Food and Bio Process Engineering

Dairy Technology

H.G. Kessler †

Fifth revised and extended edition
with 923 figures
and 109 tables

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Preface

Preamble to the fifth edition

Shortly before our father died November 1998 he finalised the manuscript of the fifth edition, unfortunately he was not able to complete the work on the book. For his former co-workers of his institute, my mother, and ourselves it was a noble commitment to finish his work.

The fifth edition of this popular textbook and handbook on food-, bioprocessing and dairy technology was thoroughly revised and significantly expanded. After 1981 the book is published in English for the second time. The original idea of our father in the seventies was to create a book summarising the diverse technologies of food processing focusing especially on the processing impact on the product. During his industrial period in the sixties our father recognised that it is of great importance to translate the scientific knowledge on products and processes into a practical language to be applied in the food manufacturing industry. This observation led to the practical character of the book targeting engineers and technologists in the food and dairy industry. For students often the link between the technologies learned during their study and the practical application in industry is missing. This book provides students with the bridge between university and college on the one hand and industry on the other that they need by showing not only the theoretical background but also practical examples.

Since the first edition, which was published 1976, the book was continuously revised and updated to include latest developments in food processing. The progressive evolution can be seen best by comparing the number of figures with the previous editions:

First Edition	(1976)	German	355 Figures
Second Edition	(1981)	English	459 Figures
Third Edition	(1988)	German	688 Figures
Fourth Edition	(1996)	German	883 Figures
Fifth Edition	(2002)	English	923 Figures

In comparison with the first English edition in 1981 changes and additions made to the present edition can be summarised as follows:

Chapter 6

From the beginning the main focus was set on heat treatment and effects. Due to its practical importance this chapter was significantly expanded and revised which led to the new name**: "Heat Treatment, Processes and Effects – Micro-organisms and Conditions of Inactivation".** The additions consider:

- Special effects on the inactivation kinetics as the concentration of certain ingredients, environmental conditions, relative humidity, sealing materials and fats.
- Heat induced whey protein denaturation as function of the protein concentration, ratio casein/ whey protein, and the contents of calcium and lactose.
- Interactions between milk proteins and fat globules due to heating and environmental conditions. Build-up of gel structures effects of stabilisation and destabilisation.

Chapter 13

Completely revised was chapter 13 " Radiation Treatment" which was renamed to "Alternative Methods of Preservation", since it comprises additionally:

- Ohmic and conductive heating
- Microwave heating
- High pressure treatment

Chapter 15

"Technology of Cream and Butter" was expanded by the following topics:

- Critical shear rated for the mechanical stability of fat globules
- Technological impacts on the whipability of cream
- Production clarified butter and cholesterol reduction in the milk fat

Chapter 17

Important changes were made on chapter 17 which now includes:

- Influence of whey protein denaturation and homogenisation on gel structure
- Coagulation characteristics and gel structure due to direct acidification with impact of technology product composition
- Effect of shearing on gel structure
- Acidification and gel structure formation by Glucono-δ-lactone
- Production of yoghurt aroma concentrate

Chapter 18

“ Manufacture of Ice Cream – Ice Crystals” was updated and extended by:

- Structure of ice cream
- Melting characteristic
- Heat transfer and residence time in scraped surface freezer
- Ice crystal growth

Chapter 19

“ Whey processing” was renamed to “ Biotechnology and Whey Processing” due to the inclusion of:

- Kinetics of cell growth
- Enzyme kinetics
- Aerobic bioprocesses – oxygen supply
- Starter cultures and enzymes
- Bioreactors

Chapter 21

Due to its practical significance chapter 21 “Fouling – Cleaning – Sanitising – Rinsing and Associate Processes at the Interface” was expanded to include:

- Fouling, comprising salt- and protein fouling, reaction kinetics, pH, concentration and composition impacts
- Concentration and composition of cleaning agents
- Rinsing and displacement of high viscous products

Chapter 23

“Physical data” physical properties and composition data of milk were added:

- Constituents and composition of milk
- Viscosity, density, heat capacity, thermal conductivity, enthalpy, surfaces tension and physiologic calorific values of milk products
- Determination of total mass, mass fraction
- Solubility of gases in liquids

