Innovations in Agricultural & Biological Engineering

Processing Technologies for Milk and Milk Products

Methods, Applications, and Energy Usage

Editors Ashok Kumar Agrawal
Megh R. Goyal

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LIST OF ABBREVIATIONS

ANN	artificial neural network
APP	atmospheric pressure plasma
ASD	adjustable speed drive
ASME	American Society of Mechanical Engineers
BHM	batch type halwasan making machine
C.O.P.	coefficient of performance
Ca	calcium
CBM	Continuous Basundi Making Machine
CFC	chlorofluorocarbon
CFL	compact fluorescent lamp
CHP	combined heat and power system
CIP	clean in place
CLA	conjugated linoleic acid
CP	cold plasma
CPV	conical process vat
CSLM	confocal scanning microscopy
CT	computed tomography
Cu	copper
DC	direct current
DM unit	demineralization unit
DMF	dual media filter
DOE	US Department of Energy
Dpi	dot per inch
DWB	dry weight basis
Eq.	equation
ET	electrical tomography
ETC	evacuated tube collectors
EU	European Union
FAO	Food and Agriculture Organization
FD	fractal dimension
FDA	Food and Drug Administration

FPC	flat plate collectors
FSSA	Food Safety and Standards Act
FSSAI	Food Safety and Standards Authority of India
FVR	fruit and vegetable residue
GAU	Gujarat Agricultural University
GB	Gigabyte
GC	gas chromatography
GHG	greenhouse gases
GM	region growing and merging
GMO	genetically modified organism
HACCP	Hazard Analysis and Critical Control Point
HAV	Hepatitis A virus
HHP	high hydrostatic pressure processing
HIPEF	high intensity pulsed electric field
HP	high pressure
HPHT	high pressure high temperature
HPLC	high pressure liquid chromatography
HPLT	high pressure low temperature
HPP	high pressure processing
HTST	high temperature short time
i.e.	exempli gratia
IBR	Indian Boiler Regulation
IEA	International Energy Agency
IIT	Indian Institute of Technology
ISSHE	Inclined Scraped Surface Heat Exchanger
LPG	liquefied petroleum gas
MB/Mb	mega bite
MCWC	microwave circulation water combination
MeV	mega electron volt
MFD	microwave freeze drying
MNRE	Ministry of New and Renewable Energy
MPa	mega pascal
MRI	magnetic resonance image
MS	monosonication
MTS	monothermosonication
MVD	microwave vacuum drying

MW	microwave
MW	megawatt
NaCAS	sodium caseinate
NDDB	National Dairy Development Board
NDRI	National Dairy Research Institute
NH_4	ammonia
NIR	near infra red
NRFI	normalized reference fruit image
OHC	oxygen holding capacity
ORAL	oxygen radical absorbance capacities
PA	particle analysis
PATP	pressure assisted thermal processing
PATS	pressure assisted thermal sterilization
PCA	principal component analysis
PDCAAS	protein digestibility corrected amino acid score
PE	polyethylene
PEF	pulsed electric field
PHE	plate heat exchanger
PI	pixel intensity
PL	pulsed light
PP	polypropylene
Ppi	pixels per inch
ppm	parts per million
PS	polystyrene
PUFA	poly-unsaturated fatty acid
PV	solar photovoltaic
RCT	rennet coagulation time
RF	radio frequency
RGB	Red Green Blue
RMRD	Raw Milk Reception Doc
RO	reverse osmosis
RO unit	reverse osmosis unit
ROI	region of interest
ROS	reactive oxygen species
rpm	revolutions per minute
RPM	rotations per minute

RTD	resistance temperature detector
RTE	ready to eat
Se	selenium
SLS	solar street-lighting system
SM	region splitting and merging
SMP	skim milk powder
SMUF	simulated milk ultra-filtrate
SNF	solids not fat (Milk)
Spi	squares per inch
SS	stainless steel
SSHE	scraped surface heat exchanger
SV	slab voxel
SWH	solar water heater
SWHS	solar water heater system
T.V.	texturized vegetable
TFSSHE	thin film scraped surface heat exchanger
TIDP	traditional Indian dairy products
TR	tone
TS	thermosonication
TS	total solid
U-value	overall heat transfer coefficient
UHP	ultra high pressure processing
UHT	ultra heat treatment
UHT	ultra high temperature
US	ultrasonication
USDA	United States Department of Agriculture
UV	ultraviolet
V	wind velocity (m/s)
VFD	variable frequency drive
Vit.	vitamin
VSD	variable speed drive
WHC	water holding capacity
WPI	whey protein isolate
Zn	zinc

LIST OF SYMBOLS

”	inches
@	at
%	percentage
°	degree
°C	degree celsius
A	rotor area (m^2)
C. jejuni	*Campylobactor jejuni*
cfu/g	colony-forming units per gram
Cs	cesium
g	gram
K	kelvin
K	potassium
kg	kilogram
kGy	kilogray
KJ/kg	kilo Joules per kilo gram
km/h	kilometer per hour
kPa	kilo Pascal
KV/cm	kilovolt per centimeter
kW	kilowatt
kWh	kilowatt-hour
L. monocytogenes	*Listeria monocytognes*
m	meter
m/s	meter per second
Mg	magnesium
MHz	mega hertz
min	minute
MJ	mega joule
mJ	milli joule
mm	millimeter
Na	sodium

