Innovations in Agricultural & Biological Engineering

Food Process Engineering

Emerging Trends in Research and Their Applications

Editors Murlidhar Meghwal
Megh R. Goyal

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FOOD PROCESS ENGINEERING

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Edited by

Murlidhar Meghwal, PhD

Megh R. Goyal, PhD, PE

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LIST OF ABBREVIATIONS

AA	ascorbic acid
AD	air drying
C16:1	palmitoleic acid
C18:0	stearic acid
C18:1	oleic acid
C18:2	linoleic acid
C18:3	linolenic acid
CHD	cardiac health disease
CVD	cardiovascular disease
DHA	docosahexaenoic acid
EPA	eicosapentaenoic acid
FAME	fatty acid methyl esters
FIR	far-infrared
GC-MS	gas chromatography mass spectrometry
GHz	Giga Hertz
H2SO4	sulphuric acid
HDPE	high-density PE
IR	infrared
LDL	low-density-lipoprotein
LDL-C	low density lipoprotein cholesterol
LDPE	low-density PE
LLDPE	linear low-density PE
LPSSD	low-pressure superheated steam drying
M	molar concentration (mol L–1)
MeOH	methanol
MFD	microwave-finish drying
MHz	Mega Hertz
mm	millimeter
MRPs	Maillard reaction products
MW	molecular weight
MWSB	microwave and spouted bed

NaCl	sodium chloride
NaOH	sodium hydroxide
PID	proportional-integral-derivative controller
ppm	parts per million
PUS	power ultrasound
RH	relative humidity
RW	refractance window
STP	standard temperature and pressure
TD	tray drying
TPs	total phenolic
US	ultrasonication
VLDPE	very low density PE
VMD	vacuum microwave drying
μm	micrometer

LIST OF SYMBOLS

A_c	collector surface area, m^2
A_e	area of edges, m^2
C_p	specific heat of air, kJ/kg K
d	distance between electrodes
d_0	penetration depth, m
E	voltage
f	frequency of electromagnetic field
F'	collector efficiency factor
F_R	collector heat removal factor
$h_{c,\ p-g}$	convective heat transfer coefficient from absorber to glass cover, W/m^2 K
$h_{r',p-amb}$	radiative heat transfer coefficient from absorber to ambient, W/m^2 K
$h_{r',p-g}$	radiative heat transfer coefficient from absorber to glass cover, W/m^2 K
h_w	wind heat transfer coefficient, W/m^2 K
I	incident solar radiation, W/m^2
K_{in}	thermal conductivity of insulation, W/m K
L_{in}	insulation thickness, m
m	mass flow rate of air, kg/s
MT	million ton
P	power
Q_u	useful energy gain of collector, W/m^2
T_{amb}	temperature of ambient air, °C
tan δ	loss tangent
T_{in}	temperature of inlet air, °C

T_{out}	temperature of outlet air, °C
U_b	bottom heat loss coefficient, $W/m^2\ K$
U_e	edge heat loss coefficient, $W/m^2\ K$
U_L	overall heat loss coefficient, $W/m^2\ K$
U_t	top heat loss coefficient, $W/m^2\ K$
ε'	dielectric constant of the material
ε''	dielectric loss
η	efficiency of collector, %
λ_0	wavelength, m
σ	Stefan–Boltzmann constant, $W/m^2\ K^4$
τ	transmissivity

PREFACE 1
By Murlidhar Meghwal

Food processing engineering is very important because everybody has to eat to survive. This sector consists of a wide range of activities. Some of its specific activities are research and development of new foods; development of new food-related pharmaceutical products; design and installation of food processes; development and operation of food manufacturing, packaging and distributing systems for food products; and marketing and technical support for food manufacturing plants. It is the responsibility of food engineers and food scientists to provide the food technological knowledge required to have food products and services be cost-effective in production and commercialization. They are employed in food processing, food machinery, food packaging, ingredient food manufacturing, instrumentation, and control for food.

Food Process Engineering: Emerging Trends in Research and Their Applications provides a global perspective of the present-age frontiers in food process engineering research, innovation, and emerging trends. It includes selected recent emerging trends and issues of food engineering. The book volume explores topics of food engineering, food technology, food science and food process engineering, that can help to provide solutions for the different issues, problems and complexity related to food crises all over globe. with the help of limited resources and technology.

Part I: Emerging Trends and Technologies in Food Processing includes trends in food packaging technology; emerging technology-based drying for food and feed products; application of emerging technologies for freezing and thawing of foods; principles of novel freezing and thawing technologies for foods application; and overview of applications of dryers for foods including: industrial, solar, novel, and infrared methods.