Many research results included in this book were originated from the former institute of our father. Especially we like to express our gratitude to the former Ph. D. students of our father, A. Bals; R. Behringer; H. Besner; H.-J. Beyer; I. C. de Carvalho; F. Dannenberg; H. Eibel; J. Fiedler; A. Fink; R. Fink; C. Gernedel; S. Geyer; B. Hammelehle; W. U. Hege; G. Helming; J. Hinrichs; F. P. Horak; R. Kennel; M. Kersten; M. Koxholt; U. Kulozik; J. Meier; J. Nassauer; H. D. Obermeyer; J. Pfeifer; J. Plock; B. Rademacher; P. Schkoda; J. Schraml; R. Schreiber; C. Schwab; T. Spiegel; A. Steffl; C. Trgo; K. Welchner; J. Wilde, who contributed importantly with their research work to the book. Additionally we like to give our thanks to his former co–workers as H. W. Bäurle; C. Baumgartner; C. Boheim; G. Borst; R. Eberhard; B. Eisenmann; B. Fertsch; M. Hager; A. Hechler; R. Hegenauer; P. Huber; M. Huss; S. Keim; S. Knapp; A. Löffler; J. Moosbauer; B. Pfeiffer; C. Piepenstock; S. Pietschmann; F. Post; S. Schindler; B. Weber and many not explicitly mentioned, who supported and contributed significantly to the book with their research work and the computer aided layout of the diagrams.

For the translation into the English language, we like to give our thanks to Dr. Sandu and M. Wotzilka. Especially Dr. Sandu we like to express our in dept gratitude for the scientific and English revision, he did for many chapters of the book. Also we like to point out the help of Prof. Dr.-Ing. Ulrich Kulozik, Prof. Dr.-Ing. Jörg Hinrichs and Dr.-Ing. Brigitte Rademacher for assisting us in final correction work, for which we are very grateful to them. In the past three years we had to sacrifice our free time and holidays for finalising the book beside our professional obligations, it was an interesting and demanding period of time, which we wouldn't have forgone.

Munich, 2002 Dr. Ulrich Kessler and Nicole Kessler

Preamble to the first English edition

The great success of this book, which was published in German in 1976, proved that for the first time the gap between food processing methods and technology for practical, research and teaching purposes has been bridged. The English edition, which is revised and extended, is based upon the most up-to-date scientific and engineering knowledge.

This book is addressed both to food technologists working within the food industry and to students. It will be of interest to all who are concerned with food processing and the design of food processing plants: process engineers, design engineers, chemists, bacteriologists, hygienists, and industrial managers.

The author's purpose in writing such a book was to create a textbook for students of food technology and, at the same time, a basic practical guide for use within the industry, which would include many examples of practical applications and important data on materials.

The basic principles of processing methods and their effects upon food products are extensively treated. Emphasis is placed on dairy technology because on the dairy industry's prominent position within the food industry. However, principles of importance to the entire food processing industry are the major concern of the book.

Other topics dealt with which are of interest to those within the sphere of food technology and which are of environmental and legislative importance are drinking water, treatment of effluents, cleaning and sterilizing.

Special attention has been paid to exact descriptions of processing methods in this book, to ensure that the book does not become out-of-date too soon, in spite of rapid technological advances.

The author wishes to express his gratitude to his co-workers for their assistance and their aid in preparing this book, especially to H. W. Bäurle, Dr. C.Gernedel, Dr. G. Helming, Dr. P. Horak, J. Kammerlehner, Dr. J. Nassauer, W.Walenta. Above all I would like to thank my secretary Mrs. I. Hobmeier for typing this book.

Munich-Weihenstephan, 1981 Prof. Dr. Heinz-Gerhard Kessler

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*) The ongoing development of the book and especially the extension of each chapter can be taken from the number of figures in comparison with the last English edition, shown by the numbers in the square brackets. This consideration reflects well the technological development of the industry.

