Food Science Text Series

P. G. Smith

Introduction to Food Process Engineering

Second Edition

Springer

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Preface to the First Edition

There are now a large number of food-related first-degree courses offered at universities in Britain and elsewhere in the world which either specialise in, or contain a significant proportion of, food technology or food engineering. This is a new book on food process engineering which treats the principles of processing in a scientifically rigorous yet concise manner, which can be used as a lead-in to more specialised texts for higher study and which is accessible to students who do not necessarily possess a traditional science A-level background. It is equally relevant to those in the food industry who desire a greater understanding of the principles of the processes with which they work. Food process engineering is a quantitative science and this text is written from a quantitative and mathematical perspective and is not simply a descriptive treatment of food processing. The aim is to give readers the confidence to use mathematical and quantitative analyses of food processes and most importantly there are a large number of worked examples and problems with solutions. The mathematics necessary to read this book is limited to elementary differential and integral calculus and the simplest kind of differential equation.

This book is the result of 15 years experience of teaching food processing technology and food engineering to students on a variety of diploma, first degree and postgraduate courses. It is designed, inter alia, to

- emphasise the importance of thermodynamics and heat transfer as key elements in food processing
- stress the similarity of heat, mass and momentum transfer and make the fundamentals of these essential concepts readily accessible
- develop the theory of mass transfer, which is underused in studies of food processing and little understood in a useful and readily applicable way
- widen the usual list of unit operations treated in textbooks for undergraduates to include the use of membranes
- introduce a proper treatment of the characterisation of food solids and of solids processing and handling

Chapters 1 and 2 set out the background for a quantitative study of food processing by defining the objectives of process engineering, by describing the mathematical and analytical approach to the design and operation of processes and by establishing the use of SI units. Much of what follows in the book is made easier by a thorough understanding of the SI system. Important thermodynamics concepts are introduced in Chapter 3 which underpins the sections on energy balances and heat transfer, itself so central to food processing. Chapter 4 is concerned with material and energy balances and concentrates upon the techniques required to solve problems. Most of the chapter is devoted to numerical examples drawn from a wide range of operations.

In Chapter 5 the concepts of heat, mass and momentum transfer are introduced; the similarity between heat, mass and momentum transfer is stressed. This acts as an introduction to the material of the following three chapters. These cover first, the flow of food fluids, in which the importance of laminar flow in food processing is emphasised, and food rheology, where the objective is to enable the reader to apply rheological models to experimental data and to understand their significance in mechanistic and structural terms. Second, heat transfer, which is at the heart of many food processing operations. The basic principles are covered in detail and illustrated with numerous worked examples. Third, mass transfer, which is often perceived as a difficult topic and indeed is poorly treated in many food texts. As a consequence, mass transfer theory is underused in the analysis of food processes. Chapter 8 is intended to redress this imbalance, and the treatment of mass transfer is extended in Chapter 9, where the principles of psychrometry are explained.

The principal preservation operations are covered in Chapters 10, 11 and 12. These include the commercial sterilisation of foods, where the bases of the general and mathematical models are outlined and emphasis is given to a clear explanation of calculation procedures; low-temperature preservation, including coverage of the principles of the refrigeration cycle; evaporation and drying. The processing of food particulates is often overlooked and Chapter 13 is an attempt to address this oversight. It considers the characterisation of individual particles and the development of relationships for particle – fluid interaction, and fluidisation is included at this point because it is a fundamental processing technique with wide application to many unit operations. Finally, Chapter 14 covers mixing and physical separation processes, including the increasingly important area of separation using ultrafiltration and reverse osmosis.

Preface to the Second Edition

In this second edition two chapters have been added. Chapter 15 covers some of the mass transfer operations used in the food industry but which are not always considered to be core food processes: distillation (including both batch and continuous operation), leaching (or solid–liquid extraction) and supercritical fluid extraction, a process of increasing importance in the food industry. In the case of distillation and leaching the outline of the relevant theory is supported by detailed worked examples to illustrate the common graphical methods which are used to determine the number of ideal or equilibrium stages.

The growing demand for safer food of ever higher quality has led to the investigation of a range of techniques which may together be labelled as minimum processing technologies. The principles of some of these techniques are outlined in Chapter 16, including ohmic heating, pulsed electric field heating (PEF), radio frequency heating (RF), high-pressure processing, irradiation and ultrasound.

The content of a number of other chapters has been updated or amended. Methods of temperature measurement, especially the details of various types of thermocouples in use, have been included in Chapter 7. A new section on the application of mass transfer to food packaging has been added to Chapter 8; data on the permeability of packaging films are presented. The coverage of freeze drying (Chapter 12) has been extended considerably to include the use of heat and mass transfer models in the prediction of drying time. The section on fluidisation in Chapter 13 has been rewritten to include more information on the estimation of heat and mass transfer coefficients in fluidised beds used in food processes.

In addition to these changes, the opportunity has been taken to review all the worked examples and problems in the book and to correct a number of errors in the first edition. The reading lists at the end of each chapter have been updated where appropriate.

Lincoln, UK
June 2010

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Chapter 1
An Introduction to Food Process Engineering

A process may be thought of as a sequence of operations which take place in one or more pieces of equipment, giving rise to a series of physical, chemical or biological changes in the feed material and which results in a useful or desirable product. More traditional definitions of the concept of *process* would not include the term *biological* but, because of the increasing sophistication, technological advance and economic importance of, the food industry, and the rise of the biotechnology industries, it is ever more relevant to do so.

Process engineering is concerned with developing an understanding of these operations and with the prediction and quantifying of the resultant changes to feed materials (such as composition and physical behaviour). This understanding leads in turn to the specification of the dimensions of process equipment and the temperatures, pressures and other conditions required to achieve the necessary output of product. It is a quantitative science in which accuracy and precision, measurement, mathematical reasoning, modelling and prediction are all important. Food process engineering is about the operation of processes in which food is manufactured, modified and packaged. Two major categories of process might be considered; those which ensure food safety, that is the preservation techniques such as freezing or sterilisation, which usually involve the transfer of heat and induce changes to microbiological populations, and those which may be classified as food manufacturing steps. Examples of the latter include the addition of components in mixing, the separation of components in filtration or centrifugation or the formation of particles in spray drying. Classification in this way is rather artificial and by no means conclusive but serves to illustrate the variety of reasons for processing food materials.

Although foods are always liquid or solid in form, many foods are aerated (e.g. ice cream), many processes utilise gases or vapours (e.g. steam as a heat source) and many storage procedures require gases of a particular composition. Thus it is important for the food technologist or the food engineer to understand in detail the properties and behaviour of gases, liquids and solids. In other words the transfer of heat, mass and momentum in fluids and an understanding of the behaviour of solids, especially particulate solids, form the basis of food processing technology. At the heart of process engineering is the concept of the unit operation. Thus the principles which underlie drying, extraction, evaporation, mixing and sterilisation are independent of the material which is being processed. Once understood, these principles can be applied to a wide range of products.

The overall purpose of food process engineering then is to design processes which result in safe food products with specific properties and structure. Foods, of course, have their own particular and peculiar properties: most food liquids are non-Newtonian; structures are often complex and multiphase; non-isotropic properties are common. In addition to this, hygiene is of paramount importance in all manufacturing steps. The correct design of such processes is possible only as a result of the development of mathematical models which incorporate the relevant mechanisms. Thus it is important to understand the chemical, structural and microbiological aspects of food in so far as they contribute

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