TP371.2.H46 2011
664'.028—dc22 2010046577

**British Library Cataloguing-in-Publication Data**

A catalogue record for this book is available from the British Library.

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

Printed in the United States of America

11 12 13 9 8 7 6 5 4 3 2 1

# FOOD PRESERVATION PROCESS DESIGN

# Food Science and Technology International Series



*A complete list of books in this series appears at the end of this volume.*

# Preface

The preservation processes for foods have evolved over several centuries, but recent attention to nonthermal technologies suggests the initiation of a new direction in food preservation. This book documents the quantitative approaches to preservation process design and prepares food science professionals for the food preservation challenges of the future—such as evaluating emerging preservation technologies and selecting appropriate food preservation technologies.

The text focuses on the three primary elements of food preservation process design:

1. Kinetic models for changes in food components, including microbial populations—the background, statistics, and applications of kinetic models used to describe changes in components of food during a preservation process.
2. Transport models for food systems—the primary transport models needed to describe the changes in physical characteristics within a food structure during a preservation process.
3. Process design models—the integration of kinetic and transport models, as needed predict the process time required to accomplish the desired objectives of the preservation process.

The concepts presented build on the strong, successful history of thermal processing of foods, using examples from these preservation processes. Significant attention has been given to the fate of food quality attributes during the preservation process and the concepts for optimizing the process parameters to maximize the retention of food quality.

*Food Preservation Process Design* is an ideal text for a capstone or senior design course at the fourth year of the undergraduate program in food science. The information in the book also provides the basis for a graduate-level course on preservation processes. The examples, tabular data, and the computational approaches are designed to stimulate individual or team efforts in process design. In addition, the content should be an excellent reference for food industry professionals involved in preservation process design.

The first chapter provides historical background on food preservation processes, with an emphasis on quantitative aspects. Attention has been given to positive outcomes from successful food preservation technologies as a basis for evaluating alternative process technologies. The introduction to the book emphasizes the challenges associated with experimental verification of preservation processes, and the opportunities for optimizing the processes to maximize retention of product quality attributes.

Chapter 2 presents the background on kinetic models currently used for food preservation process design. The evolution from reaction rate kinetics is reviewed, and examples are used to illustrate the evaluation of the appropriate kinetic parameters for first- and multiple-order models. The relationships of the typical kinetic parameters to the traditional parameters from thermal processing are presented, along with a justification for a more uniform set of parameters for the future.

Typical kinetic parameters for inactivation of microbial populations are presented in Chapter 3. Some of the best available kinetic parameters for both vegetative pathogens and pathogenic spores are presented in tabular form, along with background on the conditions of measurement. These parameters include examples for alternative process technologies. The variability associated with kinetic parameters, as well as the influence of product composition on the magnitude of the parameters, has been considered with examples illustrating the use of the kinetic parameters in process design.

Chapter 4 covers the kinetic parameters for typical food product quality attributes. Most of the available parameters are for nutrient and color changes as a function of temperature. Examples illustrate the use of kinetic models to predict the retention of quality attributes during a preservation process and provide the basis for optimizing the retention of quality.

The fundamental aspects of transport models are presented in Chapter 5, as background for food preservation process design.

The prediction models for physical properties based on product composition have been provided along with typical transport models for thermal energy exchange. Emphasis has been placed on models for prediction of temperature within the food product structure during typical preservation processes and on the unique relationships occurring during the application of alternative process technologies.

In Chapter 6, the emphasis is on process design and the integration of appropriate kinetic and transport models. The process design parameter for food preservation is established, with specific attention to microbiological safety, as well as product spoilage. The impact of product structure on uniform application of the process, as well as the influence on process design, is illustrated. The subsequent impact of the process on product quality attributes is illustrated through the use of examples.

The validation of the preservation process is the subject of Chapter 7. The challenges associated with process validation when attempting to confirm probabilities of survivors is illustrated through examples. The appropriate use of surrogate microorganisms, chemical tracers, and other approaches to measuring the impact of the process being evaluated is discussed, with some of the unique concerns and requirements for alternative technologies considered.

The process design approach presented in this book provides the ideal opportunity for optimization of preservation processes, as demonstrated in Chapter 8. The unique relationship of the magnitudes of kinetic parameters for microbial populations as compared to product quality attributes provides the basis for maximizing quality retention, while achieving the microbial safety and product shelf-life. The extension of these concepts to alternative preservation technologies is also explored.

The final chapter of the book is a brief look at the future of food preservation process design, with an emphasis on the need for more and improved kinetic parameters for both microbial populations and quality attributes. Some of the challenges associated with alternative preservation technologies are also discussed.