Table of Content

Symbols and Dimensionless Numbers

A	m^2	Cross sectional area, surface
A_M	s/m	Membrane constant
B*	-	Bacteriological effect
B_M	m/s	Membrane constant
C	%, kg/kg or kg/m^3	Concentration
C	mol/m^3	Molar Concentration
C*	-	Chemical effect
D	-	Deformation
D	m	Diameter
D	m^2/s	Diffusion coefficient
D	s	Decimal reduction time
D*	s	Permeation coefficient
E	-	Degree of cream separation
E	V/m	Electric field intensity
E_a	J/mol	Activation energy
F	-	Fat content
F	N	Force
F-value	min or s	Sterilisation value
F*	-	Degree in colour change
$G^{\#}$	J/mol	Free activation enthalpy
G'	Pa	Storage modulus
G''	Pa	Loss modulus
H	J	Enthalpy
h, H	m	Height
$H^{\#}$	J/mol	Enthalpy of activation
I	kg m/s	Momentum
J	A/m^2	Current density
K	-	Proportional factor
K	s^{-1}	Rate constant
K_L	m/s	Mass transfer coefficient
K_M, K_S	mol/m^3	Michaelis-Menten constant, Monod constant
K_{OW}	Pa s^n	Ostwald factor
l, L	m	Length
M	kg/kmol	Relative molecular mass (weight)
N	-	Number
O	m^2	Surface
OTR	kg/m^3s	Oxygen transfer rate
P	kg/m^3	Product concentration
P	N/m	Linear contact pressure
P	W	Power
P*	-	Pasteurisation effect
Q	J	Heat
$\dot{Q}$	W	Heat flow
Q_{10}	-	Dimensionless parameter from reaction kinetics

R	J/molK	Universal gas constant
R	m	Constant radius
R_A	m^2K/W	Fouling factor
R_i	J/kgK	Individual gas constant
S	kg/m^3	Substrate concentration
S	m	Unit of Length
$S^{\#}$	J/mol·K	Activation entropy
T	K	Absolute temperature
U	m	Circumference
U	W/m^2K	Overall heat transfer coefficient
V	m/s	Velocity
V	m^3	Volume
$\dot{V}$	m^3/s	Volume flow
$\Delta V^{\#}$	ml/mol	Volume of activation
W	Nm	Work
X	-	Moisture content on the basis of dry matter
X	kg/m^3	Cell density, cell concentration
X	m	Distance, thickness
X*	-	Moisture content based on total mass (water and dry matter)
Y		Yield factor
Z	-	Centrifugal constant
a	m^2/m^3	Specific area
a_w	-	Water activity
b	m	Length, width
b	m/s^2	Acceleration
b	Pa^{-1}	Conversion factor
b	s	Coefficient of flow
b/μ	s	Mass conductivity
c	J/kgK	Specific heat
d	m	Diameter
d*	-	Dimensionless diameter
d_e,d’	m	Equivalent, hydraulic diameter
f	-	Fat content
f	-	Friction coefficient
f	Hz	Frequency
g	m/s^2	Acceleration due to gravity
h	J/kg	Specific enthalpy
h	m	Length, height, width
h	W/m^2K	Heat transfer coefficient
h’	m/s	Mass transfer coefficient
k	s^{-1}	Rate constant, death rate constant
k	W/mK	Thermal conductivity
k*	m	Absolute roughness
l	m	Length
m	kg	Mass
m	kg/m^2s	Rate of drying
$\dot{m}$	kg/s	Mass flow

n	-	Flow behaviour index, exponent, number, order of reaction
n	mol	Number of moles
n	s^{-1}	Number of revolutions
p	Pa	Pressure
q	J/kg	Specific heat
$\dot{q}$	W/m^2	Heat flow rate
r	J/kg	Latent heat of evaporation or fusion
r	m	Radius
r_{Index}	J/kg	Binding enthalpy, latent heat of sublimation or fusion
s	J/kgK	Specific entropy
s	m	Unit of length
t	s	Time
v	-	Reflux ratio
v	m^3/kg	Specific volume
w	m/s	Velocity
w*	-	Dimensionless velocity
x	-	Concentration, charge
x	-	Moisture content of air
x	m	Coordinate of length
y	m	Coordinate of length
y	s^{-1}	Respiration rate
z	-	Number of discs
z	m	Coordinate of length
z-Wert	K, °C	Increase in temperature necessary to obtain the same effect in 1/10 of the time
α	°	Angle
$\alpha = \frac{k}{c_p \rho}$	m^2/s	Thermal diffusivity
α^*	-	Content of ice
β	°	Angle
β_{Index}	K^{-1}	Expansion coefficient
γ	s^{-1}	Shear rate
γ_i	-	Activity coefficient
δ	m	Distance, thickness
Δ	-	Difference
ε	-	Porosity, volume fraction
ε	-	Emittance, performance coefficient
ε_A	-	Exchanger efficiency
ε_r''	-	Relative dielectric loss factor
ζ	-	Resistance coefficient
η	-	Degree of effectiveness
ϑ	°C	Temperature
θ	-	Dimensionless temperature, wetted angle (°)
κ	-	Constriction value
κ	S/m	Electric conductivity
$\kappa = c_p/c_V$	-	Proportion of specific heats
Λ	m	Mean free path