Part II: Ultrasonic Treatment of Foods include chapters on ultrasonic-assisted derivatization of fatty acids from edible oils and determination by GC-MS and principles of ultrasonic technology for treatment of milk and milk products. *Part III: Foods for Specific Needs* covers new research on natural food colors: a technical insight; potential use of pseudo cereals:

buckwheat, quinoa and amaranth; and nutraceutical and functional foods for cardiovascular health. *Part VI: Food Preservation* includes natural antioxidants during frying: food industry perspective. *Part V: Food Hazards and Their Controls* includes chapters on the Hazard Analyses Critical Control Point Program and antibiotics in food producing animals and resistance hazards.

The targeted audience for this book includes practicing food process engineers, food technologists, researchers, lecturers, teachers, professors, food industry professionals, students of these fields and all those who have inclination for food processing sector. The book not only covers the practical aspect but also provides a lot of basic information. It is also instructive. Therefore students in undergraduate, graduate courses, and postgraduate and post-doctoral researchers will also find it informative. In order for the book to be useful to engineers, coverage of each topic is comprehensive enough to serve as an overview of the most recent and relevant research and technology. Numerous references are included at the end of each chapter.

The editors wish to acknowledge all individuals who have contributed to this book.

—Murlidhar Meghwal, PhD
December 2015

PREFACE 2
By Megh R. Goyal

The discovery of a new dish (processed food) does more for the happiness of the human race than the discovery of a star.
—Anthelme Brillat Savarin

https://en.wikipedia.org/wiki/Food_processing indicates: "*Food processing is the transformation of raw ingredients, by physical or chemical means into food, or of food into other forms. Food processing combines raw food ingredients to produce marketable food products that can be easily prepared and served by the consumer. Food processing typically involves activities such as mincing and macerating, liquefaction, emulsification, and cooking (such as boiling, broiling, frying, or grilling); pickling, pasteurization, and many other kinds of preservation; and canning or other packaging. Primary processing such as dicing or slicing, freezing or drying when leading to secondary products are also included.*"

When designing processes for the food industry, the following performance parameters may be taken into account: Hygiene, energy efficiency, minimization of waste, labor used, minimization of cleaning stops measured, and reduction of fat content in final product.

Prehistoric people knew such food-processing technology as sun-drying, preserving with salt, and various types of cooking (such as roasting, smoking, steaming, and oven baking) for using processed foods in his daily life. Evidence for the existence of these methods can be found in the writings of the ancient Greek, Chaldean, Egyptian and Roman civilizations as well as archaeological evidence from Europe, North and South America, and Asia. These tried and tested processing techniques remained essentially the same until the advent of the industrial revolution. Examples of ready-meals also date back to before the preindustrial revolution. Modern food processing technology was developed in large part to serve military needs. Although initially expensive and somewhat hazardous due to the lead used in cans, canned goods would later become a staple around the world. Pasteurization improved the quality of preserved foods and also introduced wine, beer, and milk preservation. In the 20th century, World War II, the space race, and the rising consumer society contributed to the growth of food processing with such advances as spray drying, juice concentrates, freeze drying, and the introduction of artificial sweeteners, coloring agents, and such preservatives as sodium benzoate. In the late 20th century, products such as dried instant soups, reconstituted fruits and juices, and self-cooking meals such as MRE food rations were developed. Processors utilized the perceived value of time to appeal to the postwar population, and this same appeal contributes to the success of convenience foods today.

Benefits of food processing include toxin removal; preservation; easing of marketing and distribution tasks; food consistency; yearly availability of many foods; enabling transportation of delicate perishable foods across long distances from the source to the consumer; reducing the incidence of foodborne disease; allowing more free time and improving the quality of life for people with allergies, diabetics, and other people who cannot consume some common food elements. Food processing can also add extra nutrients such as vitamins.

Any processing of food can affect its nutritional density. The amount of nutrients lost depends on the food and processing method. For example the heat destroys vitamin C. Therefore, canned fruits possess less vitamin C than their fresh alternatives. The USDA study in 2004 indicates that in the majority of foods, processing reduces nutrients by a minimal amount. On average this process reduces any given nutrient by as little as 5–20%. Abundant food processing (not fermentation of foods) endangers that environment. Using food additives (e.g., sweeteners, preservatives, and stabilizers) may represent another safety concern. Certain additives can also result in an addiction to a particular food item. The mixing, grinding, chopping and emulsifying equipment in the production process may introduce a number of contamination risks.