P	phosphorus
P	power
W	watt
W/cm^2	watt per square centimeter
w/w	weight-to-weight ratio
Y. enterocolitica	*Yersiniaenterocolitica*
μ	Mu
μΦ	microfarad
μμ	micrometer
μs	microsecond
ρ	air density (kg/m^3)

FOREWORD BY UMESH K. MISHRA

The present scenario of dairying in the world is promising in many ways. The world's milk production has reached about 800 million tons per annum, which will continue to increase in the future also. The entire array of dairying, particularly milk processing and dairy product manufacturing, has achieved exceptional growth momentum throughout the world. Efficient production, processing, and marketing of milk is largely credited for this transformation. In developing countries, a substantial quantity of milk is now also processed in organized processing plants, thus assuring a quality milk supply to masses. The step up in milk production is essential to meet the increasing demand generated by increasing populations and income levels. There is an urgent need to take care of the health of children and other consumers by offering them safely processed milk and milk products.

In line with the modern industrial trends, new processes and corresponding new equipment are being introduced. The development of highly sensitive measuring and control devices have made it possible to incorporate automatic operation with high degree of mechanization to meet the huge demand of quality milk and milk products. In order to encourage dairying on economic terms and to stimulate awareness about emerging techniques, there is a need to disseminate the unseen knowledge among all stakeholders of dairy and food industry. The technical keenness in dairy technocrats will help in better utilization of existing equipment and better planning of future equipment, instruments, process controls and automation. It would enable them to conserve various processing utilities, thereby facilitating production with minimum environmental impact.

This book has the ready-made solution to quench the quest of qualified dairy personnel. It would fulfill a thirst for knowledge about recent developments in processing of milk and dairy products. This compendium deals with the salient aspects of the milk processing and dairy product manufacturing. The cutthroat competition of modern era necessitates the knowledge of fundamentals of emerging processes, acquaintance with innovative equipment, and self-assurance regarding instruments and automatic control systems for commercial processing of milk and dairy products.

The task of providing comprehensive information about pertinent topics, more ubiquitous in the future milk and dairy product industry, is nicely done. The authors and editors deserve accolades for this stupendous work. Various authors have distinguished themselves in their interest in the engineering and technology of milk and milk product processing.

I am confident that this book will be very useful for students, as a reference book for researchers, and as a source book for teachers. It would be equally useful for all professionals working in various capacities in the milk and dairy product manufacturing industry.

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PREFACE 1 BY ASHOK K. AGRAWAL

This volume, *Processing Technologies for Milk and Dairy Products: Methods, Applications, and Energy Usage,* is compiled with the view to fill the gap due to non-availability of relevant books having recent information on these subjects. The milk processing and dairy product preparation is the sunrise sector of food processing, and its scope is expanding with leaps and bounds due to rapid urbanization, improving life styles and higher paying capacity. The expected growth in milk consumption is based mostly on the number of growing consumers who are earning more than US$ 5 per day, and this is increasing. The speed of growth has to be higher than the sum of the inflation rate and percentage of population increase. The demand for quality milk products is increasing throughout the world. Food patterns are changing from eating plant protein to animal protein due to increasing incomes.

The so-called dairy basket now contains some non-traditional dairy products also in demand by the common consumer. This is particularly true for developing countries, which are witnessing popularity of Western products along with their own conventional dairy products. Coordinated efforts from all stakeholders are needed to sustain and develop this trend in the future also. This book is compiled with a view to meet the key requirement of fulfilling the technical competency in budding technocrats of dairy industry. This book contains particularly those topics that would inculcate inspiration among its readers by exposing them to recent advances in the field of the milk and dairy product processing.

The processing of milk and conversion of raw milk into some dairy products adds significant value to the output from the dairy processing plants. The broad objective of this book is to provide readers with an improved understanding about processing of milk and manufacturing of the dairy products. This book is divided into three sections: (i) Innovative Techniques in Dairy Engineering; (ii) Processing Methods and Their Applications in the Dairy Industry; and (iii) Energy Usage in Dairy Engineering: Sources, Conservation, and Requirements.

The role of processing in dairy industry involves the designing of the equipment/storage structure. During preparation of dairy products from raw milk, many different types of engineering processes are involved. There are various established and promising techniques for completion of these processes. In dairy and food processing, quality of food is most important because it is deciding factor for its on-going demand. Looking to this, a separate chapter on uses and potential of digital image analysis as a tool for food quality evaluation is included. The chapter on passivation (a method to ensure quality of dairy and food processing equipment) shows the necessity and logic behind the pre-treatment given to processing equipment. The chapter on technology of protein rich vegetable-based formulated foods deals with processing of those food products that are gaining importance as some wellness scientists have pointed out drawbacks associated with non-vegetarian foods and have advocated adoption of vegan foods.