In closing, I would like to acknowledge the feedback and encouragement from many colleagues as the content of this book evolved. These colleagues include many students enrolled in courses where several of the concepts covered in this volume were presented and tested. The comments from all have been valuable in finalizing the concepts shared throughout these pages.

Dennis R. Heldman

# Contents


Preface . . . vii

1 **Introduction** . . . **1**
History of preservation processes . . . **6**
The quantitative approach . . . **9**
Bibliography . . . **17**

2 **Kinetic Models for Food Systems** . . . **19**
Rate equations and rate constants . . . **20**
First-order model . . . **25**
Multiple-order models . . . **27**
Agent intensity models . . . **30**
Thermal process models . . . **37**
Uniform parameters . . . **43**
List of symbols . . . **46**
Bibliography . . . **47**

3 **Kinetics of Inactivation of Microbial Populations** . . . **49**
Characteristics of microbial survivor curves . . . **50**
Kinetic parameters for microbial populations . . . **54**
Applications of kinetic parameters . . . **59**
Definition of microbial inactivation . . . **76**
Kinetic parameters for alternative preservation technologies . . . **77**
List of symbols . . . **77**
Bibliography . . . **78**

4 **Kinetics of Food Quality Attribute Retention** . . . **87**
Characteristics of quality retention kinetics . . . **88**
Kinetic parameters for product quality retention . . . **91**
Applications of kinetic parameters for quality attributes . . . **95**
Impacts of preservation processes on quality attributes . . . **105**
List of symbols . . . **106**
Bibliography . . . **107**

5 **Physical Transport Models** . . . . . . . . . . . . . . . . . . . . 111
Physical properties . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 112
Heating and cooling in containers . . . . . . . . . . . . . . . . 125
Ohmic heating . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 138
Microwave heating . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 139
Ultra-high pressure applications . . . . . . . . . . . . . . . . . . 141
List of symbols . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 143
Bibliography . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 144

6 **Process Design Models** . . . . . . . . . . . . . . . . . . . . . . . . 147
The process design parameter . . . . . . . . . . . . . . . . . . . 148
General approaches to preservation process design. . . 150
Process design targets . . . . . . . . . . . . . . . . . . . . . . . . . . 166
Integrated impacts of preservation processes . . . . . . . 171
Design of a microwave process . . . . . . . . . . . . . . . . . . 182
Design of an ohmic heating process. . . . . . . . . . . . . . . 193
Design of ultra-high pressure processes . . . . . . . . . . . 197
Design of pulsed-electric-field processes . . . . . . . . . . 202
Design of combined processes. . . . . . . . . . . . . . . . . . . 209
List of symbols . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 212
Bibliography . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 214

7 **Process Validation and Evaluation** . . . . . . . . . . . . . . 217
Process validation for microbial inactivation . . . . . . . . 219
Alternative approaches to validation. . . . . . . . . . . . . . . 229
Process validation for alternative process technologies . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 237
List of symbols . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 243
Bibliography . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 243

8 **Optimization of Preservation Processes**. . . . . . . . . . 245
The HTST concept. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 246
Applications to nonliquid foods . . . . . . . . . . . . . . . . . . 249
List of symbols . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 263
Bibliography . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 265

9 **Designing Processes in the Future** . . . . . . . . . . . . . . 267
Assembly of kinetic parameters . . . . . . . . . . . . . . . . . . 268
Transport models. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 271
Process models . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 272
Opportunities for evolving process technologies . . . . . 273
Bibliography . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 276

Appendix . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 279
Index . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 341

# Introduction

# 1

1.1 History of preservation processes . . . . . . . . . . . . . . . . . . . . . . . . . . . 6
1.2 The quantitative approach . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 9
Bibliography. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 17

People have been preserving foods for centuries! Of course, the processes used for preservation have evolved at different points in history, but the evaluation and design of processes have become quantitative as more scientific research on the processes has been completed. The overall purpose of this book is to illustrate the applications of the most recent research for quantitative evaluation and description of preservation processes. These illustrations should strengthen the quantitative basis of current preservation process design and provide the background to identify information needed to enhance quantitative design of processes in the future.