Who does not know how to cook food, boil milk or prepare omelet? I learned food-processing skills when I was in the seventh grade. I knew how to dry red chillies in the open sun, prepare mango pickles, cook rice, and prepare evaporated milk with sugar. When we got married in February of 1970, my wife knew almost zero processing and cooking Indian foods. I taught her the culinary skills. Now she does not let me enter into the kitchen. At the first Mango Festival at the Agricultural Experiment Station – University of Puerto Rico in Jana Diaz, I prepared my own recipes (mango shake/ice cream/yogurt/chutney/pickles/cookies/jam or jelly, etc.) for sale at the festival. Many of my recipes were promoted in the local newspapers. My three grandchildren enjoy *Indian Potato-Filled Cooked Bread (Parantha).* What I want to emphasize that each one you has processed food for personal use at least once in your life.

At the 49th annual meeting of the Indian Society of Agricultural Engineers at Punjab Agricultural University (PAU) during February 22–25 of 2015, a group of ABEs and FEs convinced me that there is a dire need to publish book volumes on focus areas of agricultural and biological engineering (ABE). This is how the idea was born for new book series titled "Innovations in Agricultural and Biological Engineering." This book, *Food Process Engineering: Emerging Trends in Research and Their Applications*, is the fifth volume under this book series, and it contributes to the ocean of knowledge on food engineering.

The contributions by all cooperating authors to this book volume have been most valuable in the compilation. Their names are mentioned in each chapter and in the list of contributors. I appreciate the authors for having patience with my editorial skills. This book would not have been written without the valuable cooperation of these investigators, many of whom are renowned scientists who have worked in the field of food engineering throughout their professional careers.

I am glad to introduce Dr. Murlidhar Meghwal, who is an Assistant Professor in the Food Technology, Center for Emerging Technologies at Jain University – Jain Global Campus in District Karnataka, India. With several awards and recognitions, including from the President of India, Dr. Meghwal brings his expertise and innovative ideas to this book series. Without his support, and leadership qualities as editor of the book volume and his extraordinary work on food engineering applications, readers will not have this quality publication.

I will like to thank editorial staff, Sandy Jones Sickels, Vice President, and Ashish Kumar, Publisher and President at Apple Academic Press, Inc., for making every effort to publish the book when the diminishing water and food resources are a major issue worldwide. Special thanks are due to the AAP Production Staff for the quality production of this book.

I request that the reader offer your constructive suggestions that may help to improve the next edition.

I express my deep admiration to my family and colleagues for their understanding and collaboration during the preparation of this book volume. Can anyone live without food or water? Who has escaped from processed food today? As an educator, there is a piece of advice to one and all in the world: "*Permit that our almighty God, our Creator, provider of all and excellent teacher, feed our life with Healthy Food Products and His Grace—and Get married to your profession.*"

—Megh R. Goyal, PhD, PE
Senior Editor-in-Chief
December 31, 2015

WARNING/DISCLAIMER

READ CAREFULLY

The goal of this book volume on *Food Process Engineering: Emerging Trends in Research and Their Applications* is to guide the world community on how to manage efficiently the technology available for different processes in food engineering. The reader must be aware that the dedication, commitment, honesty, and sincerity are most important factors in a dynamic manner for complete success. It is not a one-time reading of this compendium. Read and follow every time, it is needed.

The editors, the contributing authors, the publisher and the printer have made every effort to make this book as complete and as accurate as possible. However, there still may be grammatical errors or mistakes in the content or typography. Therefore, the contents in this book should be considered as a general guide and not a complete solution to address any specific situation in food engineering. For example, one type of food process technology does not fit all case studies in dairy engineering/science/technology.

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Currently, Dr. Meghwal is working on developing inexpensive, disposable and biodegradable food containers using agricultural wastes; quality improvement, quality attribute optimization and storage study of kokum (*Garcinia indica Choisy*); and freeze drying of milk. At present, he is actively involved in research and is the course coordinator for MTech (Food Technology) courses. He is also teaching at the Food Science and Technology Division, Jain University Bangalore, India. He has written two books and many research publications on food process engineering. He has attended many national and international seminars and conferences. He is reviewer and member of editorial boards of reputed journals.

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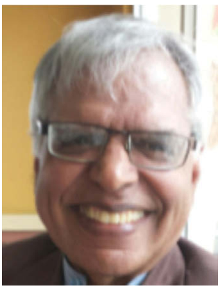

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He was first agricultural engineer to receive the professional license in Agricultural Engineering in 1986 from College of Engineers and Surveyors of Puerto Rico. On September 16, 2005, he was proclaimed as “Father of Irrigation Engineering in Puerto Rico for the twentieth century” by the ASABE, Puerto Rico Section, for his pioneer work on micro irrigation, evapotranspiration, agroclimatology, and soil and water engineering. During his professional career of 45 years, he has received awards such as: Scientist of the Year, Blue Ribbon Extension Award, Research Paper Award, Nolan Mitchell Young Extension Worker Award, Agricultural Engineer of the Year, Citations by Mayors of Juana Diaz and Ponce, Membership Grand

Prize for ASAE Campaign, Felix Castro Rodriguez Academic Excellence, RashtryaRatan Award and Bharat Excellence Award and Gold Medal, Domingo Marrero Navarro Prize, Adopted son of Moca, Irrigation Protagonist of UPRM, Man of Drip Irrigation by Mayor of Municipalities of Mayaguez/Caguas/Ponce and Senate/Secretary of Agriculture of ELA, Puerto Rico.