μ	Pa s	Dynamic, absolute viscosity
μ	s^{-1}	Specific rate of growth
μ	-	Diffusion resistance factor, friction coefficient
ν	s^{-1}	Specific productivity
ν	m^2/s	Kinematic viscosity
ξ_A	m^{-1}	Fouling resistance
ξ	m^{-2}	Specific flow resistance
ξ	-	Mol fraction
ξ_m	-	Mean salt content of cheese
ρ	kg/m^3	Density
σ	N/m	Surface tension, interfacial tension
σ	N/m^2	Tension of the material
σ	W/m^2K^4	Thermal radiation constant
Π	Pa	Osmotic pressure
τ	N/m^2	Shear stress
φ	-	Relative humidity
ϕ	-	Angular ratio
ϕ	-	Fraction of a volume
ω	s^{-1}	Angular velocity
$(\lambda c \rho)^{0.5}$	$Jm^{-2}K^{-1}s^{-0.5}$	Heat penetration factor

Dimensionless Numbers

Ar	=	$(d^3 \cdot g \cdot \Delta\rho) / (\rho \cdot \nu^2)$	Archimedes number
Bi	=	$(h \cdot X) / k_{solid}$	Biot number
Da	=	$v_{max}/(A \cdot h' \cdot S_b)$	Damköhler number
Fi	=	$(D \cdot t) / X^2$	Fick number
Fo	=	$(\alpha \cdot t) / d^2$	Fourier number
Fr	=	$w^2 / (g \cdot d)$	Froude number
Fr	=	$(n^2 \cdot d) / g$	Froude number
Ga	=	$(g \cdot d^3) / \nu^2 = Re^2 / Fr$	Galilei number
Gr	=	$(d^3 \cdot g \cdot \Delta\vartheta \cdot \beta_V) / \nu^2$	Grashof number
Kn	=	Δ / d	Knudsen number
La	=	$(\Delta p \cdot d) / \sigma$	Laplace number
Le	=	α / D	Lewis number
Ne	=	$P / (\rho \cdot n^3 \cdot d^5)$	Newton number
Nu	=	$(h \cdot d) / k_{fluid}$	Nusselt number
Pe	=	$(w \cdot d) / \alpha$	Péclet number
Pr	=	ν / α	Prandtl number
Ra	=	$(d^3 \cdot g \cdot \beta \cdot \Delta\vartheta) / (\nu \cdot \alpha) = Gr \cdot Pr$	Rayleigh number
Re	=	$(w \cdot d) / \nu$	Reynolds number
Sc	=	ν / D	Schmidt number
Sh	=	$(h' \cdot d) / D$	Sherwood number
St	=	$h / (w \cdot \rho \cdot c_p)$	Stanton number
Th	=	$\Delta p_2 / \Delta p_1$	Thoma number
We	=	$(w^2 \cdot d \cdot \rho) / \sigma$; $= \tau \cdot d / (4\ \sigma)$	Weber number
ϕ	=	$\frac{R}{3}\sqrt{\frac{v_{max}}{K_M \cdot D}}$	Thiele-Modul

Introduction

In the last decades the development of food manufacturing and especially of the dairy industry was characterised by concentration and formation of large food producing enterprises. This transition was accompanied with intensive research activities comprising the fields of chemistry, physics, biology, hygiene, and food technology. In parallel engineers designed machines, apparatus, processes with control and measuring equipment and new methods for the manufacture of foods.

For a long time there was a gap between the basic sciences focusing on the substrate and the engineering sciences considering especially the technique and physical basics of food processing. This gap was filled with the development of a more technological orientated basic science and a process focused evolution of engineering sciences.

The intention of the book is to join even more basic sciences and process engineering. To achieve such a goal it would be wrong to separately consider food-technological processes of some special products, since processes but even products change with time. Therefore, it is more useful to individually reflect more on unit operations than on the extensive and complex processes of food manufacturing. The knowledge of the laws of interactions of the specific fields shall finally result in new and better processes, new qualitatively improved foods and economic production. In addition this unit approach allows the analysis of the process steps separately for solving problems in practical operation.

Under this scope the book focuses on the basic principles and the unit operations and their impact on food. The increase of knowledge in the different fields of science has developed significantly in the past years, which required reducing the representation to only essential parts.