The primary focus of food preservation has been on controlling microbial populations, with a specific emphasis on pathogenic microorganisms. According to Potter and Hotchkiss (1995), the primary preservation technologies for foods include the following:

**Heat:** The use of thermal energy to increase the temperature of a food is the most recognized and widely used agent for food preservation. Elevated temperatures cause a decline in microbial populations and extend the shelf life of the product by eliminating microorganisms causing food spoilage and food-borne illness in humans. Many shelf-stable foods are available to consumers as a result of thermal processing. These processes have been

Food Preservation Process Design
ISBN: 978-0-12-372486-1

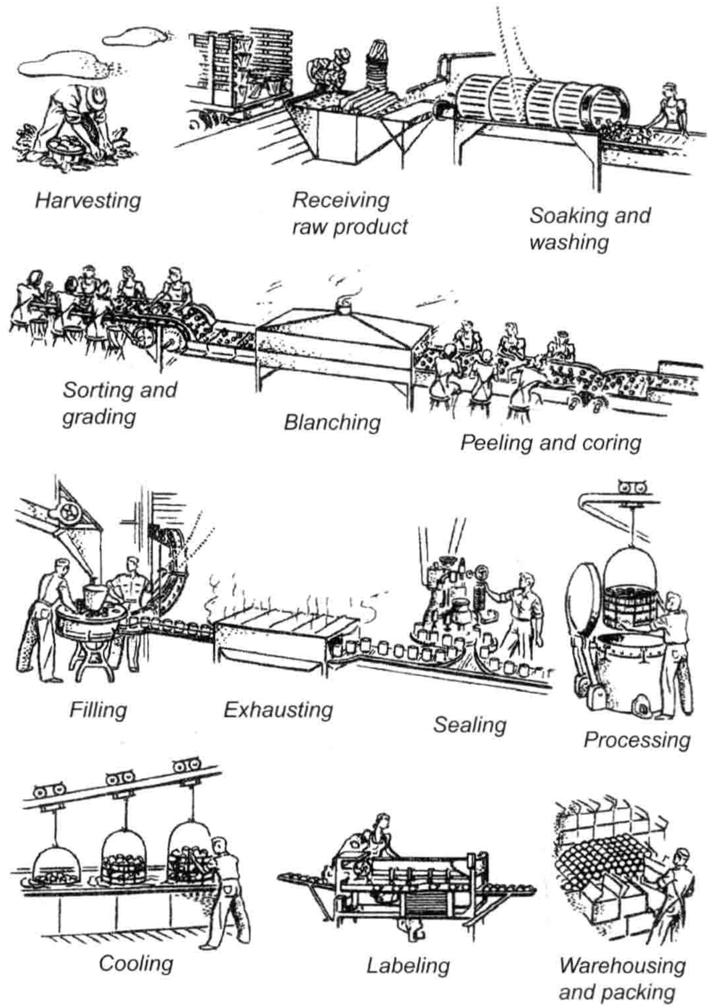



**Figure 1.1** Typical steps in the heat preservation process (from Jackson & Shinn, 1979).

described in a quantitative manner for many years and provide a fundamental basis or structure for describing other preservation processes (Figure 1.1).

**Refrigeration:** The use of reduced temperatures to extend food product shelf life has a long history. Ice has been used for centuries to reduce the temperature of foods and prevent spoilage. In general, the reduction of a food product temperature does not reduce the microbial population but prevents microbial growth

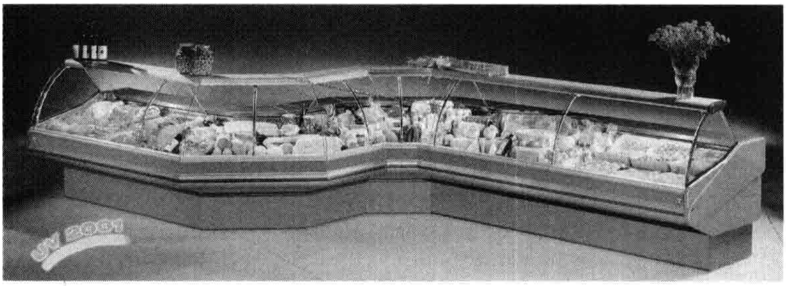


**Figure 1.2** A refrigerated storage cabinet for food products (Nuline Refrigeration www.nulinerefrigeration.com.au/5.html).

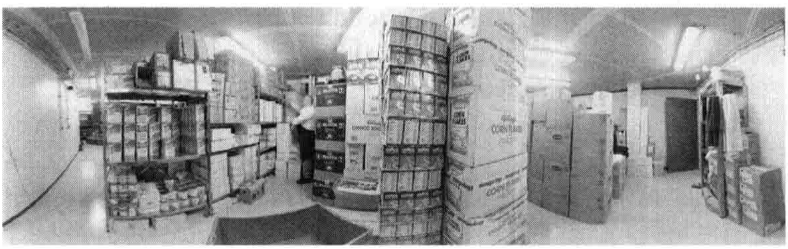


**Figure 1.3** An array of packaged dry foods (www.gdargaud.net/Antarctica/WinterDCe.html).

and the associated deterioration of other food quality attributes (Figure 1.2).

