

Pulsed Electric Fields Technology For The Food Industry Fundamentals And Applications Food Engineering Series

Written by leading experts in the field, the first edition of this textbook was the first of its kind to address numerous potential applications such as the technology of high-voltage insulation in pulsed inhomogeneous fields, and applications related to cavitation development in liquid dielectrics, treatment of different materials and plasma medicine. This second edition addresses the development of the theory over the past few years and features extensive revisions, as well as some expanded chapters. A new inclusion is an explanation of how the critical pressure at which cavitation is initiated is determined according to the surface tension coefficient at the boundary of small nanovoids and microbubbles. Discussion of the quantum mechanical nature of the cavitation inception in liquid helium is also provided, along with the derived values of critical negative pressure for the appearance of cavitation, and its characteristics at low temperatures.

This book focuses on bioelectrics, a new multidisciplinary field encompassing engineering and biology with applications to the medical, environmental, food, energy, and biotechnological fields. At present, 15 universities and institutes in Japan, the USA and the EU comprise the International Consortium of Bioelectrics, intended to advance this novel and important research field. This book will serve as an introductory resource for young scientists and also as a textbook for use by both undergraduate and graduate students – the world's first such work solely devoted to bioelectrics.

Nonthermal Processing Technologies for Food offers a comprehensive review of nonthermal processing technologies that are commercial, emerging or over the horizon. In addition to the broad coverage, leading experts in each technology serve as chapter authors to provide depth of coverage. Technologies covered include: physical processes, such as high pressure processing (HPP); electromagnetic processes, such as pulsed electric field (PEF), irradiation, and UV treatment; other nonthermal processes, such as ozone and chlorine dioxide gas phase treatment; and combination processes. Of special interest are chapters that focus on the "pathway to commercialization" for selected emerging technologies where a pathway exists or is clearly identified. These chapters provide examples and case studies of how new and nonthermal processing technologies may be commercialized. Overall, the book provides systematic knowledge to industrial readers, with numerous examples of process design to serve as a reference book. Researchers, professors and upper level students will also find the book a valuable text on the subject.

Preservation of Foods with Pulsed Electric Fields discusses the basics of high voltage PEF as a low temperature food processing method, and the application of this technology in food preservation. This technology is attracting a great deal of interest around the world because it is more cost effective than conventional systems due to the conservative nature of PEF. This book thoroughly covers the electrical and food engineering aspects, as well as the food science components (i.e. food microbiology, enzyme inactivation kinetics, and sensory evaluation). Fundamentals of high intensity pulsed electric fields Design of PEF processing equipment Biological principles for microbial inactivation in electric fields PEF-induced biological changes PEF inactivation of vegetable cells, spores, and enzymes in foods Food processing by PEF HACCP in PEF processing PEF in the food industry for the new millennium

This volume presents the proceedings of the 1st World Congress on Electroporation and Pulsed Electric Fields in Biology, Medicine and Food & Environmental Technologies (WC2015). The congress took place in Portorož, Slovenia, during the week of September 6th to 10th, 2015. The scientific part of the Congress covered different aspects of electroporation and related technologies and included the following main topics: · Application of pulsed electric fields technology in food: challenges and opportunities · Electrical impedance measurement for assessment of electroporation yield · Electrochemistry and electroporation · Electroporation meets electrostimulation · Electrotechnologies for food and biomass treatment · Food and biotechnology applications · In vitro electroporation - basic mechanisms · Interfacial behaviour of lipid-assemblies, membranes and cells in electric fields · Irreversible electroporation in clinical use · Medical applications: electrochemotherapy · Medical applications: gene therapy · Non-electric field-based physical methods inducing cell poration and enhanced molecule transfer · Non-thermal plasmas for food safety, environmental applications and medical treatments · PEF for the food industry: fundamentals and applications · PEF proce ss integration - complex process chains and process combinations in the food industry · Predictable animal models · Pulsed electric fields and electroporation technologies in bioeconomy · Veterinary medical applications

This major reference work is a one-shot knowledge base on electroporation and the use of pulsed electric fields of high intensity and their use in biology, medicine, biotechnology, and food and environmental technologies. The Handbook offers a widespread and well-structured compilation of chapters ranging from the foundations to applications in industry and hospital. It is edited and written by most prominent researchers in the field. With regular updates and growing in its volume it is suitable for academic readers and researchers regardless of their disciplinary expertise, and will also be accessible to students and serious general readers. The authors of chapters have established scholarly credentials and come from a wide range of disciplines. This is crucially important in a highly interdisciplinary field of electroporation and the use of pulsed electric fields of high intensity and its applications in different fields from medicine, biology, food processing, agriculture, process engineering, energy and environment. An Editorial Board of distinguished scholars from across the world has selected and reviewed the various chapters to ensure the highest quality of this Handbook.