There are some types of equipment that are often used during manufacturing of various dairy products. Hence, a critical review is made on utilization of scraped surface heat exchanger in manufacturing of various dairy products. Another emerging technique on high-pressure processing is discussed by two distinguished authors. The new discoveries in various field of science have their inbuilt applications in food processing. The emergence of the novel thermal technologies, for example, microwave heating, allows producing high-quality products with improvements in terms of heating efficiency and, consequently, in energy savings. In the near future, more and more thermal processes in the dairy product manufacturing field may be diverted toward the use of microwaves. Hence, a discussion on microwave is also included.

In today's world, quality has to be maintained for a huge quantity of food. Better and newer techniques are being continuously evolved that are particularly capable of tackling and storing millions of liters of milk. Hence, a chapter is incorporated to highlight this aspect it collects some information about mass milk storage structures called milk silos. Milk is required to be kept in a safe condition from its production up to consumption.

In this book, a chapter is devoted for utilization of alternate sources of energy for processing of milk and dairy products while the other two chapters deal with its conservation for achieving lower cost of milk processing. Upon identifying the various outlets of energy in milk processing and dairy product manufacturing, ‘pumps’ would come out at the top. An article is included to focus the reduction of power/energy consumption by pumps.

Renewable energy sources are continuously replenished by natural processes, for example, solar energy, wind energy, bio-energy, hydropower, etc. There are number of renewable energy sources that can be easily integrated into the dairy industry for energy conservation. Considering this as a prominent matter, a chapter on renewable energy is also included. Gone are the days when water was available in plenty and free of cost. For a layman, it may be unbelievable that in a dairy plant, quantity of water handled is much more than quantity of milk processed. Hence, its conservation is important from not only from a quantity-wise perspective but also energy-wise. In dairy processing beside equipment, utilities like steam, refrigerant, vacuum, compressed air, are topics that need attention, as a major cost of processing is attributed to this aspect. Conserving consumption of this would ultimately result in huge savings of energy, time and operation period, and labor. Cooling of milk is another facet of dairying that needs a sincere approach to maintain quality of milk.

I hope this book will fulfill the expectations of all dairy professionals who are constantly working for betterment of human life by ensuring the availability of milk as nature’s nectar, which is time and again proved only next to elixir. The very purpose of the publication of this compilation would be suitably accomplished if it caters to the need of budding scientists, engineers and technologists working in the field of processing of milk and dairy products.

Completion of this book would have been impossible without significant input from many colleagues and fellow dairy professionals. The opportunity to collaborate with these scientists and engineers has made this a memorable experience. The continuous support of Dr. Megh R. Goyal deserves special mention and lots of appreciation throughout the compilation and editing of this book. Dr. Goyal has excelled as a devoted editor of Apple Academic Press, Inc. (AAP) to bring out quality book volumes under the book series *Innovations in Agricultural and Biological Engineering*.

Ours is a profession with a future, and it needs professional books in all focus areas. I hope that my colleagues will seriously consider publishing in this book series as I find AAP to be a world-renowned source.

—Ashok K. Agrawal, PhD

PREFACE 2 BY MEGH R. GOYAL

On March 30 of 1983, I was driving on Puerto Rico Highway 52 to visit some historic places in Cayey. While driving, I drank the chocolate milk and threw the empty bottle on the road. My five-year-old son (today, he is 38 years old) requested me to stop the car to pick up the empty bottle from the road and added that "*we should not contaminate our beautiful island*." At that time, there were no recycling plants for solid waste in Puerto Rico. The attention by my child helped me to love my mother planet by conserving our natural resources. Therefore, in my introduction to this book volume, I want to emphasize the importance of treating solid/liquid/gas wastes that are generated in the operations of milk and milk products. One must follow all local regulations for waste disposal, taking into consideration human health. I invite my fellow colleagues to suggest book volumes on this focus area under my book series. Apple Academic Press, Inc., has identified this topic as one of the priority areas to help save our planet from degradation and perish. We, engineers, are meant to help all persons at all levels and at all places. Can you help us?

Agricultural waste treatment is the treatment of waste produced in the course of agricultural activities. Agriculture is a highly intensified industry in many parts of the world, producing a range of waste requiring a variety of treatment technologies and management practices. Farms with large livestock and poultry operations, such as factory farms, can be a major source of waste. In the United States, these facilities are called concentrated animal feeding operations or confined animal feeding operations (CAFOs) and are being subjected to increasing US government regulations. Agricultural waste also includes waste from dairy farms, dairy industries, and processing industries involved in milk and milk products.

https://en.wikipedia.org/wiki/Dairy#Waste_disposal mentions that "*in countries where cows are grazed outside year-round, there is little waste disposal to deal with. The most concentrated waste is at the milking shed, where the animal waste may be liquefied (during the water-washing process) or left in a more solid form, either to be returned to be used* *on farm ground as organic fertilizer. In the associated milk processing factories, most of the waste is washing water that is treated, usually by composting, and spread on farm fields in either liquid or solid form. This is much different from half a century ago, when the main products were butter, cheese and casein, and the rest of the milk had to be disposed of as waste (sometimes as animal feed). In dairy-intensive areas, various methods have been proposed for disposing of large quantities of milk. Large application rates of milk onto land, or disposing in a hole, is problematic as the residue from the decomposing milk will block the soil pores and thereby reduce the water infiltration rate through the soil profile. As recovery of this effect can take time, any land based application needs to be well managed and considered. Other waste milk disposal methods commonly employed include solidification and disposal at a solid waste landfill, disposal at a wastewater treatment plant, or discharge into a sanitary sewer*."