**Dehydration:** Drying foods may have been one of the earliest forms of preservation. Exposure of many foods to thermal energy from the sun causes water to evaporate from the product. Sufficient reductions of moisture content inhibit the growth of microorganisms, and the product spoilage associated with microbial growth (Figure 1.3).

**Acidity:** Adjustments in the pH of a food is a popular preservation step for many products. This type of preservation occurs in different ways in different foods, ranging from naturally low pH (high acid) foods to fermentation processes where growth of selected microorganisms causes an adjustment in the pH of the product, and the inhibition of growth of pathogens and spoilage microorganisms. Often, the pH of the food is used in combination with other processes, such as thermal, to accomplish preservation.

**Water activity:** Many food components (natural or added) influence the growth of microbial populations in products. Elevated concentrations of sugars and salts cause microbial cell dehydration, which is the diffusion of water from the cell, leading to inhibition of growth or complete inactivation. These same impacts occur in dry and intermediate moisture foods. The magnitude of product water activity has become an indictor used in control of food deterioration, including spoilage due to microbial growth.

**Smoke:** A traditional method of preservation for meat and meat products involves the use of smoke to control microbial growth. The impact of the method is due to the influence of smoke components on microorganisms, a mild temperature increase for an extended period of time along with a reduced moisture content of the food, at least near the product surface.

**Atmospheric composition:** The shelf life of many food products has been extended by reducing or eliminating the concentration of oxygen in the atmosphere or gas in direct contact with the product. This approach has been effective for products with deterioration caused by aerobic spoilage microorganisms. Several packaging systems have been developed using these concepts. However, there are obvious concerns and limitations to this approach when anaerobic pathogens or spoilage microorganisms are present in the product.

**Additives:** Many chemicals inhibit the growth of microbial populations or inactivate microorganisms, and a few of these additives have been approved for use in foods at low levels, as preservatives. Most of the additives are specific for certain spoilage microorganisms and for specific product applications.

**Radiation:** Various wavelengths within the electromagnetic spectrum are effective for inactivation of microorganisms, and many have been evaluated as preservation processes for food products. Only a limited number of products preserved by radiation have been made available to consumers, due to the negative perception of the technology.

**Alternatives:** During the past 15 years, several alternative technologies have evolved for evaluation as preservation processes for food products. These technologies include ultra-high pressure, microwave or ohmic heating, and pulsed electric fields.

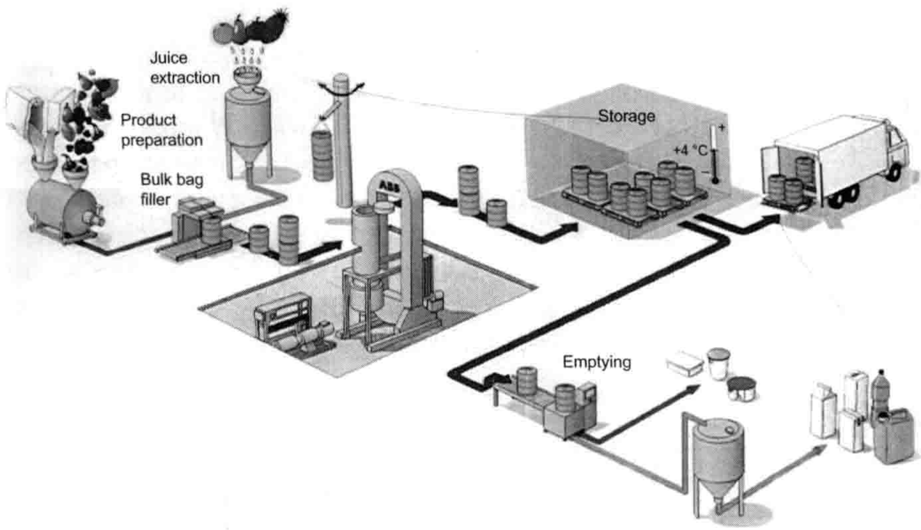



**Figure 1.4** Use of high pressure for food preservation (from Singh & Yousef, 2005).

Sufficient information on the influence of these processes on microbial populations in foods must be assembled to allow quantitative evaluation of the processes (Figure 1.4).