He has authored more than 200 journal articles and textbooks on: "Elements of Agroclimatology (Spanish) by UNISARC, Colombia"; two bibliographies on "Drip Irrigation." Apple Academic Press Inc. (AAP) has published his books, namely: "Management of Drip/Trickle or Micro Irrigation," and "Evapotranspiration: Principles and Applications for Water Management."

During 2014–2015, AAP has published his ten-volume set in "*Research Advances in Sustainable Micro Irrigation.*" During 2016–2017, AAP will be publishing book volumes on emerging technologies/issues/challenges under book series, "*Innovations and Challenges in Micro Irrigation*," and "*Innovations in Agricultural and Biological Engineering*." Readers may contact him at: goyalmegh@gmail.com.

BOOK ENDORSEMENTS

Here is a well-written book on recent advances in food process engineering that will be useful for food process engineering professionals, industrialists, undergraduate and postgraduate students.

—Deepak Kumar Garg, PhD
Postdoctoral Research Associate
ADM Institute for the Prevention of Postharvest Loss
University of Illinois at Urbana–Champaign, USA

My heartiest congratulations to Professors Murlidhar Meghwal and Megh R. Goyal for carrying out this book, which covers most of the topics relevant to food process engineering. This will be a great help for all the academicians and non-academicians interested in food systems.

—Abhinav Mishra, PhD
Research Scholar, Department of Nutrition and Food Science and
Center for Food Safety and Security Systems
University of Maryland, College Park, Maryland, USA

Food Process Engineering: Emerging Trends in Research and Their Applications is a well-arranged and well-written book on recent advances in food process engineering, food technology and food technology related topics. This book will be very useful for the fraternity of educators.

—Tridib Kumar Goswami, PhD
Professor, Agricultural and Food engineering Department
Indian Institute of Technology, Kharagpur, West Bengal, India

This book provides a comprehensive coverage of the various aspects of food engineering. Topics including emerging trends and technologies in food processing, ultrasonic treatment of foods, foods for specific needs, food preservation, food hazards and their controls and health-related aspects will be very useful to students and professionals in food process engineering. Increasing awareness on food processing and preservation and the growing processed food markets make this book an excellent source for reference in these areas.

—Narendra Reddy, PhD
Professor and Ramalingaswami Fellow
Centre for Emerging Technologies, Jain University
Jain Global Campus, Jakkasandra Post, Bangalore

The topics in the book have been wisely selected. They cover not only the entire aspect of food engineering and processing, but also the health benefits. This book would be useful to the students, researchers and professionals in the field of food process engineering.

—Soumitra Banerjee, PhD
Professor, Food Technology
Centre for Emerging Technologies, Jain University
Jakkasandra, Ramanagara, Karnataka

The book (*Food Engineering Emerging Issues, Modeling, and Applications*, Editors: Murlidhar Meghwal, PhD, Megh R. Goyal, PhD) is nicely written and surely will be very useful for researchers, industry people and students.

—Kacoli Banerjee, PhD
Assistant Professor, Department of Zoology
Maharaja Sayajirao University of Baroda, Baroda, India

This book is a nice piece of work on food process engineering for professionals, industrialists, and others.

—Winny Routray, PhD
Assistant Professor, Marine Bioprocessing Facility
Centre of Aquaculture and Seafood Development
Marine Institute of Memorial University of New Foundland
St. John's, Newfoundland, Canada

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- Technological Interventions in Management of Irrigated Agriculture

EDITORIAL

Apple Academic Press Inc., (AAP) will be publishing various book volumes on the focus areas under book series titled *Innovations in Agricultural and Biological Engineering*. Over a span of 8 to 10 years, Apple Academic Press Inc., will publish subsequent volumes in the specialty areas defined by American Society of Agricultural and Biological Engineers (http://asabe.org).

The mission of this series is to provide knowledge and techniques for agricultural and biological engineers (ABEs). The series aims to offer high-quality reference and academic content in Agricultural and Biological Engineering (ABE) that is accessible to academicians, researchers, scientists, university faculty, and university-level students and professionals around the world. The following material has been edited/ modified and reproduced below [From: "*Goyal, Megh R., 2006. Agricultural and biomedical engineering: Scope and opportunities. Paper Edu_47 Presentation at the Fourth LACCEI International Latin American and Caribbean Conference for Engineering and Technology (LACCEI' 2006): Breaking Frontiers and Barriers in Engineering: Education and Research by LACCEI University of Puerto Rico – Mayaguez Campus, Mayaguez, Puerto Rico, June 21–23*"]:

WHAT IS AGRICULTURAL AND BIOLOGICAL ENGINEERING (ABE)?

