FOOD ENGINEERING

G.V. Barbosa-Cánovas and P. Juliano
Department of Biological Systems Engineering, Washington State University, USA

Keywords: Automation, canning, chemical kinetics, drying, education, engineering, extrusion, nonthermal processing, flow diagram, food, food engineering, food materials science, fermentation, pasteurization, preservation, food processing, food safety, food waste, freezing, hurdle, heat transfer, mass transfer, ingredients, manufacturing, microstructure, models, optical properties, packaging, plant design, physical properties, profession, quality, raw material, rheology, sanitation, simulation, spoilage, sterilization, technology, texture, thermal property, thermodynamics, unit operations.

Contents

Summary

Food engineering, which became an academic discipline in the 1950s, is a professional and scientific multidisciplinary field related to food manufacturing that covers the

practical applications of food science. The purpose of this evolving field is to advance the implementation of efficient industrial processing in the transformation of raw materials of biological origin into edible forms, which includes packaging, storage, and distribution. Food engineers are employed in academia by government and industry and as private consultants to assess the problems concerning food production, food quality, process and plant design, and food regulation. They conduct research and develop unit operations such as sterilization, irradiation, concentration, extrusion, and freezing. Ancient activities like milling, dehydration, and fermentation have been transformed through the increasing demand of food supply systems into automatic installments.

Food engineering includes the study of engineering properties, for example, compositional properties like boiling or freezing point; physical characteristics such as size, shape, volume, surface area, density, and porosity; mechanical properties such as compressive strength, impact, and shear; sensory properties such as texture and color; and thermophysical properties such as specific volume, specific heat, thermal conductivity, and viscosity. Today's food engineering research leaders tend to be experts in materials science (e.g., rheology, mass transfer properties, and thermal and electrical food properties), applied mathematics and modeling, and biochemical engineering applied to foods. Food engineers of the future will advance the development of computational techniques as tools for process automation, control, design, and improvement. Novel technologies like the application of high hydrostatic pressure, pulsed electric fields, light pulses, oscillating magnetic fields, and ultrasound have the potential to impact nonthermal processing preservation. Food Engineers will lead in implementing such processes in the actual design of industrial facilities, in combination with hurdles, which will help maintain the nutritional and sensory aspects of safer natural food products.

1. Introduction

Supplying food to an ever-increasing population is one of the largest and oldest business activities in the world; it involves planting and harvesting, transportation and handling, storage, processing and preservation, packaging, distribution, and marketing. Over the years, typically small family-type businesses have been converted into huge, increasingly sophisticated, integrated food supply systems. This transformation has been dictated by increasing concentrations of people in urban areas, where large segments of the population depend on vast amounts of pretreated, preprocessed, or ready-to-eat, safe foodstuffs. The development of efficient mass production and transportation of food supplies is becoming more and more necessary. The food industry has grown from such demands, requiring the support of diversified, well-rounded teams of scientists, engineers, economists, and marketing specialists.

Food Engineering is a relatively new profession and a scientific field involved with food manufacturing and the processing of refined foods. It encompasses the practical application of food science to develop efficient industrial production, packaging, storage, and physical distribution of nutritious and convenient foods that are uniform in quality and safe. The most remarkable difference between food engineering and food science is that the former includes the knowledge of unit operations and processes. However, these operations involve applied food science, just as chemical engineering involves chemistry and thermodynamics. Food science deals primarily with acquiring knowledge to elucidate the course of reactions or changes occurring in foods whether natural or induced by handling procedures. On the other hand, food engineering is the application of principles and the facts of science, engineering, and mathematics to the processing, preservation, storage, and utilization of food.

Food engineering should be differentiated from food technology. In teaching technology, some schools include considerable engineering in the curriculum to train students in the practical application of food science. Graduates are in effect food engineers. Other schools emphasize food science and qualify graduates primarily for research and quality control work. The food technologists from these schools are actually food scientists.