This book conveys many significant messages for the food engineering and allied professions: the importance of working in multidisciplinary teams, the relevance of developing food engineering based on well-established principles, the benefits of developing the field by bringing together experts from industry, academia and government, and the unparalleled advantage of working as globally as possible in the understanding, development, and applications of food engineering principles. I am delighted to welcome this book to the Series and I am convinced colleagues from all parts of the world will gain great value from it.

The aim of this book is to describe chemical and biochemical aspects of winemaking that are currently being researched. The authors have selected the very best experts for each of the areas. The first part of the book summarizes the most important aspects of winemaking technology and microbiology. The second most extensive part deals with the different groups of compounds, how these are modified during the various steps of the production process, and how they affect the wine quality, sensorial aspects, and physiological activity, etc. The third section describes undesirable alterations of wines, including those affecting quality and food safety. Finally, the treatment of data will be considered, an aspect which has not yet been tackled in any other book on enology. In this chapter, the authors not only explain the tools available for analytical data processing, but also indicate the most appropriate treatment to apply, depending on the information required, illustrating with examples throughout the chapter from enological literature.

Food Safety Engineering is the first reference work to provide up-to-date coverage of the advanced technologies and strategies for the engineering of safe foods. Researchers, laboratory staff and food industry professionals with an interest in food engineering safety will find a singular source containing all of the needed information required to understand this rapidly advancing topic. The text lays a solid foundation for solving microbial food safety problems, developing advanced thermal and non-thermal technologies, designing food safety preventive control processes and sustainable operation of the food safety preventive control processes. The first section of chapters presents a comprehensive overview of food microbiology from foodborne

pathogens to detection methods. The next section focuses on preventative practices, detailing all of the major manufacturing processes assuring the safety of foods including Good Manufacturing Practices (GMP), Hazard Analysis and Critical Control Points (HACCP), Hazard Analysis and Risk-Based Preventive Controls (HARPC), food traceability, and recalls. Further sections provide insights into plant layout and equipment design, and maintenance. Modeling and process design are covered in depth. Conventional and novel preventive controls for food safety include the current and emerging food processing technologies. Further sections focus on such important aspects as aseptic packaging and post-packaging technologies. With its comprehensive scope of up-to-date technologies and manufacturing processes, this is a useful and first-of-its kind text for the next generation food safety engineering professionals. This book introduces readers to essential advances in the application of physical processing technology in food processing that have been made in recent years. It analyzes and describes the application of Power Ultrasound, Pulsed Electric Field, Supercritical-CO₂, and Infrared Heating in the contexts of food sterilization, extraction, modification, drying and safety control. Covering all aspects of food physical processing, from basic principles to the latest technological developments, it offers a valuable application guide for food engineers and food researchers alike. Food processing technologies are an essential link in the food chain. These technologies are many and varied, changing in popularity with changing consumption patterns and product popularity. Newer process technologies are also being evolved to provide the added advantages. Conventional and Advanced Food Processing Technologies fuses the practical (application, machinery), theoretical (model, equation) and cutting-edge (recent trends), making it ideal for industrial, academic and reference use. It consists of two sections, one covering conventional or well-established existing processes and the other covering emerging or novel process technologies that are expected to be employed in the near future for the processing of foods in the commercial sector. All are examined in great detail, considering their current and future applications with added examples and the very latest data. Conventional and Advanced Food Processing Technologies is a comprehensive treatment of the current state of knowledge on food processing technology. In its extensive coverage, and the selection of reputed research scientists who have contributed to each topic, this book will be a definitive text in this field for students, food professionals and researchers.