In the first two chapters some principles of fluid mechanics and of heat and mass transfer are summarised being essential for basic calculations in practical applications. Special hydro- and thermodynamic issues are handled in ensuing sections.

Separation technology is discussed in two different sections. The first one considers technologies using centrifugal forces as separator and its application but also cyclones for dust separation. The second one contemplates membrane separation and filtration used for protein recovery, separation of microorganisms, concentration of solutions, water purification, demineralisation, and decontamination. A further mechanical process follows with emulsion technology using homogenisation. In all chapters special focus was put on application for food and impact on the product.

Several chapters are devoted to thermal unit operations also including measures for energy saving. Heat treatment processes as pasteurisation and sterilisation and their impact on food are considered first. Emphasis is on reaction kinetics. The next chapter focuses on concentration by evaporation and vacuum evaporation including thermal and mechanical vapour compression. Special attention was put on drying; spray, roller, fluidised bed and freeze-drying are presented as well as product instanisation by agglomeration. In a further section the moisture sensitivity and sorption characteristics of dried food are discussed. A separate chapter contemplates enthalpy moisture diagram for air and air conditioning due to its importance in food technology for ripening, storage and drying. Gentle thermal preservation and concentration methods i.e. cooling, freezing and freeze concentration, are also presented extensively.

The new, additional added section on alternative methods of preservations shows and discusses possibilities and limits of the application of radiation treatment, ohmic and microwave heating as well as the ultra-high-pressure technology.

Packaging technology is one important processing step in food manufacturing and aseptic packaging and sterilisation of the packaging material are appropiately discussed.

The effect of single-unit operations on a total process is demonstrated in 4 chapters with the manufacturing of special dairy products such as cream, butter, cheese, whey, casein, lactose, fermented milk products and ice cream.

Whey serves as substrate for several biotechnological processes. This was the reason for establishing a chapter on bioprocess technologies, in which the basics of biotechnological processes are presented in

a general way using the example of various whey-processing methods. Reactors and applications are described beside the kinetics of bacterial growth and enzymes.

Holdings tanks, pumps, mixers and stirrers are important elements in a food processing plant and are concisely summed up in a separate chapter. The chapter on cleaning and disinfections was strongly extended including the description of product layers, formation kinetics and their control by process technical methods.

Hygiene and water quality is a prerequisite for food processing and is reflected in more detail. Special focus was devoted to water treatment and biological methods with their recent process engineering developments.

An extensive collection of physicochemical properties, conversion tables and calculation correlations concludes the book. With this content the book may not only serve as book for education and information but also used as handbook for direct application.

Engineers specialised in biotechnology, food technology and process engineering were involved in the development of all of them. And those are exactly the three majors you can decide between in the course of your studies. What is it about?Â The bachelorâ€™s degree programme Bio, Food and Process Technology is made up of seven semesters. They are divided into a basic part, a major, general skills modules and time for an internship and your bachelorâ€™s thesis. At the end of your studies you will be admitted as a Bachelor of Science (B.Sc.). At the beginning of your studies we will show you the industries you will be qualified for, youâ€™ll be able to gather first experience in the lab and get to know the contents and objectives of the degree programme in projects â€“ all this is part of the introductory module. Food Process Engineering focuses on the application of engineering principles to the design of postharvest and food processing equipment; changes that may occur within products during handling, processing, and storage; measuring and controlling the quality of raw food materials; food supply chain safety; the handling and utilization of wastes generated during on-farm processing.Â Industrial bioprocess technology for the conversion of raw agricultural products to useful food products, biomaterials with specific growth promoting properties are developed for application in organic farming. To strengthen applicability of microorganisms for specific purposes, courses are given in genetic engineering of microorganisms. Biotechnology and Bioprocess Engineering is an international bimonthly journal published by the Korean Society for Biotechnology and Bioengineering.Â EMBiology, Expanded Academic, Food Science and Technology Abstracts, Gale, Gale Academic OneFile, Industrial and Applied Microbiology Abstracts (Microbiology A), OCLC WorldCat Discovery Service, ProQuest ABI/INFORM, ProQuest Advanced Technologies & Aerospace Database, ProQuest Agricultural & Environmental Science Database, ProQuest Biological Science Database, ProQuest Biology Database, ProQuest Biotechnology Research Abstracts, ProQuest Business Premium Collection, ProQuest Central, ProQuest Health & Medical Collection, ProQuest Health Research Premium.