Where food processing is involved, understanding only one branch of science is not enough. Scientists and engineers with knowledge of the different fields relevant to various aspects of food manufacturing are needed. Management of different disciplines will enable them to couple principles from traditional engineering fields with principles of food preservation and safety to obtain the most suitable solutions to food processing problems. There have been instances in which a civil, mechanical or chemical engineer has been assigned the task of devising a new procedure for handling food. The process designed often was very efficient from an engineering point of view, but inadequate from a microbiological point of view. For example, allowance was not made for proper cleaning of equipment. An engineer trained as a food technologist would recognize this possibility and select the next best option, one that is less efficient but least likely to permit spoilage and pathogenic organisms to flourish.

Engineers in other industries are almost exclusively physical science oriented. However, functional engineers in the food industry must be knowledgeable of the biological and chemical sciences as applied to the food industry, including sanitation, food shelf life extension, public health, environmental control, and biological process engineering, in which microorganisms are used to drive or mediate processes to produce food materials or products. In effect, a food engineer is a generalist on science rather than an adherent of only one branch of science. As foods are composed of a large variety of physically and chemically complex materials, they need to be studied on a micro scale through disciplines such as biochemistry, microbiology, or food chemistry; or on a macro scale by exploring their use in thermodynamics, transport phenomena, rheology, or heat transfer.

A powerful analysis and design concept, called unit operations, originated from, and was extensively developed, by those in the field of chemical engineering. This concept has been immensely useful in food engineering, ranging from raw material utilization to finished product storage. Unit operations permit a myriad of processing steps that consist of relatively few basic physical and chemical transformations. In food factories, unit operations are the mechanical manipulation and handling of a food employed to change its physical form or composition; the food is moved from one environment to another and then packaged. Unit processes also include methods to change the chemical or biological characteristics of a food, for preservation, as in curing meat; to make it more palatable, as in aging cheese; or to develop special qualities, as in fermenting wort in beer production by developing alcohol and carbon dioxide. Particularly, crushing, mixing, and filtering are physical unit operations, while application of heat, fermenting, curing, and aging are biochemical unit operations. Food engineering has assumed a lead role in making improvements to dehydration, sterilization, freezing, and extrusion.

Food engineering is a vital link between farms and food outlets in the life support of modern civilization. The food requirements of the modern world can no longer be met by small, isolated, and nonintegrated food production systems. The logistic requirements and the complexity of feeding a world in which many countries are unable to produce sufficient supplies of food have created a demand for a more science- and engineering-based approach.

2. The History and Future Trends of Food Engineering

Food engineering arose as an academic discipline in the 1950s. Its initial development was concerned with post harvest operations related to food processing equipment performance. The past two decades have seen revolutionary advances in computer technology, molecular biology, and materials science, transforming the scope and focus of food engineering.

Although food engineering is a relatively new scientific discipline, the activities it encompasses are ancient. Collections of early writings on the art of food processing indicate that folklore and expertise were involved in its development; different cultures had various taboos concerning not only consumption, but also the modes of food preparation. Wars and exploration voyages have always had a profound impact on the development of food technology. For instance, the Napoleonic wars led to thermal sterilization and the Civil War in the United States promoted dehydration and concentration of foods. World War II initiated the technical development of protective packaging, and the Vietnam War led to the utilization of freeze-drying and flexible thermo-sterilized containers (flexcans). NASA’s Apollo and Skylab missions led to profound developments in the engineering of foods, and “clean room” packaging technology. Activities performed since ancient times and still a legitimate concern to food engineers include milling, dehydration, packaging, storage, baking, and fermentation processes. At present, concerns have shifted to health and food wholesomeness, and food engineers have been increasingly mobilizing to address these matters.

Modern food engineering (the intellectual offspring of agricultural engineering that matured in the 1900s) did not arise until the twentieth century. During the 1950s when food science and food technology were established at several U.S. universities, a number of influential works appeared. For example, solutions to food engineering problems related to sterilization, biological reaction kinetics, and disinfection were found in chemical engineering. A theme that became important in the 1970s was the need to reduce industrial environmental damage. Food engineers in universities and governmental institutions such as the United States Department of Agriculture (USDA) and other regional research centers established processing methodologies to minimize use of renewable resources and maximize utilization of waste streams. In research and development, food engineers have pioneered important advances in thermal sterilization, irradiation processes, concentration methods (e.g., evaporation, freeze concentration, and membrane processes), extrusion, dehydration, and engineering of packaging and storage.