"*The constituents of animal wastewater typically contain: Strong organic content — much stronger than human sewage; High concentration of solids; High nitrate and phosphorus content; Antibiotics; Synthetic hormones; Often high concentrations of parasites and their eggs; Spores of Cryptosporidium (a protozoan) resistant to drinking water treatment processes; Spores of Giardia; Human pathogenic bacteria such as Brucella and Salmonella. Milking parlor wastes are often treated in admixture with human sewage in a local sewage treatment plant. This ensures that disinfectants and cleaning agents are sufficiently diluted and amenable to treatment. Running milking wastewaters into a farm slurry lagoon is a possible option although this tends to consume lagoon capacity very quickly. Land spreading is also a treatment option*," according to https://en.wikipedia.org/wiki/Agricultural_wastewater_treatment#Milking_parlor_.28dairy_farming.29_wastes.

In dairy industries, a large amount of waste is discarded in the form of diluted milk that may have whey liquid, detergents, sanitizers and other chemicals used for the purpose of sterilization. Clean-in-Place (CIP) is also a process of cleaning the place, where a huge amount of contaminated water is released. Along with these drippings, problem and accidental leakage from the packaging process and from the CIP respectively occur. This leakage will end up in the sewer system and create a lot of problems.

Whey is one of main product left after manufacturing of cheese. It is watery in nature and left after the separation of curd when the milk had been coagulated with enzyme or acid. The generation is quite high, approximately 9 liters of whey per one kg of cheese. Due to higher Biological Oxygen Demand (BOD: approx. 40 g/l), it is not advisable to dispose of this liquid without pretreatment. It will trigger diseases and health risks. The higher value of BOD is due to the presence of sugar, called lactose. Although the concentration of lactose is around 5%, it can cause damages. However, industries are opting for new techniques of utilizing the whey or discarding it after pretreatment. But some losses still occur in small-scale industries, where rules and regulations are not followed properly. In the current scenario, different methods have been developed to dry the whey to blend with edible food to prepare food at lesser cost. It can be blended with different categories of foods. The technique of reverse osmosis (RO) can also be utilized to manufacture a protein-based product.

Another area for whey utilization is the preparation of single cell protein (SCP). The SCP and other protein concentrates are gaining value in the market for their fortification in the value addition of different products. The application of whey utilization is quite large and includes a number of techniques for producing products: fermentation method to produce ethyl alcohol and lactic acid; formation of concentrate (whey protein, dried whey); and pasteurization technique to process whey cream and sweet whey. Membrane filtration has also been designed to separate compounds from whey. A filtration technique called ultra-filtration can be used for the segregation of proteins from the solution, which have mainly lactose. Similarly number of techniques like evaporation, spray drying, and crystallization are used for the purpose of separation of valuable nutrients like protein, minerals matter, and other chemical compounds. But these techniques are quite expensive. Therefore industries are looking for some innovative, affordable, and economical techniques. These days, ultra-filtration and RO are gaining importance for the purpose of separation. Concentrate of whey protein is known for its nutritive value throughout the world.

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 the focus areas of agricultural and biological engineering (ABE). This is how the idea was born for the new book series titled *Innovations in Agricultural and Biological Engineering*. This book *Processing Technologies for Milk and Dairy Products: Methods, Applications, and Energy Usage,* is twelfth volume in this book series, and it contributes to the ocean of knowledge on dairy engineering.

The contribution by the cooperating authors to this book volume has been most valuable in the compilation. Their names are mentioned in each chapter and in the list of contributors. 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. Ashok K Agrawal, who is Professor and Head of Department of Dairy Engineering in the College of Dairy Science and Food Technology at Chhattisgarh Kamdhenu Vishwavidyalaya (CGKV), Raipur- India. He is a professor/researcher and is specialized in dairy and dairy products. Without his support, and leadership qualities as lead editor of this book and his extraordinary work on dairy engineering applications, readers would 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. Special thanks are due to the AAP production staff for the quality production of this book.

I request that readers offer their constructive suggestions that may help to improve the next edition.

I express my deep admiration to Subhadra D. Goyal for understanding and collaboration during the preparation of this book volume.

Can anyone live without food or milk? 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 Milk and Milk Products and His Grace; and Get married to your profession.*"

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

WARNING/DISCLAIMER

PLEASE READ CAREFULLY

The goal of this book volume, *Processing Technologies for Milk and Dairy Products: Methods, Applications, and Energy Usage,* is to guide the world community on how to manage efficiently for technology available for different processes of milk and milk products.

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 dairy technology does not fit all cases in dairy engineering/science/technology.

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ABOUT THE LEAD EDITOR

Ashok Kumar Agrawal, PhD, is a distinguished engineer, researcher, and professor of dairy engineering at the College of Dairy Science and Food Technology at Chhattisgarh Kamdhenu University–Durg, Raipur, in India, where he heads the Dairy Engineering Department. He also served as Dean of the college. Dr. Agrawal is also acting as Principal Investigator of the National Agricultural Development Project on the operation of small milk processing plants with the utilization of solar energy. He is a life member of the Indian Dairy Engineers Association, the Indian Society of Agricultural Engineers, and the Indian Dairy Association.