Fluid milk processing is energy intensive, with high financial and energy costs found all along the production line and supply chain. Worldwide, the dairy industry has set a goal of reducing GHG emissions and other environmental impacts associated with milk processing. Although the major GHG emissions associated with milk production occur on the farm, most energy usage associated with milk processing occurs at the milk processing plant and afterwards, during refrigerated storage (a key requirement for the transportation, retail and consumption of most milk products). Sustainable alternatives and designs for the dairy processing plants of the future are now being actively sought by the global dairy industry, as it seeks to improve efficiency, reduce costs, and comply with its corporate social responsibilities. Emerging Dairy Processing Technologies: Opportunities for the Dairy Industry presents the state of the art research and technologies that have been proposed as sustainable replacements for high temperature-short time (HTST) and ultra-high temperature (UHT) pasteurization, with potentially lower energy usage and greenhouse gas emissions. These technologies include pulsed electric fields, high hydrostatic pressure, high pressure homogenization, ohmic and microwave heating, microfiltration, pulsed light, UV light processing, and carbon dioxide processing. The use of bacteriocins, which have the potential to improve the efficiency of the processing technologies, is discussed, and information on organic and pasture milk, which consumers perceive as sustainable alternatives to conventional milk, is also provided. This book brings together all the available information on alternative milk processing techniques and their impact on the physical and functional properties of milk, written by researchers who have developed a body of work in each of the technologies. This book is aimed at dairy scientists and technologists who may be working in dairy companies or academia. It will also be highly relevant to food processing experts working with dairy ingredients, as well as university departments, research centres and graduate students.

"Andi Dorfman, the beloved finalist of season eighteen of The Bachelor who infamously rejected Juan Pablo and went on to star on season ten of The Bachelorette, dishes about what it's like to live out a love story--and its collapse--in front of the cameras, offering hard-won advice for moving on after a break-up, public or not"--

While conventional technologies such as chilling and freezing are used to avoid deteriorative processes like autolytic and microbial spoilage of seafood, innovative technologies have also been developed as a response to economic and environmental demands. Innovative Technologies in Seafood Processing gives information on advances in chilling, freezing, thawing, and packaging of seafood and also updates knowledge of novel process technologies (high-pressure processing, irradiation, ultrasound, pulsed electric field, microwave and radio frequency, sous vide technology, novel thermal sterilization technologies, ozone and nanotechnological applications, and other innovative technologies such as cold plasma, ohmic heating, infrared heating supercritical carbon dioxide, and high-intensity pulsed light) for the seafood industry. Features ? Reviews novel process technologies applied in the seafood industry ? Highlights processing effects on product quality and safety of treated seafood ? Focuses on the development of safe and effective natural antimicrobials and additives ? Assesses alternative techniques to utilize fish discards and waste as high value products Further it highlights aspects related to quality of seafood treated with these innovative technologies, effect on food constituents, possible risk, security/safety both of seafood and consumers, the environmental impact, and the legislative aspects. The book also addresses the growing international environmental concern for fish discards and fish waste generated in the seafood processing industries by including a chapter, Advances in Discard and By-Products Processing, which assesses alternative techniques to utilize fish discards and waste as high value products. This book will be of value to researchers and technicians in the food technology area, especially those dealing with seafood.

This book presents the latest developments in the area of non-thermal preservation of foods and covers various topics such as high-pressure processing, pulsed electric field processing, pulsed light processing, ozone processing, electron beam processing, pulsed magnetic field, ultrasonics, and plasma processing. Non-thermal Processing of Foods discusses the use of non-thermal processing on commodities such as fruits and vegetables, cereal products, meat, fish and poultry, and milk and milk products. Features: Provides latest information regarding the use of non-thermal processing of food products Provides information about most of the non-thermal technologies available for food processing Covers food products such as fruits and vegetables, cereal products, meat, fish and poultry, and milk and milk products Discusses the packaging requirements for foods processed with non-thermal techniques The effects of non-thermal processing on vital food components, enzymes and microorganisms is also discussed. Safety aspects and packaging requirements for non-thermal processed foods are also presented. Rounding out coverage of this technology are chapters that cover commercialization, regulatory issues and consumer acceptance of foods processed with non-thermal techniques. The future

trends of non-thermal processing are also investigated. Food scientists and food engineers, food regulatory agencies, food industry personnel and academia (including graduate students) will find valuable information in this book. Food product developers and food processors will also benefit from this book.