All of the preceding approaches to preservation of foods have contributed to the safety and stability of foods available to consumers by controlling or eliminating microbial populations in foods. Many of the technologies are used in combination with another technology, and do not accomplish the desired result independently. Only heat (or the thermal process) and radiation have been demonstrated to cause a reduction in a target microbial population and have been quantified in a consistently predictable manner. Due to negative consumer perceptions about radiation, it is unlikely that consumers will accept food products from radiation preservation in the near future. Due to this situation, radiation has not been included as a preservation technology for analysis in this book. Heat has been used in combination with many of the other preservation technologies mentioned. In addition, other technologies used in combination with heat influence the effectiveness of thermal processes. Recent developments with ultra-high pressure and pulsed electric fields suggest that these technologies are similar to thermal and may be used in combination with other technologies.

In summary, this book focuses on the quantitative evaluation of preservation processes for food products. The process design concepts build on the long and successful history of thermal process design but extend the analysis to combination processes and to nonthermal technologies, such as ultra-high pressure and pulsed electric fields. In addition, the analysis covers concepts needed to estimate the impact of a process on food components, including nutrients and other product-quality attributes. Finally, the book explores opportunities to optimize preservation processes to achieve process efficiency and product quality retention.

## 1.1 History of preservation processes

Although the history of food preservation dates back many centuries to the use of thermal radiation from the sun to create dry foods, the work of Nicholas Appert is recognized as the first successful controlled process. Appert (1810) developed a system for sealing food in glass bottles and used thermal energy to increase the temperature of the product to levels exceeding 100°C. His work was stimulated by a prize offered by the French Directory in 1795, in response to the need to provide sufficient and safe foods to Napoleon's troops. By 1809, Appert had succeeded in preserving certain foods by immersing glass containers, containing the food, in boiling water. He was awarded the prize from the French government. Appert's accomplishments are recognized as the beginning of thermal processing (commercial sterilization) to create shelf-stable foods (Figure 1.5).

Nearly 50 years passed before a fellow Frenchman, Louis Pasteur, discovered that the origin of food spoilage was the growth of microorganisms. Today, Pasteur is recognized for another thermal preservation process: Pasteurization.

Many developments and occurrences have contributed to the evolution of preservation process design. Following the breakthrough discoveries of Appert and Pasteur, developments were very slow for nearly 100 years. The pioneers of thermal processing research and application in the United States were Prescott and Underwood (1897). These researchers completed the important research on microbiology of canned foods. These developments were accompanied by new methods for manufacturing metal

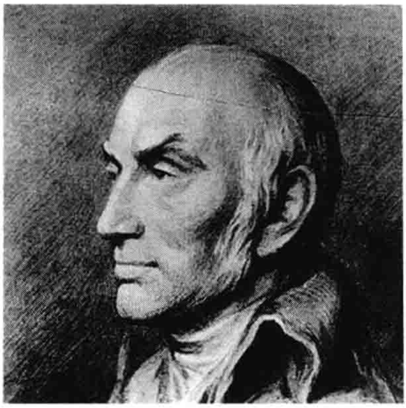


**Figure 1.5** Portrait of Nicholas Appert (Appert, Nicholas. 1810. *L'art de conserver*. Chez Patri et Cie).

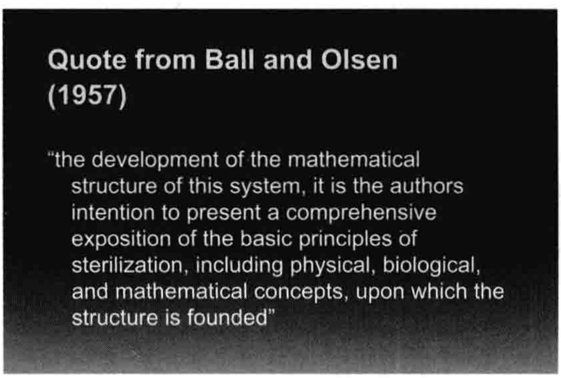



**Figure 1.6** Quote from Ball and Olson (1957).

cans, specifically for food applications. In the 1920s, research by Bigelow (1922) and Ball (1923) began to provide the basis for quantification of the process and introduced opportunities for predictive process design. The book *Sterilization in Food Technology* by Ball and Olson (1957) provided exhaustive documentation of these developments. Among the contributions during this time was the application of the thermocouple to the measurement of temperatures during experimental processing of foods. Shortly thereafter, Stumbo (1965) published *Thermobacteriology in Food Processing* and provided an additional view on the need for predicting process times for thermal processing of shelf-stable foods. The consistent trend toward quantification of the preservation process during this time period is best emphasized by the quote from the preface of Ball and Olson (1957) in Figure 1.6.