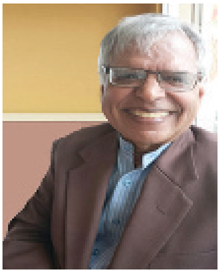
His major areas of research are parboiling and storage studies of granular and horticultural crops. He is engaged in the teaching of various dairy and food engineering courses to undergraduate, postgraduate, and doctoral students. He has supervised about 20 students for their research work leading to advanced degrees in dairy engineering and agricultural process and food engineering.

He has edited the proceedings of the National Conference on Dairy Engineers for the Cause of Rural India and the 5th Convention of the Indian Dairy Engineers Association. He has published about 60 research papers in national and international journals; 25 research articles in national and international conferences/symposiums as well as some popular articles. Dr. Agrawal is also a reviewer for some several journal, including the Indian Journal of Dairy Science and the Journal of Food Processing and Preservation. He was conferred a Best Teacher Award by his own university and has received awards for his presentations at many national and international conferences.

He obtained his BTech (Agricultural Engineering) degree from the College of Agricultural Engineering, J. N. Agricultural University, Jabalpur, India; his MTech (Postharvest Engineering) degree from the

Indian Institute of Technology, Kharagpur, India; and his PhD from the Indian Institute of Technology in Dairy and Food Engineering. In his PhD research, he worked on development of double wall basket centrifuge for pressing and chilling for batch production of Indian cheese (paneer).

ABOUT THE SENIOR EDITOR-IN-CHIEF



Megh R. Goyal, PhD, PE
Retired Professor in Agricultural and Biomedical Engineering, University of Puerto Rico, Mayaguez Campus Senior Acquisitions Editor, Biomedical Engineering and Agricultural Science, Apple Academic Press, Inc.

Megh R. Goyal, PhD, PE, is a Retired Professor in Agricultural and Biomedical Engineering from the General Engineering Department in the College of Engineering at the University of Puerto Rico–Mayaguez Campus; and Senior Acquisitions Editor and Senior Technical Editor-in-Chief in Agriculture and Biomedical Engineering for Apple Academic Press, Inc.

He has worked as a Soil Conservation Inspector and as a Research Assistant at Haryana Agricultural University and Ohio State University. He was the first agricultural engineer to receive the professional license in Agricultural Engineering in 1986 from the 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 pioneering work on micro irrigation, evapotranspiration, agroclimatology, and soil and water engineering. During his professional career of 45 years, he has received many prestigious awards, including 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, Rashtrya Ratan 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. On March 1, 2017:

Tamil Nadu Agricultural University conferred on him "Distinguished Scientist Award" at National Congress on Sustainable Microirrigtion by Water Technology Centre.

A prolific author and editor, he has written more than 200 journal articles and textbooks and has edited over 48 books including: *Elements of Agroclimatology* (Spanish) by UNISARC, Colombia; and two bibliographies on drip irrigation.

He received his BSc degree in engineering from Punjab Agricultural University, Ludhiana, India; his MSc and PhD degrees from Ohio State University, Columbus; and his Master of Divinity degree from Puerto Rico Evangelical Seminary, Hato Rey, Puerto Rico, USA.

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,* his ten-volume set on *Research Advances in Sustainable Micro Irrigation.* During 2016–2020, AAP will be publishing book volumes on emerging technologies/issues/challenges under two 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

Dairy and food engineering combines the fundamentals of basic branches of engineering for specific applications to the dairy and food industry. The present book is an amalgamation of review chapters on various emerging topics of milk processing and dairy products manufacturing. The comprehensive text, written by various technocrats, is very useful for all persons engaged in various facets of dairying. The source book of this type is needed urgently, particularly for dairy professionals. It would fill the information gap between textbooks and findings of present investigations.

—S. P. Agarwala, PhD
Ex-Head, Principal Scientist and Emeritus Scientist,
Dairy Engineering Division,
National Dairy Research Institute, Karnal – 132001, India

Agricultural processing and food engineering is the integral portion of agricultural engineering curricula. The undergraduate program is comprised of basic courses while the postgraduate program consists of advanced courses of dairy and food engineering. This volume presents several chapters that would be helpful in understanding the recent developments in this emerging field. This is a well-written book that gives a lucid exposition and addresses the needs of the professionals of both the academic and the industrial obligations. I have no doubt in saying that the undergraduate and post-graduate courses of the various universities engaged in fields like agricultural processing, milk and milk product processing, food processing, etc. would find this book as a useful contribution toward dissemination of knowledge. I extend my warm greetings and best wishes for all success.

—V. K. Pandey, PhD
Dean, S.V. College of Agric. Eng. and Tech. and Research Station,
Raipur – 492012, India

The book edited by Dr. A. K. Agrawal and Dr. M. R. Goyal has covered various aspects of dairy and food engineering in a most useful manner for professionals, entrepreneurs, scientists and research scholars who are working in this field. This book will be useful as a reference book for future dairy and food engineering research. In the production of dairy and food products, newer and better techniques are continuously evolved. This book presents information on these aspects. I extend my warm greetings and best wishes to the publisher for future success.