"*Agricultural Engineering (AE) involves application of engineering to production, processing, preservation and handling of food, fiber, and shelter. It also includes transfer of technology for the development and welfare of rural communities*," according to http://isae.in. "*ABE is the discipline of engineering that applies engineering principles and the fundamental concepts of biology to agricultural and biological systems and tools, for the safe, efficient and environmentally sensitive production, processing, and management of agricultural, biological, food, and natural resources* *systems*," according to http://asabe.org. "*AE is the branch of engineering involved with the design of farm machinery, with soil management, land development, and mechanization and automation of livestock farming, and with the efficient planting, harvesting, storage, and processing of farm commodities*," the definition by http://dictionary.reference.com/browse/agricultural+engineering.

"AE incorporates many science disciplines and technology practices to the efficient production and processing of food, feed, fiber and fuels. It involves disciplines like mechanical engineering (agricultural machinery and automated machine systems), soil science (crop nutrient and fertilization, etc.), environmental sciences (drainage and irrigation), plant biology (seeding and plant growth management), animal science (farm animals and housing) etc.," as indicated by http://www.ABE.ncsu.edu/academic/agricultural-engineering.php.

According to https://en.wikipedia.org/wiki/Biological_engineering: "*BE* (*Biological engineering) is a science-based discipline that applies concepts and methods of biology to solve real-world problems related to the life sciences or the application thereof. In this context, while traditional engineering applies physical and mathematical sciences to analyze, design and manufacture inanimate tools, structures and processes, biological engineering uses biology to study and advance applications of living systems*."

SPECIALTY AREAS OF ABE

Agricultural and Biological Engineers (ABEs) ensure that the world has the necessities of life including safe and plentiful food, clean air and water, renewable fuel and energy, safe working conditions, and a healthy environment by employing knowledge and expertise of sciences, both pure and applied, and engineering principles. Biological engineering applies engineering practices to problems and opportunities presented by living things and the natural environment in agriculture. BA engineers understand the interrelationships between technology and living systems, have available a wide variety of employment options. The http://asabe.org indicates that "*ABE embraces a variety of following specialty areas*." As new technology and information emerge, specialty areas are created, and many overlap with one or more other areas.

1. **Aqua Cultural Engineering**: ABEs help design farm systems for raising fish and shellfish, as well as ornamental and bait fish. They specialize in water quality, biotechnology, machinery, natural resources, feeding and ventilation systems, and sanitation. They seek ways to reduce pollution from aqua cultural discharges, to reduce excess water use, and to improve farm systems. They also work with aquatic animal harvesting, sorting, and processing.
2. **Biological Engineering** applies engineering practices to problems and opportunities presented by living things and the natural environment.
3. **Energy:** ABEs identify and develop viable energy sources—biomass, methane, and vegetable oil, to name a few—and to make these and other systems cleaner and more efficient. These specialists also develop energy conservation strategies to reduce costs and protect the environment, and they design traditional and alternative energy systems to meet the needs of agricultural operations.
4. **Farm Machinery and Power Engineering**: ABEs in this specialty focus on designing advanced equipment, making it more efficient and less demanding of our natural resources. They develop equipment for food processing, highly precise crop spraying, agricultural commodity and waste transport, and turf and landscape maintenance, as well as equipment for such specialized tasks as removing seaweed from beaches. This is in addition to the tractors, tillage equipment, irrigation equipment, and harvest equipment that have done so much to reduce the drudgery of farming.
5. **Food and Process Engineering:** Food and process engineers combine design expertise with manufacturing methods to develop economical and responsible processing solutions for industry. Also food and process engineers look for ways to reduce waste by devising alternatives for treatment, disposal and utilization.
6. **Forest Engineering**: ABEs apply engineering to solve natural resource and environment problems in forest production systems and related manufacturing industries. Engineering skills and expertise are needed to address problems related to equipment design and manufacturing, forest access systems design and construction; machine-soil interaction and erosion control; forest operations

analysis and improvement; decision modeling; and wood product design and manufacturing.