"The book covers the applications of some alternative approaches for prolonging food shelf life. The book describes the role of food safety objectives, natural compounds (such as oils and microbial enzymes), pressure and atmospheric techniques and alternat"

The second edition of *Emerging Technologies in Food Processing* presents essential, authoritative, and complete literature and research data from the past ten years. It is a complete resource offering the latest technological innovations in food processing today, and includes vital information in research and development for the food processing industry. It covers the latest advances in non-thermal processing including high pressure, pulsed electric fields, radiofrequency, high intensity pulsed light, ultrasound, irradiation, and addresses the newest hurdles in technology where extensive research has been carried out. Provides an extensive list of research sources to further research development Presents current and thorough research results and critical reviews Includes the most recent technologies used for shelf life extension, bioprocessing simulation and optimization Pulsed Electric Fields Technology for the Food Industry Fundamentals and Applications Springer Science & Business Media

This book is a printed edition of the Special Issue "Phenolic Compounds in Fruit Beverages" that was published in *Beverages*

Transport in Biological Media is a solid resource of mathematical models for researchers across a broad range of scientific and engineering problems such as the effects of drug delivery, chemotherapy, or insulin intake to interpret transport experiments in areas of cutting edge biological research. A wide range of emerging theoretical and experimental mathematical methodologies are offered by biological topic to appeal to individual researchers to assist them in solving problems in their specific area of research. Researchers in biology, biophysics, biomathematics, chemistry, engineers and clinical fields specific to transport modeling will find this resource indispensable. Provides detailed mathematical model development to interpret experiments and provides current modeling practices Provides a wide range of biological and clinical applications Includes physiological descriptions of models

This new book discusses food quality and safety standards that are critically important for both developed and developing economies, where consumer safety is among the primary issues to be considered in food supply chain management. The editors consider that food safety is a multi-faceted subject, using microbiology, chemistry, standards and regulations, and risk management to address issues involving bacterial pathogens, chemical contaminants, natural toxicants, additive safety, allergens, and more; hence, the volume emphasizes the interrelationship between these areas and their equal importance in food production. With chapters from researchers from around the world, this book looks at critically important advances and topics in technology that has become indispensable in controlling hazards in the modern food industry. The varied topics include the role of mineral content of soils in food safety, microwaveassisted extraction of phenolic compounds, foodborne pathogenic anaerobes, enzymatic modification of ferulic acid content, and more.

Extraction is an important operation in food engineering, enabling the recovery of valuable soluble components from raw materials. With increasing energy costs and environmental concerns, industry specialists are looking for improved techniques requiring less solvents and energy consumption. *Enhancing Extraction Processes in the Food Industry* is a

Non-thermal operations in food processing are an alternative to thermal operations and similarly aimed at retaining the quality and organoleptic properties of food products. This volume covers different non-thermal processing technologies such as high-pressure processing, ultrasound, ohmic heating, pulse electric field, pulse light, membrane processing, cryogenic freezing, nanofiltration, and cold plasma processing technologies. The book focuses both on fundamentals and on recent advances in non-thermal food processing technologies. It also provides information with the description and results of research into new emerging technologies for both the academy and industry. Key features: Presents engineering focus on non-thermal food processing technologies. Discusses sub-classification for recent trends and relevant industry information/examples. Different current research-oriented results are included as a key parameter. Covers high-pressure processing, pulse electric field, pulse light technology, irradiation, and ultrasonic techniques. Includes mathematical modeling and numerical simulations. *Food Processing: Advances in Non-Thermal Technologies* is aimed at graduate students, professionals in food engineering, food technology, and biological systems engineering.

Pulsed Electric Fields to Obtain Healthier and Sustainable Food for Tomorrow illustrates innovative applications derived from the use of pulsed electric fields beyond microbial inactivation. The book begins with an introduction on how pulsed electric fields work and then addresses the impact of pulsed electric fields on bioaccessability/bioavailability and the development of nutraceuticals and food additives. Other sections explore the reduction of contaminants and assess the improvement of industrial process efficiency. A final section explores patents and commercial applications. This book will be a welcomed resource for anyone interested in the technological, physiochemical and nutritional perspectives of product development and the reduction of food toxins and contaminants. The concepts explored in this book could have a profound impact on addressing the concept of "food on demand," a concept that is a top priority in industry.