—Sudhir Uprit, PhD
Dean, College of Dairy Science and Food Technology,
Raipur – 492012, India

This book is a valuable asset for all dairy plants engineers, managers, professionals as well as for the decision makers working in dairy and food processing industries. This book gives a glimpse of advance knowledge in various topics of dairy and food processing. It would serve as a reference book for all investigators working in these fields.

—B. P. Shah, PhD
Former Principal and Dean,
SMC College of Dairy Science, Anand, India

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EDITORIAL

Apple Academic Press, Inc., (AAP) is publishing book volumes in the specialty areas as part of the *Innovations in Agricultural and Biological Engineering* book series over a span of 8 to 10 years. These specialty areas have been 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 "*Goyal, Megh R., 2006. Agricultural and biomedical engineering: Scope and opportunities. Paper Edu_47 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)?

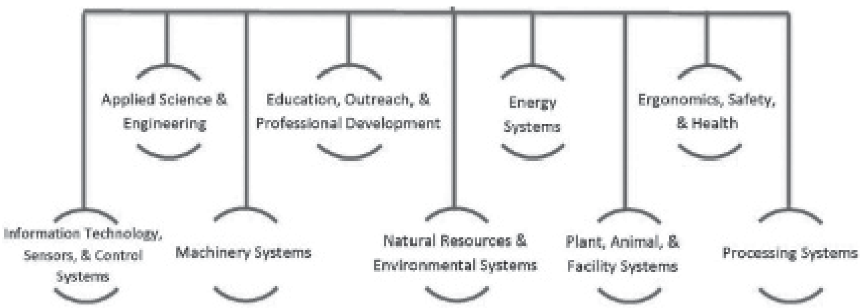
"*Agricultural Engineering (AE) involves application of engineering to production, processing, preservation and handling of food, fiber, and shelter. It also includes transfer of technology for the development and welfare of rural communities*," according to http://isae.in." *ABE is the discipline of 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*," 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.," 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. "*ABE embraces a variety of following specialty areas*," http://asabe.org. As new technology and information emerge, specialty areas are created, and many overlap with one or more other areas.



1. **Aquacultural 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 aquacultural 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.

CAREERS IN AGRICULTURAL AND BIOLOGICAL ENGINEERING

One will find that university ABE programs have many names, such as biological systems engineering, bioresource 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 team up to design, build, and test new processes or products.

For more information on this series, readers may contact:

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PART I

INNOVATIVE TECHNIQUES IN DAIRY ENGINEERING

CHAPTER 1

INNOVATIVE TECHNIQUES IN MILK PROCESSING: A REVIEW

BHUSHAN D. MESHRAM, P. G. WASNIK, K. K. SANDEY, SHAKEEL ASGAR, and A. K. AGRAWAL

CONTENTS

1.1 INTRODUCTION

The thermal food processing is a classic technique for ensuring the microbiological safety of foods [77, 193]. This technique leads to unwanted changes in the sensory attributes foods (by overheating) or to low nutritional value of the food products [206]. The increased interest of consumers in high quality foods with higher nutritive value and fresh-like sensory attributes led to the development of a number of non-thermal food processing technologies as alterative to conventionally heat treatments [193, 167]. Among these novel technologies, microwave heating, high pressure processing (HPP), ohmic heating, atmospheric pressure plasma (APP), ultrasonic, high hydrostatic pressure (HHP) and pulsed electric field (PEF) are the most investigated ones [77].

HHP is an innovative technology for food preservation that protects the foods' sensory attributes and produces minimal quality loss [19]. In addition, HHP has the potential to improve energy efficiency and sustainability of food production [158]. PEF is a non-thermal technology that provides minimally processed, safe, nutritious and like-fresh foods to consumers [212, 158]. PEF has been commercially applied for preservation of liquid foods, as pre-step for solid food processes such as drying and for extraction [63]. These two technologies rely on the lethal effect of HHPs and strong electric fields, respectively and are entrusted to result in better quality retention and longer shelf-life [212].

In the recent years, Microwave heating, the HVAD, the cold plasma (CP), ultraviolet light (UV), ultrasound (US), pulsed light (PL) and ionizing radiation are also proposed as alternative non-thermal processing for foods. HVAD consists in application of electricity to pasteurize fluids by rapidly discharging electricity through an electrode gap, generating intense waves and electrolysis, thereby inactivating the microorganisms [149]. The use of arc discharge for foods is unsuitable largely because electrolysis and the formation of highly reactive chemicals occur during the discharge. CP is a relatively unexplored decontamination technology which does not require extreme process conditions compared to HVAD treatment [174]. Gamma irradiation has long been developed and researched and it has high potential in producing safe and nutritious food. Unfortunately, its development and commercialization has been hampered in the past by unfavorable public perceptions. Although several researches have demonstrated the effectiveness of plasmas for killing microorganisms, yet further studies into the nutritional and chemical changes in plasma treated food are required to accurately assess the effect of plasma treatment on product quality and shelf-life and to confirm that no harmful by-products are generated [67]. Although HHP, PEF, HVAD and CP offer great opportunities for food preservation, yet they are often technically difficult to apply into production practice, expensive and require specialized equipment and trained personnel [77]. Moreover, consumer acceptance and safety issues should be considered. The majority of European food producers are small companies with few resources and limited expertise to develop and implement novel emerging technologies.