7. **Information and Electrical Technologies Engineering** is one of the most versatile areas of the ABE specialty areas, because it is applied to virtually all the others, from machinery design to soil testing to food quality and safety control. Geographic information systems, global positioning systems, machine instrumentation and controls, electromagnetics, bioinformatics, biorobotics, machine vision, sensors, spectroscopy: These are some of the exciting information and electrical technologies being used today and being developed for the future.
8. **Natural Resources:** ABEs with environmental expertise work to better understand the complex mechanics of these resources, so that they can be used efficiently and without degradation. ABEs determine crop water requirements and design irrigation systems. They are experts in agricultural hydrology principles, such as controlling drainage, and they implement ways to control soil erosion and study the environmental effects of sediment on stream quality. Natural resources engineers design, build, operate and maintain water control structures for reservoirs, floodways and channels. They also work on water treatment systems, wetlands protection, and other water issues.
9. **Nursery and Greenhouse Engineering**: In many ways, nursery and greenhouse operations are microcosms of large-scale production agriculture, with many similar needs—irrigation, mechanization, disease and pest control, and nutrient application. However, other engineering needs also present themselves in nursery and greenhouse operations: equipment for transplantation; control systems for temperature, humidity, and ventilation; and plant biology issues, such as hydroponics, tissue culture, and seedling propagation methods. And sometimes the challenges are extraterrestrial: ABEs at NASA are designing greenhouse systems to support a manned expedition to Mars!
10. **Safety and Health:** ABEs analyze health and injury data, the use and possible misuse of machines, and equipment compliance with standards and regulation. They constantly look for ways in which the safety of equipment, materials and agricultural practices can be improved and for ways in which safety and health issues can be communicated to the public.

11. **Structures and Environment:** ABEs with expertise in structures and environment design animal housing, storage structures, and greenhouses, with ventilation systems, temperature and humidity controls, and structural strength appropriate for their climate and purpose. They also devise better practices and systems for storing, recovering, reusing, and transporting waste products.

CAREER IN AGRICULTURAL AND BIOLOGICAL ENGINEERING

One will find that university ABE programs have many names, such as biological systems engineering, bioresources engineering, environmental engineering, forest engineering, or food and process engineering. Whatever the title, the typical curriculum begins with courses in writing, social sciences, and economics, along with mathematics (calculus and statistics), chemistry, physics, and biology. Student gains a fundamental knowledge of the life sciences and how biological systems interact with their environment. One also takes engineering courses, such as thermodynamics, mechanics, instrumentation and controls, electronics and electrical circuits, and engineering design. Then student adds courses related to particular interests, perhaps including mechanization, soil and water resource management, food and process engineering, industrial microbiology, biological engineering or pest management. As seniors, engineering students work in a team to design, build, and test new processes or products.

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PART I

EMERGING TRENDS AND TECHNOLOGIES IN FOOD PROCESSING

CHAPTER 1

TRENDS IN FOOD PACKAGING TECHNOLOGY

CHANDANI SEN[1] and MADHUSWETA DAS[2]

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CONTENTS

1.1 INTRODUCTION

Packaging is one of the most important processes to maintain the quality of food products for storage, transportation and consumption. It prevents quality deterioration and facilitates distribution and marketing. The basic

TABLE 1.1 Trends in the Evaluation of Food Packaging

Period	Functions and issues		References
1960	Convenience	Efficiency of packaging material	[12, 28, 37]
1970	Light weight,		
1980	source reduction, energy saving Tamper evidence		
1990 onwards	In addition to efficiency of packaging material its environmental impact also came into picture.		

functions of packaging are protection, containment, information and convenience. Apart from preservation, packaging also has secondary functions- such as selling and sales promotion, which contributes significantly to a business profit [12].

Food industry uses a lot of packaging materials, and thus even a small reduction in the amount of material used for each package would result in a significant cost reduction, and may improve solid waste problems. Packaging technology has attempted to reduce the volume and/or weight of materials in efforts to minimize resources and costs. Trends of food packaging can be summarized as presented in Table 1.1.

The food-packaging sector has a huge marketing potential. Food and beverage packaging comprises about 65–70% of the global food packaging sales [5] which has been projected to rise by 3% in real terms to $797 billion (approx. Rs. 500,211 million) in 2013 [2] and are expected to grow at an annual rate of 4% to 2018 [2] fetching about $284 billion (approx. = 170,892 million Rs.), of which drinks packaging shares around 50% [5].

This chapter summarizes the brief history of food packaging, basic mechanisms of mass transfer followed by the innovative packaging trends like, modified atmosphere packaging (MAP), active packaging (AP) intelligent packaging (IP) and biodegradable packaging (BDP).

1.2 BRIEF HISTORY OF FOOD PACKAGING

It took over 150 years for food packaging to undergo several steps and finally evolve into the current form. A brief review of the most popular packaging developments is described in this chapter.