Reflecting current trends in alternative food processing and preservation, this reference explores the most recent applications in pulsed electric field (PEF) and high-pressure technologies, food microbiology, and modern thermal and nonthermal operations to prevent the occurrence of food-borne pathogens, extend the shelf-life of foods, and improve

The second edition of the Food Processing Handbook presents a comprehensive review of technologies, procedures and innovations in food processing, stressing topics vital to the food industry today and pinpointing the trends in future research and development. Focusing on the technology involved, this handbook describes the principles and the equipment used as well as the changes - physical, chemical, microbiological and organoleptic - that occur during food preservation. In so doing, the text covers in detail such techniques as post-harvest handling, thermal processing, evaporation and dehydration, freezing, irradiation, high-pressure processing, emerging technologies and packaging. Separation and conversion operations widely used in the food industry are also covered as are the processes of baking, extrusion and frying. In addition, it addresses current concerns about the safety of processed foods (including HACCP systems, traceability and hygienic design of plant) and control of food processes, as well as the impact of processing on the environment, water and waste treatment, lean manufacturing and the roles of nanotechnology and fermentation in food processing. This two-volume set is a must-have for scientists and engineers involved in food manufacture, research and development in both industry and academia, as well as students of food-related topics at undergraduate and postgraduate levels. From Reviews on the First Edition: "This work should become a standard text for students of food technology, and is worthy of a place on the bookshelf of anybody involved in the production of foods." *Journal of Dairy Technology*, August 2008 "This work will serve well as an excellent course resource or reference as it has well-written explanations for those new to the field and detailed equations for those needing greater depth." *CHOICE*, September 2006

This book is an example of a successful addition to the literature of bioengineering and processing control within the scientific world. The book is divided into twelve chapters covering: selected topics in food engineering, advances in food process engineering, food irradiation, food safety and quality, machine vision, control systems and economics processing. All chapters have been written by renowned professionals working in food engineering and related disciplines.

The Microbiology of Skin, Soft Tissue, Bone and Joint Infections: Volume 2 discusses modern approaches in diagnosis, treatment, and prophylaxis of skin, soft tissue, bone, and joint infections. The volume has been divided into three sections. The first section includes chapters on diagnosis, treatment, and prophylaxis of skin and soft tissue infections. It discusses antimicrobial and surgical treatment of wounds, diabetic foot, and different soft tissue infections. Ten chapters are devoted to cutaneous and musculoskeletal infections in special groups of patients, which have their own specificity, i.e. in pediatric and HIV-infected patients. Together with chapters on commonly present diseases, there are chapters which discuss interesting but not well studied pathologies (natal cleft pilonidal sinus) and pathogens (*Malassezia* and *Shewanella* spp.). The second section reviews etiology, pathogenesis, diagnosis and treatment of bone and joint infections, mainly osteomyelitis and prosthetic joint infections. Also, one chapter in this section discusses a newly emerging bacterial pathogen that causes skeletal infections, *Kingella kingae*. The third section incorporates alternative and new approaches—such as nanotechnology, ultrasound, novel delivery approaches and phyto-derived medicines—to the treatment and prophylaxis of skin, soft tissue, bone, and joint infections. Encompasses a broad range of skin, soft tissue, bone, and joint infections, including questions of etiology, pathogenesis, diagnosis, prognosis, treatment, and prophylaxis Written by highly professional and eminent surgeons, microbiologists, and infectious disease specialists Discusses topics using modern insight, providing all necessary scientific information on each aspect Includes scientific understanding and practical guidelines, which make it interesting for both research scientists and practitioners working with skin, soft tissue, bone, and joint infections

This two-volume work contains the papers presented at the 2016 International Conference on Civil, Architecture and Environmental Engineering (ICCAE 2016) that was held on 4-6 November 2016 in Taipei, Taiwan. The meeting was organized by China University of Technology and Taiwan Society of Construction Engineers and brought together professors, researchers, scholars and industrial pioneers from all over the world. ICCAE 2016 is an important forum for the presentation of new research developments, exchange of ideas and experience and covers the following subject areas: Structural Science & Architecture Engineering, Building Materials & Materials Science, Construction Equipment & Mechanical Science, Environmental Science & Environmental Engineering, Computer Simulation & Computer and Electrical Engineering.