The aim of this chapter is to present some general aspects about HHP, PEF, HVAD, and CP and to explore the opportunities and drawbacks for the food and milk industry.

1.2 HIGH HYDROSTATIC PRESSURE PROCESSING (HHPP)

In these days, in the emerging field of functional foods, minimal processed foods have increased in popularity along with organic foods. One of the promising technology which could serve as an alternative method for food preservation is the application of HHPP. For the first time in history, this technique was proposed by Royer in 1895 to kill bacteria and Hite in 1899 explored HHPP effects on milk, meat, fruits and vegetables processing.

1.2.1 THE PROCESS

Typically, HHPP of food is performed at 300–600 MPa at room temperature for 2–30 min. During pressurization, an increase in temperature (3–9°C per 100 MPa, depending on the pressure-transmitting fluid) occurs due to adiabatic heating; and a corresponding decrease occurs during depressurization [9]. These changes can be minimized by temperature control of the high-pressure equipment by circulating water. Conversely, this temperature rise can be used to achieve desired effects in the treated foods. During HHPP, the pressure is instantaneously and uniformly transmitted in all directions, regardless of the shape or volume (based on Pascal's principle) of the food in question. The large bio-molecules such as proteins, nucleic acids and polysaccharides that depend on non-covalent bonding to maintain structure and function are most affected. On the other hand, smaller organic molecules such as those responsible for colors, flavors, and nutrients are hardly affected. Milk treated at 400 MPa resulted in no significant loss of vitamins B1 and B6 [185]. The low temperature at which high-pressure treatments are usually performed ensures little or no heat induced changes in these components. However, recent developments in the use of pressure assisted thermal processing (PATP) and pressure assisted thermal sterilization (PATS) utilize both heat and pressure and hence cause some heat-induced changes.

1.2.2 BASIC PRINCIPLES

Hydrostatic pressure is generated by increasing the free energy by physical compression during pressure treatment in the closed system by mechanical volume reduction. Usually HHPP accompanied by a moderate increase in temperature, called the adiabatic heating, depends on the composition of the food product being processed [59]. There are three fundamental operational principles that govern the behavior of foods under underlying HHPP: Le-Chatelier's principle [74], isostatic principle [90], and principle of microscopic ordering [115, 116].

1.2.3 ADVANTAGES OF HHPP

- Significant reduction of heating, this will minimize thermal degradation of food components.
- Inactivation of microorganisms, spores and enzymes.
- High retention of flavor, color and nutritional value.
- Pressure is transmitted uniformly and instant so that food product retains its shape.

- Potential for the design of new products due to the creation of new textures, tastes and functional properties.
- Clean technology, flexible system for number of products and operation.
- Process time is less dependence of product shape and size.
- Reduced requirement of chemical additives, and Increased bioavailability.
- Positive consumer appeal.

1.2.4 DISADVANTAGES OF HHPP

- Food must contain water, as the whole phenomenon is based on compression.
- Some enzymes are very pressure resistant.
- May not inactivate spores.
- Structurally fragile foods needs special attention, and
- High installation cost.
- Foods should have approximately 40% free water for anti-microbial effect.
- Batch processing.
- Limited packaging options.
- Regulatory issues to be resolved.

1.2.5 EFFECTS OF HHPP ON DAIRY PRODUCTS AND PROCESSES

HHPP inactivates most of spoilage and pathogenic bacteria present in milk. Resistance of microorganisms to pressure varies considerably depending on the applied pressure range, temperature and treatment duration, and type of microorganism [188, 199]. Heat resistant groups of microorganisms were usually pressure resistant [59]. The number of yeasts, molds, psychrotrophs and coliforms were decreased more rapidly with pressure than that of acidic and heat-resistant bacteria and proteolytic microorganisms [117]. The lower resistance of Gram-negative bacteria compared with Gram-positive bacteria is due to their lack of teichoic acid, which strengthens the cell wall of Gram-positive bacteria. Bacteria in the log phase of growth are more sensitive than those in the stationary phase.

1.2.6 IMPACT OF HHPP ON PHYSICO-CHEMICAL PROPERTIES OF MILK

White color of milk is due to scattering of light particles by fat globules and casein Micelles. Hunter Luminance value (L-value) of milk [88] was reported to be reduced by HHPP treatment, due to disintegration of casein micelles, thus leading to decrease in the turbidity of milk. Treatment of milk at 200 MPa showed slight effect on L-value; while at 250–450 MPa significant decreased in the L-value was observed. When skim milk treated at 600 MPa for 30 min, L value decreased from 78 to 42 and skim milk becomes almost translucent or semi-transparent [54].

