Thermal Processing of Foods

Control and Automation

EDITOR

K. P. Sandeep

WILEY-BLACKWELL

IFT PRESS

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Control and Automation

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WILEY-BLACKWELL

A John Wiley & Sons, Ltd., Publication

IFT PRESS

Edition first published 2011

Blackwell Publishing was acquired by John Wiley & Sons in February 2007. Blackwell's publishing program has been merged with Wiley's global Scientific, Technical, and Medical business to form Wiley-Blackwell.

Editorial Office
2121 State Avenue, Ames, Iowa 50014-8300, USA

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Library of Congress Cataloging-in-Publication Data

Thermal processing of foods : control and automation / edited by K.P. Sandeep.
p. cm. – (IFT Press series)
Includes bibliographical references and index.
ISBN 978-0-8138-1007-2 (hardback)
1. Food–Preservation. 2. Food–Effect of heat on. 3. Automation. I. Sandeep, K. P.
TP371.2.T442 2011
664′.028–dc22

2010040521

A catalog record for this book is available from the U.S. Library of Congress.

Set in 11.5/13.5 Times NR PS by Aptara® Inc., New Delhi, India
Printed and bound in Singapore by Markono Print Media Pte Ltd

1 2011

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Chapter 1

INTRODUCTION

K.P. Sandeep

Thermal processing of foods in one form or the other has been in place since the 1900s. Although the fundamental principles remain the same, there have been numerous improvements in the control and automation of thermal processes. The various chapters in this book provide an insight into the details of the control and automation processes and details involved for different thermal processes. In order to fully understand and appreciate these details, it is important to have an understanding of the improvements that have taken place in equipment design (novel heat exchangers), process specifications (lower tolerances), product formulations (new types of ingredients), enhancement of quality (by decreasing the extent of overprocessing), and process safety requirements (identification and control of critical parameters in a process). All these are based on the fundamental and practical understanding of various topics. A brief summary of these topics is presented in this chapter.

1.1. Composition and classification of foods

Processed foods consist of carbohydrates (C, H, and O), proteins (C, H, O, and N), fats (usually glycerol and three fatty acids), vitamins, enzymes, flavoring agents, coloring agents, thickening agents, antioxidants, pigments, emulsifiers, preservatives, acidulants, chelating agents, and replacements for salt, fat, and sugar. Some of these are naturally present in the food, while some others are added for

Thermal Processing of Foods: Control and Automation. Edited by K.P. Sandeep

achieving specific functionality. Addition of different ingredients to a food product may have an effect on the stability, functionality, or properties of the food and have to thus be added in precise and predetermined quantities. During a thermal process, these constituents of a food product may undergo changes, resulting in changes in the properties, quality, and physical appearance of the food product as a whole, some of which may not be desirable. Thus, it is important to minimize the extent of thermal process a food receives.

Foods are generally classified as low acid if their equilibrium pH is greater than or equal to 4.6 and acid if their equilibrium pH is less than 4.6. The choice in the pH value of 4.6 arises from the fact that it has been documented by various researchers that the most heat-resistant pathogenic organism of concern in foods, *Clostridium botulinum*, does not grow at pH values below 4.6. Low-acid foods that have a water activity of 0.8 or higher and are stored under anaerobic and nonrefrigerated conditions have to undergo a very severe thermal process to ensure adequate reduction in the probability of survival of *C. botulinum*, in order to render the product commercially sterile. Acid products, on the other hand, need to be subjected to a much milder heat treatment as the target organisms are usually molds and yeasts. Thus, it is important to know if the product under consideration for thermal processing belongs to the low-acid or acid category.

1.2. Preservation of foods

A food can be preserved (under refrigerated or nonrefrigerated conditions) by several methods. Some of the commonly used techniques include the lowering of its water activity (by dehydration, cooling, or addition of salt/sugar), removal of air/oxygen, fermentation, and removal/inhibition/inactivation of microorganisms. Commercial and large-scale operations associated with preservation of foods by inactivating microorganisms usually include thermal processing. Foods meant to be refrigerated are generally subjected to a pasteurization treatment, while foods meant to be shelf-stable are subjected to retorting, hot-filling, or an aseptic process. The quality of the ingredients used, the degree of thermal treatment, the packaging used, and the storage conditions affect the shelf life of the foods.

1.3. Properties of foods

The properties of importance in thermal processing of foods are the physical (density, viscosity, and glass transition temperature), thermal (thermal conductivity and specific heat for conventional heating), electrical (electrical conductivity for ohmic heating), and dielectric (dielectric constant and loss factor for microwave and radiofrequency heating). Some of the other product characteristics to be considered are the shape, size, water activity, ionic strength, denaturation of protein, and gelatinization of starch. Some of the product system characteristics of importance are the heat transfer coefficients, pressure drop, and extent of fouling. Many of these properties are dependent on a variety of factors, but most importantly on temperature. Several empirical correlations exist to determine the properties of many foods as a function of their composition and temperature.

1.4. Heating mechanisms

Numerous methods exist for thermal processing of foods. Some of these techniques include the use of steam injection, steam infusion, tubular heat exchangers, shell and tube heat exchangers, plate heat exchangers, scraped surface heat exchangers, extruders, ohmic heaters, infrared heaters, radiofrequency heaters, microwave heaters, and variations/combinations of these. The choice of the heating mechanism is based on several factors including the nature of the product (inviscid, viscous, particulate, etc.), properties of the product (thermal, electrical, and dielectric), floor space available, need for regeneration, need or acceptability of moisture addition/removal, nature heating required (surface versus volumetric), ease of cleaning, and of course, cost (capital and operating).

