

***FOOD***

***ENGINEERING***

***OPERATIONS***

**THIRD EDITION**

J. G. Brennan, J. R. Butters,  
N. D. Cowell and A. E. V. Lilley

ELSEVIER APPLIED SCIENCE

# FOOD ENGINEERING OPERATIONS

Third Edition

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# **FOOD ENGINEERING OPERATIONS**

**Third Edition**

## FOREWORD TO THE THIRD EDITION

I am honoured and delighted to be able to welcome the new third edition of this standard textbook on the principles of food engineering. The National College of Food Technology has become well-known and respected, largely through those who have used this textbook, either as students at Weybridge or in other courses taught in countries around the world.

Since the last edition appeared, the National College has merged with the Department of Food Science at the University of Reading and now, as the Department of Food Science and Technology, occupies an excellent, well-equipped modern building on the attractive Whiteknights campus in Reading. This facility, including a versatile modern food processing plant, was largely provided by the generosity of the British food industry, recognising the contribution which has already been made, and will be increasingly needed, to meet the exacting standards of the modern food industry.

The modern consumer wants food to be convenient to use, to be as 'natural' as possible, only minimally preserved and, of course, to be safe. The increasingly international and competitive food industry can only fulfil these needs by employing food scientists, technologists and process engineers who understand and can apply optimal food processing methods, meeting the twin needs of process efficiency and product safety. This third edition of *Food Engineering Operations* will be an essential text for present and future undergraduate students. Today's students will need to purchase their own copies of this book to help establish their personal reference libraries in the demanding years ahead.

Geoffrey Campbell-Platt  
*National College Professor of Food Technology and  
Head of the Department of Food Science and Technology,  
University of Reading, UK*

## **PREFACE TO THE THIRD EDITION**

In preparing this third edition, the authors have endeavoured to take account of significant changes in processing techniques, equipment design and applications which have occurred since the second edition was published in 1976. Examples of changes made for this edition are: new membrane materials and configurations in Chapter 6; extraction with supercritical CO<sub>2</sub> in Chapter 8; extrusion cooking in Chapter 10; developments in irradiation in Chapter 15 and extension of the discussion of aerobic and anaerobic treatments for waste materials in Chapter 18. The reference lists at the end of each chapter have been updated but some early key references have been retained. In Appendix II the section on unsteady state heat transfer by conduction has been enlarged. A new chapter on 'Pumping in the Food Industry' has been added to complement the chapter on 'Materials Handling'. The importance of packaging in maintaining quality and extending the shelf life of foods has been acknowledged by the inclusion of a new chapter on that topic.

J.G.B.  
J.R.B.  
N.D.C.  
A.E.V.L.

## PREFACE TO THE SECOND EDITION

In preparing the second edition, the whole work has been revised and more extended treatments given in some places. New sections have been added, e.g. on membrane separation and thawing, and one new chapter on solid-liquid extraction and expression. However, the guiding principle in this edition has been the same as in the first: to produce an undergraduate textbook giving a basic coverage of the subject and, through selected references, directing the reader's attention to more extensive or detailed treatments of specific topics.

The SI system of units has been used throughout, but in certain circumstances, particularly when discussing topics where these units are not yet extensively used, quantities expressed in SI units are accompanied by their equivalents in more conventional terms.

The authors acknowledge with gratitude the assistance given by Mr I. F. Davison in the preparation of this second edition.

J.G.B.  
J.R.B.  
N.D.C.  
A.E.V.L.

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## **PART I**

# **PRELIMINARY OPERATIONS**



## CHAPTER 1

# THE RAW MATERIAL AND THE PROCESS

### 1.1. INTRODUCTION

Food processing is seasonal in nature, both in the demand for its output and in the availability of its raw materials, many of which have to be imported. In common with any other manufacturer the food processor would prefer his raw materials: to be continuously available in sufficient quantity and quality to enable him to operate on a planned year-round basis; to be stable in storage; to be of uniform characteristics and to be of predictable price. In practice few, if any, of these criteria are satisfied and it is the purpose of this chapter to identify the particular raw material requirements of the food industry, to indicate some of the problems of supply and to show how the industry and its suppliers respond to these.

In general, the process suitability ( $S$ ) of a food raw material is determined by a balanced assessment of its properties such as: its availability ( $a$ ); its geometric ( $g$ ), physical ( $p$ ), functional ( $f$ ), growth ( $gr$ ) and mechanical ( $m$ ) properties and its thermal ( $t$ ) and electrical characteristics ( $e$ ), etc.

Thus:

$$S = \phi(a + g + p + f + gr + m + t + e + \dots) \quad (1.1)$$

The relative importance of these factors in their contribution to the suitability index will, of course, vary depending on the raw material, the process applied to it and the end product made from it.

Properties of major importance in the selection of food raw materials are:

- (i) *Geometric properties*—shape, shape uniformity, freedom from surface irregularities, unit size, unit weight.
- (ii) *Other physical properties*—colour, texture, aero- and hydrodynamic characteristics, frictional and surface properties.



- (iii) *Functional properties*—flavour, stress resistance, defect level, processability.
- (iv) *Growth properties*—growth and maturation characteristics.

## 1.2. GEOMETRIC PROPERTIES OF THE FOOD

Foods of regular geometry are best suited to high speed mechanised processes. Potato varieties of smooth shape and with shallow eyes are preferred for mechanical peeling and washing. Again, smooth-skinned tomato varieties are more easily washed than ribbed varieties (which also tend to harbour insects such as *Drosophila*). Other examples of shape selection are pigs with long lean backs for bacon and straight runner beans for mechanical snapping (i.e. topping and tailing) and slicing. Thus, shape, uniformity of shape, freedom from surface irregularities and size are important processing indices.

### 1.2.1. SHAPE

The dimensional relationships of a food unit are important: in packaging; in controlling fill-in weight; in freezing; in canning and other heat processes; and in determining the way in which materials behave during pneumatic conveying and bulk storage.

Measurement of a set of specimens enables the magnitude of the contribution of each dimensional variable to the overall process suitability to be estimated. Griffiths and Smith<sup>1</sup> found that the volume of quartzite pebbles could be estimated simply from the relationship:

$$\log(\text{volume}) = b_1 \cdot \log(\text{major axis}) + b_2 \cdot \log(\text{minor axis})$$

Using this measurement of maximum and minimum dimensions of a representative sample of fruits and vegetables permits estimation of the number or weight of these which will fit into a given container or vessel. Mohsenin<sup>2</sup> describes the application of this technique to the measurement of the volumes of irregularly shaped maize kernels and other foods.

### 1.2.2. UNIFORMITY OF SHAPE

This is of importance during: filling into containers; conveying; heat treatment; freezing; dehydration; and during sorting and grading operations.

The roundness of biscuits and hamburgers; the sphericity of apples or potatoes; pears which are of uniform pyriform shape and cucumbers of