During the past two decades, however, chemical engineering and food engineering have shown a dramatic change in research emphasis because of revolutionary developments in biotechnology (genetic engineering), computer science and technology, and material science (molecular structure in relation to functional properties of materials). Recent research in the field of food engineering has been conducted mainly in material science and modeling, which continues to be evident in current academic research. Today's food engineering research leaders tend to be experts in materials science (e.g., rheology, mass transfer properties, and thermal and electrical food properties), applied mathematics and modeling (e.g., kinetics, neural networks, and fuzzy logic), and biochemical engineering applied to foods. Furthermore, the use of computers for analysis simulation and control of food products plays a leading role in the development of industrial food processes.

The most recent advances in food engineering have provided a strong basis for making major improvements in processing operations throughout the food chain. Food engineers are seeking new approaches that include synergistically combined processes. Innovations are expected in transforming bench-scale processes into industrial-scale manufacturing of foods while maintaining desirable quality attributes. However, processing efficiencies related to the use of resources such as energy and water in a number of food operations will require dramatic improvements.

Some outstanding achievements in food engineering include:

- Continuous bread-dough making and forming
- Manufacture of low-cost, high quality prepared mixes
- Development of instant coffee and tea processes
- Dehydration of potatoes to produce an instant mashed product
- Production of precooked frozen convenience foods
- Continuous butter churning
- Freeze-drying or sublimation
- Extrusion processing
- Preservation of beer and wine by micropore filtration
- Pneumatic bulk handling of dry and liquid raw materials
- Aseptic filling of packages
- Automatic control processes
- Controlled atmosphere and modified atmosphere storage of fruits and vegetables
- Ohmic heating
- Irradiation of foods
- High hydrostatic Pressure

Recently, there has been a growing interest in the area of nonthermal processing of foods. Emerging technologies using pulsed electric fields and high pressure have encouraged food engineers to seek new materials for equipment, to determine process conditions for high-quality foods, and to ensure the safety and reliability of the process, such as generation of membranes. These materials will significantly enhance a range of applications in food processing, from minimizing water use in processing plants, to improving efficiency in separating high-value components in foods that have desirable food and nonfood applications. An area of major change in the food field is that of biotechnology or "genetic engineering" as sometimes called. For example, new plant genome initiatives will bring improved vegetable oils.

In the future, food engineering will enhance computational techniques to provide a better mechanistic understanding of food process design. At a molecular level, knowledge of food properties and reaction kinetics will provide the required basis for creating desirable food structures and functions that can be scaled to a manufacturing level. A quantitative understanding of food properties and advances in sensing technologies, such as ultrasonic and magnetic resonance imaging, will enhance the development of advanced online sensors for use in food manufacturing.

These advancements will require food engineers to use highly creative approaches in designing food-packaging systems, including the use of edible coatings for increasing shelf life to deliver a high quality product to consumers.

3. Food Engineering: The Profession

Employers of food engineers and food scientists include academia, government and industry, consulting firms, entrepreneurial endeavors of various sorts, and private consultants. Crucial to almost any profession is the education its members received prior to entering that profession.

-
-
-

Bibliography

Aguilera J.M. (2000). Structure-Property Relationships of Foods (eds. J.E. Lozano, C. Añón, E. Parada-Arias, and G.V. Barbosa-Cánovas), 1 pp. *Trends in Food Engineering*. New York: Technomic. [A description of structure of foods in relation to engineering]

Altomare R.E. (2001). What Engineers do in the Food Industry: A Look at Process Analysis and Benchmarking (eds. K. Mallikarjunan, and G.V. Barbosa-Cánovas), 41 pp. Proceedings of the 7th Conference of Food Engineering. USA: AIChE. [A brief description of data collection in food processing]