1.2.1 PAPER

Paper (derived from Greek word *papyrus*), invented in ancient China during 206 BC to 220 AD, is the oldest form of "flexible packaging" [3]. During the next fifteen hundred years, the papermaking technique was refined and transported to the Middle East, Europe and USA. Paperboard was first used to manufacture folding cartons in the early 1800s [27]. Corrugated boxes that today are widely used as a shipping container to hold a number of smaller packages were developed in the 1850s [27].

1.2.2 PLASTICS

Plastics including cellulose nitrate, styrene, and vinyl chloride were discovered in the 1800s. Polyethylene was one of the first plastics used widely for food packaging. There are several types of polyethylene in use today including low-density (LDPE), high-density (HDPE), linear low-density (LLDPE), and very low density (VLDPE). LDPE was the first to be developed by Imperial Chemical Industries in 1933 by compressing ethylene gas and heating it to a high temperature [19].

Isotactic polypropylene was discovered by Professor Giulio Natta in 1954 [13]. The film is often oriented after the casting or forming process by first stretching the material in the machine direction and then stretching it in the crosswise direction to give oriented polypropylene (OPP). This stretching aligns the molecules, making a film with a better moisture vapor barrier, better clarity, and more stiffness.

One process that is used to improve barriers even further is metallization. In this process, an aluminum wire is heated to 1700°C in a large vacuum chamber [13]. This vaporizes the aluminum, which deposits on the surface of the film as it is run through the chamber. In the case of a 50 gauge polyester film, metallizing improves the *moisture vapor transmission rate* (MVTR) from 2.0 g/(100 in.^{2}; 24 h. 90% RH) to 0.05, i.e., a 40-fold improvement [13]. Oriented polypropylene and polyethylene terephthalate (PET) are the most common films used for metallization followed by nylon, polyethylene and cast polypropylene [24].

One process that has improved overall properties of plastic films is co extrusion, developed in 1964 by Hercules [27]. In this process, a film with two or more layers of different types of plastic can be made in one step, without any adhesive and eliminating the use of solvents. Multiple-layer films offer better protection for products as some films are better moisture barriers and others offer better barriers to gases. One example is polyester film, which provides a better gas barrier, whereas polypropylene and *ethylene vinyl alcohol* (EvOH) films are better moisture barriers. These three can be combined readily in one structure to give protection from both moisture and oxygen permeation [27].

In addition to broad developments in materials, there have been a number of specific packages that have both created new food categories and changed the way to deliver a product to the consumer. Polyethylene naphthalene (PEN) (approved for food contact by FDA), polyethylene terephthalate (PET) and aluminum cans, which currently have a huge market potential for carbonated beverages-are among some of the most popular categories.

1.3 MASS TRANSFER THROUGH PACKAGING MATERIALS

In all flexible packaging, permeability plays a significant role. For food powder packaging, water vapor permeability of the film should be less to maintain free flow character, essential for long shelf life. For aromatic components like tea leaves or spices, the packaging material should have proper aroma barrier property for better aroma retention. In case of MAP of fresh fruits and vegetables, where the principle is to extend the shelf life by controlling reaction rate, the oxygen/carbon di oxide gas permeability of the film is the decisive factor. So, permeability is one of the major properties of packaging films on which its application is dependent. To know what permeability is, basic knowledge of mass transfer is necessary.

Under steady state condition, gas will diffuse through film at a constant rate if a constant pressure difference is maintained across the barrier (Figure 1.1). The diffusive flux, J, of a permeant can be defined as the amount passing through a plane (surface) of unit area normal to the direction of flow in unit time:

$$J = Q/At \tag{1}$$

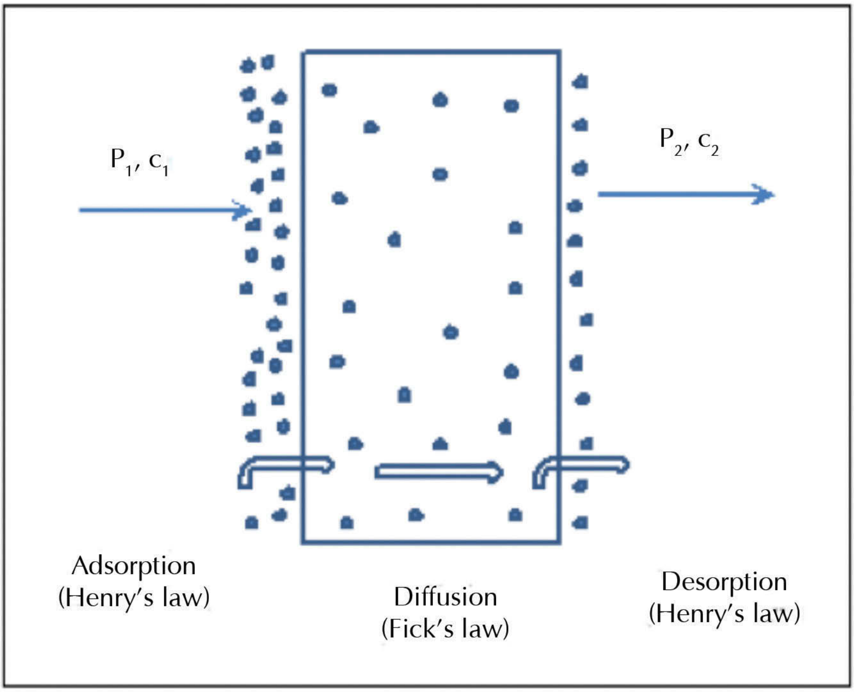

FIGURE 1.1 Basic mechanism of gas and vapor permeation through a packaging film.

where, Q is the total amount of permeant, which has passed through area A in time t.

The rate of permeation and the concentration gradient is directly proportional to each other and embodied in Fick's first law:

$$J = -D\frac{\partial c}{\partial x} \quad (2)$$

where, J is the flux per unit area of permeant through the polymer film, kg mol/m^2; D is the diffusion coefficient, m^2/h; c is the concentration of the permeant, kg mol/m^3; $\delta c/\delta x$ is the concentration gradient of the permeant across a thickness δX, m.

In steady state condition, when J = constant, integrating Eq. (2), we get:

$$JX = D\,(c_1 - c_2) \quad (3)$$

Substituting for J using Eq. (1), the quantity of permeant diffusing through a film of area A in time t can be calculated:

$$Q = \frac{D.(c_1 - c_2).A.t}{X} \tag{4}$$

When the permeant is a gas, it is more convenient to measure the vapor pressure p rather than the actual concentration. Henry's law applies at low concentrations and c can be expressed as:

$$C = Sp \tag{5}$$

where, S is the solubility coefficient of the permeant in the polymer (it reflects the amount of permeant in the polymer).

Combining Eqs. (4) and (5),

$$Q = \frac{D.S.(p_1 - p_2).A.t}{X} \tag{6}$$

The product of D and S is referred to as the permeability, and is represented by the symbol P. Thus,

$$P = \frac{Q.X}{A.t.(p_1 - p_2)} \tag{7}$$

Hence, permeability (P) is the proportionality constant between the flow of the penetrant gas per unit film area per unit time and the driving force (partial pressure difference) per unit film thickness. The amount of gas penetrating through the film is expressed in terms of either moles per unit time (flux) or weight or volume of the gas at STP. Commonly, it is expressed in terms of volume.

1.3.1 TEMPERATURE QUOTIENT FOR PERMEABILITY

The influence of temperature on permeability of polymeric films was quantified with the value, which is the permeability increase for a 10°C rise in temperature and is given by the following equation:

$$Q_{10}^{P} = \left(\frac{P2}{P1}\right)^{10/(T2-T1)} \tag{8}$$

where, Q_{10}^{P} , the temperature quotient for permeability, and P_1 and P_2 are the permeabilities at temperatures T_1 and T_2, respectively (Table 1.2).

TABLE 1.2 Gas and Water Vapor Permeability of Different Commercial Packaging Materials [20, 28]

Material	**P x 10^{11} [ml(STP)cm cm^{-2} s^{-1} (cm Hg)$^{-1}$]**			
Polymer	O_2	CO_2	N_2	H_2O at 90% RH
Low density polyethylene	30–69	130–280	1.9–3.1	800
High density polyethylene	6–11	45	3.3	180
Polypropylene	9–15	92	4.4	680
Polyethylene Terephthalate	0.3–0.75	1.6–3.0	0.04–0.06	1300
Polystyrene	15–27	105	7.8	12,000–18,000

1.4 INNOVATIVE FOOD PACKAGING

Traditional food packages are passive barriers designed to delay the adverse effects of the environment on the food product. Advance technologies, like modified atmosphere packaging, active packaging, intelligent packaging, and biodegradable packaging, however, are needed to allow packages to take care of the food and environment as well [6, 18].

1.4.1 MODIFIED ATMOSPHERE PACKAGING (MAP)

Modified Atmosphere Packaging (MAP), usually used for fresh produces, is a package in which the atmosphere inside the package is modified or altered to provide an optimum atmosphere for increasing shelf life. Modification of the atmosphere may be achieved either actively or passively. Active modification involves displacing the air with a controlled, desired mixture of gases, and is generally referred to as gas flushing. Passive modification occurs as a consequence of the respiration/metabolism of the enclosed commodity, which changes the gaseous concentrations inside the package.

The normal composition of air by volume is 78.08% nitrogen, 20.95% oxygen, 0.93% argon, 0.03% carbon dioxide, and traces of other nine gases. The three main gases used in active MAP are O_2, CO_2 and N_2, either