Pulsed Electric Fields (PEF) is a method used in non-thermal food preservation. Chapter One of this book provides inactivation kinetic models for PEF treatment. Chapter Two discusses PEF in the winemaking process. Chapter Three reviews fruit juice preservation. Chapter Four investigates the effect of amplitude and treatment time of PEF on *E. coli* in carrot juice. Chapter Five analyzes the contribution of major electrical parameters on PEF treatment of *Salmonella typhimurium* in grape juice. Chapter Six reviews the effect of PEF on the quality of fresh apple fruits. Chapter Seven examines further potential of PEF treatments for the food industry. Chapter Eight discusses network simulation of the electrical response to PEF of ion-exchange membranes in electrodialysis.

Consumer pressure and increased regulation has made environmental awareness increasingly important in the food industry. Exploring how to achieve environmentally-friendly food production, this book reviews the assessment of various food products and the ways in which the industry can improve their operations and become more environmentally responsible. The editors and their panel of experts evaluate the environmental impact of food processing operations areas in such as fruit, vegetable, meat, and fish processing. They cover good practice in food processes including packaging, recycling, and waste treatment and highlight methods of improving energy consumption.

Many novel technologies have been proposed in the attempt to improve existing food processing methods. Among emerging nonthermal technologies, high intensity pulsed electric fields (PEF) is appealing due to its short treatment times and reduced heating effects. This book presents information accumulated on PEF during the last 15 years by experienced microbiologists, biochemists, food technologists, and electrical and food engineers.

Pulsed electric field (PEF) food processing is a novel, non-thermal preservation method that has the potential to produce foods with excellent sensory and nutritional quality and shelf-life. This important book reviews the current status of the technology, from research into product safety and technology development to issues associated with its commercial implementation. Introductory chapters provide an overview of the process and its history. Part one then discusses the technology of PEF food preservation, with chapters on circuitry and pulse shapes, chamber design and technical and safety requirements. The second part of the book focuses on important product safety and quality issues such as probable mechanisms of microbial inactivation by PEF, adaptation potential of microorganisms treated by this method, toxicological aspects, the impact on food enzymes and shelf life. Chapters in the final part of the book cover topics relating to the commercialisation of the technology, including current and future applications, pitfalls, economic issues and scaling up, and public and regulatory acceptance. Food preservation by pulsed electric fields is a standard reference for all those involved in research into PEF food processing and its commercialisation. Reviews the current status of PEF technology with an overview of the process and its history Discusses the technology involved in PEF food preservation Focuses on important product safety and quality issues such as the impact on food enzymes and shelf life

Pulsed Electric Fields (PEF) is one of the nonthermal processing approaches that is receiving considerable attention by scientists, government and the food industry as a potential technique to be fully adopted to process foods at the industrial level. PEF presents a number of advantages including minimal changes to fresh foods, inactivation of a wi

A reflection of the intense study of the effects of electromagnetic fields on living tissues that has taken place during the last decades, *Advanced Electroporation Techniques in Biology and Medicine*

summarizes most recent experimental findings and theories related to permeabilization of biomembranes by pulsed electric fields. Edited by experts and including contributions from pioneers in the field, the book focuses on biophysical mechanisms of electroporation and applications of this phenomenon in biomedical research and medicine. The field of electroporation is now mature enough to move from journal pages to book covers. The book leads readers from the basics and history of electroporation, through mechanisms of membrane permeabilization in lipid bilayers and living cells, to electrically-mediated gene delivery and cancer therapy in animals and humans. This book is an interdisciplinary compilation intended broadly for biomedical and physical scientists, engineers, and clinicians. It can also be used as a textbook for students in advanced courses in biomedical engineering, molecular and cell biology, as well as in biophysics and clinical medicine.

Pulsed electric field (PEF) is a promising technology for the non-thermal disinfection of water. Although research has already been conducted on the inactivation of pathogens using PEF, the emphasis of this project was the optimization of the electric parameters for improved disinfection of water. In this regard, magnetic pulse compressors due to their high repetition-rates and long-lifetimes, appear to be a promising alternative to the existing used for sterilization applications. The magnetic pulse compressor was used to drive a treatment cell through which water is flowed. This program investigated the use of the system for inactivation of E.coli and Spores in drinking water. Inactivation data for E.coli and spores under various electrical support the studies that high voltage pulses of short duration with high electric field strengths have a strong lethal effect on bacteria. Higher inactivation efficiency is achieved with lower energy consumption (7 J/cm³).

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