Bolado-Rodríguez S., Góngora Nieto M.M., Pothakamury U., Barbosa-Cánovas G.V., and Swanson B.G. (2000). A Review of Nonthermal Technologies (eds. J.E. Lozano, C. Añón, E. Parada-Arias, and G.V. Barbosa-Cánovas), 227 pp. *Trends in Food Engineering*. New York: Technomic. [A review in high pressure technology, pulsed light treatment, pulsed electric fields technology, and oscillating magnetic fields]

Clark J.P. (1997). Food Plant Design – food Engineering in practice (ed. R. Jowit). Engineering & Food at ICEF 7. Part I. Sheffield, UK: Sheffield Academic Press. [Some key lessons in practical food engineering]

Fellows P.J. (1997). *Traditional foods: processing for profit*. London, UK: Intermediate Technology Publications. [Full information on regionally-specific traditional foods, with in-depth technical detail on processing and preservation of these foods and many useful illustrations]

Fellows P.J. (1997). Food Processing Technology: Principles and Practice / P. Fellows. Cambridge, UK: Woodhead. [A review of all main food manufacturing technologies, covering the underlying theory, advantages and disadvantages, equipment and principal applications, and effects on the sensory and nutritional properties of foods]

Francis F.J. (2000). *Encyclopedia of Food Science and Technology*. New York: Wiley. [A very complete introduction to Food Science and Engineering careers and the role of each field in Food Technology applications]

Fryer P.J., Pyle D.L., and Rielly C.D. (1997). *Chemical engineering for the food industry*. London, UK: Blackie Academic & Professional. [Covers process design, hazard and risk analysis, heat and mass transfer and food rheology, explaining important applications in the food industry]

Heldman D.R. (1992). Food Freezing (eds. D.R. Heldman, and D.B. Lund), 277 pp. *Handbook of Food Engineering*. New York: Marcel Dekker. [Contains a cross-section of food properties for different process designs and unit operations with emphasis on the essential properties, rate constants, and related data for each unit operation]

Hutchings J.B. (1994). *Food Colour and Appearance*. New York: Blackie Academic & Professional. [A complete, detailed description of food color properties and measurements, and their applications]

Karel M. (1997). The history and future of food engineering (eds. P. Fito, E. Ortega-Rodríguez, and G.V. Barbosa-Cánovas), 3-19. *Food Engineering 2000*. New York: Chapman & Hall: International Thomson Publication. [A review of food engineering development as a profession as related to food processing studies]

Kokini J.L. (1992). Rheological Properties of Foods (eds. R.H. Heldman and D.B. Lund), 1 pp. *Handbook of Food Engineering*. New York: Marcel Dekker. [A review of measurement methods and mathematical simulation of viscoelastic properties of semisolid foods and their biopolymeric components]

Levine L. (1992). Extrusion Processes (eds. R.H. Heldman and D.B. Lund), 621 pp. *Handbook of Food Engineering*. New York: Marcel Dekker. [Provides quantitative understanding of performance of various extrusion devices as well as their applications to useful references]

Lilford P.J. (2000). Food Composites (eds. J.E. Lozano, C. Añón, E. Parada-Arias, and G.V. Barbosa-Cánovas), 65 pp. *Trends in Food Engineering*. New York: Technomic. [A review on physical properties of foods, food structure and its architecture]

Lund D.B. (1992). Food Engineering Research: An Opportunity for Cooperation (eds. R.P. Singh and M.A. Wirakatakusumah). *Advances in Food Engineering*. Boca Raton, USA: CRC Press. [Strategies to assist in finding solutions to problems encountered in Food Engineering development]

Oliveira J.C. and Medina A.G. (1997). The future of food engineering education in Europe (eds. P. Fito, E. Ortega-Rodríguez, and G.V. Barbosa-Cánovas), 403-411. *Food Engineering 2000***.** New York: Chapman & Hall: International Thomson Publication. [An update on the state of the art of Food Engineering careers in Europe]