1.5. Microorganisms and their kinetics

Microorganisms are classified as aerobes and anaerobes (either facultative or obligate) depending on their need for the presence or absence, respectively, of oxygen, for their growth. They may also be classified as psychrotrophs (grow under refrigerated conditions), mesophiles (grow under ambient/warehouse conditions), or thermophiles (grow under temperatures encountered in deserts) and can be obligate or facultative. Thus, on the basis of the package environment (presence or absence of oxygen/air) and storage temperature, the organisms that can proliferate vary. Thus, these factors, along with the other important factors (pH and water activity), form the basis for the determination of the target organism for processing any product.

The inactivation of most bacteria (at a constant temperature) usually follows the first-order kinetics reaction described by the following equation:

$$N = N_0 10^{-t/D_T} \tag{1.1}$$

where N_0 is the initial microbial count, N is the final microbial count, t is the time for which a constant temperature is applied, and D_T is the decimal reduction time.

The effect of temperature on the heat resistance of microorganisms is generally described by the D-z model given by the following expression:

$$D_T = D_{ref} 10^{(T_{ref}-T)/z} \tag{1.2}$$

where T_{ref} and D_{ref} are the reference temperature and the decimal reduction time at the reference temperature, respectively, and z is the temperature change required for an order of magnitude change in the decimal reduction time.

An alternate and more fundamental approach describing the heat resistance of microorganisms as a function of temperature is the Arrhenius kinetics approach and is given by the following equation:

$$k = A e^{-E_a/RT} \tag{1.3}$$

where k is the reaction rate, A is the collision number (or the frequency factor), and E_a is the activation energy.

Due to the simplicity of the D-z model, it is the preferred model for use in the food industry to describe the effect of temperature on the inactivation of microorganisms. It should be noted that the link between the D-z model and the Arrhenius model is provided by the following equation:

$$E_a = \frac{2.303R(T)(T_{ref})}{z} \tag{1.4}$$

1.6. Process safety and product quality

Once the target microorganism is identified and the kinetic parameters (D and z values) of the organism are determined, a thermal process (time and temperature) is then designed to reduce the population of the target microorganism to an acceptable level (that level depends on the product characteristics process categories discussed in the preceding sections). Even for a constant temperature process, it should be noted that several combinations of time (t) and temperature (T) can result in identical levels of inactivation of microorganisms. The F value, described by the following equation, is used to describe these combinations:

$$F = 10^{T-T_{ref}/z}t = D_{ref}\log\frac{N_0}{N} \tag{1.5}$$

Nonisothermal process temperatures are handled by integrating the above equation with temperature as a function of time.

For both isothermal and nonisothermal temperatures, an F value can be computed for any process, based on the above equation. This value has to be equal to or greater than the predetermined F value for the process to be safe. It is easy to see that the minimum required F value can be achieved by increasing the process time or temperature. However, it should also be noted that different quality and nutritional attributes of the food will be lost at different rates and to different degrees at different combinations of time and temperature. Thus, a process optimization has to be conducted to ensure food safety and maximize product quality. The cook value (C), given by the following equation, is used to determine the critical quality attribute of concern within a food product:

$$C = 10^{(T-T_{ref})/z_c}t \tag{1.6}$$

The above equation describing the cook value (C) is very similar to the equation for F value (equation (1.5)). The main differences between the two equations are the choice of the reference temperature (generally, $T_{ref} = 121.1°C$ for computing the F value and $T_{ref} = 100°C$ for computing the C value) and the magnitudes of z and z_c (generally, $z = 10°C$ and z_c is much greater than 10°C).

The process of optimization involves ensuring food safety by making sure that the F value obtained using equation (1.5) is at least the minimum value required for that type of product and at the same time minimizing the C value of the critical quality attribute obtained using equation (1.6). For the case of z_c greater than z, this optimization process results in recommending the use of higher temperatures for short times.

1.7. Concluding remarks

A thorough knowledge of the above-described topics is important to fully understand the control and automation of various thermal processes. The chapters that follow discuss details starting from techniques of process controls and build up to process control of retorting and aseptic processing, strategies to correct deviant thermal processes, optimization of thermal processes, and control and modeling of continuous flow microwave processing.

Chapter 2

ELEMENTS, MODES, TECHNIQUES, AND DESIGN OF PROCESS CONTROL FOR THERMAL PROCESSES

David Bresnahan

2.1. Introduction

Thermal processes are used to develop the product quality and food safety aspects of many food products. Control of the process parameters is therefore critical to the ability to produce a quality product while ensuring product safety. Often the thermal process effects on the product quality attributes are inverse to the effects on product safety attributes, and therefore precise control becomes even more important.

One definition of *process control* could be "the measurement and control of process variables to achieve the desired product attributes." Again, the paramount process attribute in many thermal processes is food safety. Proper design, implementation, and validation of the system are key to achieving this result.

Automatic control provides greater consistency of operation, reduced production costs, and improved safety. A process that is vulnerable to upsets is going to have a more consistent output if the process variables are adjusted constantly by an automatic control system. Human variability can be taken out of an operation with a properly implemented automatic control system.

Thermal Processing of Foods: Control and Automation. Edited by K.P. Sandeep