Parada-Arias E. and Ordorica-Vargas C. (1997). Human resources formation for food technology in Ibero-America (eds. P. Fito, E. Ortega-Rodríguez, and G.V. Barbosa-Cánovas), 377-401. *Food Engineering 2000*. New York: Chapman & Hall: International Thomson Publication. [A thorough review and statistics for Food Technology educational programs in 14 Ibero-American countries]

Rao M.A. (1997). Engineering properties of foods: current status (eds. P. Fito, E. Ortega-Rodríguez, and G.V. Barbosa-Cánovas), 39-54. *Food Engineering 2000*. New York: Chapman & Hall: International Thomson Publication. [Major accomplishments pertaining to engineering properties of foods such as rheological, electrical, and thermal properties]

Roos Y.H. (1992). Phase Transitions and Transformations in Food Systems (eds. R.H. Heldman and D.B. Lund), 145 pp. *Handbook of Food Engineering*. New York: Marcel Dekker. [An introduction to glass transition theory as well as other physicochemical transformations occurring in foods]

Singh R.P. (1997). Food engineering curricula: North American and Asian perspectives (eds. P. Fito, E. Ortega-Rodríguez, and G.V. Barbosa-Cánovas), 367-375. *Food Engineering 2000*. New York: Chapman & Hall: International Thomson Publication. [An update on Food Engineering as a career in the U.S. and Asia]

Welti-Chanes J. (1999). Impact of the CYTED Program on the Development of the Research and Teaching of Food Engineering in Latin-America (eds. G.V. Barbosa-Cánovas and S.P. Lombardo), 729 pp. Proceedings of the 6th Conference on Food Engineering. USA: AIChE. [A brief description of a statistical research program on teaching and research differences in Food Engineering in Latin America]

Biographical Sketches

Gustavo V. Barbosa-Cánovas received his B.S. in Mechanical Engineering at the University of Uruguay and his M.S. and Ph.D. in Food Engineering at the University of Massachusetts-Amherst. He then worked as an Assistant Professor at the University of Puerto Rico from 1985-1990, during which he was granted two National Science Foundation (NSF) awards for research productivity. Following he went to Washington State University (WSU) where he is now Professor of Food Engineering and Director of the Center for Nonthermal Processing of Food (CNPF). Dr. Barbosa-Cánovas chaired the Organizing Committee for the 1997 and 1999 Conference of Food Engineering (CoFE). In addition, he is an Editor of the journal Food Science and Technology International published by SAGE, the journal Innovative Food Science and Emerging Technologies published by Elsevier Science, and the Food Engineering theme in the Encyclopedia of Life Support Systems (EOLSS) to be published by UNESCO. Dr. Barbosa-Cánovas is the Editor-in-Chief of the Food Engineering Book Series published by Kluwert Academic and Plenum Publishers (KAPP) as well as of the Food Preservation Technology Book Series published by CRC Press. He has chaired and organized several technical sessions at the American Institute of Chemical Engineers (AIChE) and Institute of Food Technologists (IFT) annual meetings, edited 12 books on Food Engineering topics, and authored, among others, *Dehydration of Foods* (Chapman@Hall), *Nonthermal Preservation of Foods* (Marcel Dekker), *Food Engineering Laboratory Manual* (Technomic), and *Engineering Properties of Biological Materials* (ASAE). Dr. Barbosa-Cánovas is also part of the editorial board for four technical journals, including the Journal of Food Engineering, Journal of Food Process Engineering, Journal of Food Science and Technology (LWT), and the International Journal of Physical Properties of Foods. He is International Consultant for the United Nations' Food Agriculture Organization (FAO), Associate Researcher for the United Nations' PEDECIBA (a special program to develop basic sciences), and a consultant for several major food companies in the United States.

Pablo Juliano received a B.S. in Chemistry from the University of Uruguay in 1999. In 2000, he was awarded a scholarship from the Organization of American States to pursue graduate studies at Washington State University toward an M.S. in Food Engineering, where he is currently pursuing Ph.D. studies. He worked in quality assurance at Nestle (Uruguay) between 1996 and 2000 where he applied his ISO 9000 Quality Specialist Degree.