1.2.7 IMPACT OF HHPP ON CREAM, BUTTER AND ICE CREAM

HHPP treatment induces fat crystallization, shortens the time required to achieve a desirable solid fat content and thereby reduces the aging time of ice-cream mix and also enhances the physical ripening of cream for butter making [25]. The cream was subjected to HHPP of 100 to 150 MPa at 23°C for pasteurization and then studied for freeze fracture and transmission electron microscopy [24]. It was observed that pasteurization of cream induced fat crystallization within the small emulsion droplets mainly at the globule periphery [24]. Fat crystallization increased with the length of pressure treatment and was maximal after processing at 300–500 MPa. Moreover, the crystallization proceeded during further storage, after the pressure was released. Two potential applications of HHPP were fast aging of ice cream mix and physical ripening of dairy cream for butter making. Whipping properties were improved when cream was treated at pressure of 600 MPa for up to 2 min [61] probably due to better crystallization of milk fat. When treatment conditions exceeded the optimum conditions, an excessive denaturation of whey protein occurred which resulted in longer whipping time and destabilization of whipped cream. Study with modified whey protein concentrate added at a concentration of less than 10% in ice-cream mix exhibited enhanced overrun and foam stability, confirming the effect of HHPP on foaming properties of whey proteins in a complex system [127].

1.2.8 IMPACT OF HHPP ON YOGURT

Yoghurt suffers from common defects of syneresis and low viscosity. Preservation and rheological properties of yogurt can be improved by pressure treatment. Skim milk treated with combined treatments of HHPP (400–500 MPa) and thermal treatment (85°C for 30 min) showed increased yield stress, resistance to normal penetration, elastic modulus and reduced syneresis [88].

Pressure treatment at 200–300 MPa at 10–20°C for 10 min can be used to control 'post- acidification' of yogurt without decreasing the number of viable lactic acid bacteria (LAB) or modifying the yogurt texture. Treatment at higher pressures destroyed LAB. When exceeding 400 MPa for 15 min, *Lactobacillus delbrueckii* subsp. *bulgaricus* was inactivated, whereas *Streptococcus thermophilus* was more resistant but it lost its acidifying capacity. An extended shelf life probiotic yogurt has been developed using pressure of 350–650 MPa at 10–15°C. The process inactivated yeasts and molds but not specially selected pressure-resistant probiotics, extending the shelf life of yogurt up to 90 days.

1.2.9 IMPACT OF HHPP ON CHEESE

High-pressure treatment of milk at ≤300 MPa decreased the rennet coagulation time (RCT) and increased the curd-firming rate, curd firmness and curd yield during cheese manufacturing. At such pressures, the casein micelle was largely intact or increased slightly in size, and the extent of denaturation of β-lactoglobulin was modest. At higher pressures (>300 MPa), the RCT remained unaffected or increased when compared to that of untreated milk. The effect of high pressure appeared to be the result of two mechanisms with opposite effects: (i) disintegration of the casein micelle and (ii) denaturation of β-lactoglobulin. The quality of Cheddar cheese manufactured from high-pressure treated (31-min cycle at 586 MPa) milk was not significantly different in sensory quality to that made from high-temperature, short-time (HTST) pasteurized milk. However, the pressurized milk cheese had higher moisture content, which led to pasty and weak texture defects, due to the increased water-holding capacity of milk proteins [58, 159].

Milk treated at 300–400 MPa significantly increased wet curd yield up to 20% and reduced both the loss of protein in whey and the volume of whey, due to the denaturation of β-Lg and thus its incorporation in the curd. This leads to high cheese yield to the extent of 7%. Quick maturation and stronger flavor development has also been reported when treated at 400–600 MPa/5–15 min cycle [5, 94]. This can help in accelerating cheese-ripening process and provides better opportunity for improving cheese prepared from low fat milk. The cheese curd obtained from milk treated by HP gives dense network of fine strands thereby having a great potential for the design of new products due to the creation of modified textures, tastes and functional properties [50].

1.2.10 COMMERCIAL APPLICATIONS OF HHPP

A potential application of HHPP is the tenderization of meat. Commercially produced products also include pressure-processed salted raw squid and fish sausages [89]. Other possible applications are improved microbiological safety and elimination of cooked flavors from sterilized meats and pate [102]. Processing at 103 MPa and 40–60°C for 2.5 min improved the eating quality of meat and reduced cooking losses. The extent of tenderization depends on three factors: pressure, temperature and holding time. Starch molecules are similarly opened and partially degraded, to produce increased sweetness and susceptibility to amylase activity. Other research indicated that the appearance, odor, texture and taste of soybeans and rice did not change after processing, whereas root vegetables (potato and sweet potato) became softer, more pliable, sweeter and more transparent [74].

Fruit products are reported to retain the flavor, texture and color of the fresh fruit. Other applications include tempering chocolate, where the high pressures transform cocoa butter into the stable crystal form, preservation of honey and other viscous liquids, sea foods, dairy products such as unpasteurized milk and mold ripened cheese [74]. Compared to thermal and chemical alternatives, HHPP is an effective non-thermal technology. The effects of HHPP (600 MPa, 3 min) and storage (40 days, 4°C) were positive on the stability of avocado paste (*Persea americana* cv. Hass) carotenoids. Likewise, the effects of HHPP and storage on hydrophilic and lipophilic oxygen radical absorbance capacities (ORAC) of the product were studied [47]. Pressurization induced a significant increase (approx. 56%) in concentrations of total extractable carotenoids. Highest increases for individual carotenoids were observed for neoxanthin-β (513%), followed by α-cryptoxanthin (312%), α-carotene (284%), β-cryptoxanthin (220%), β-carotene (107%), and lutein (40%). Carotenoid levels declined during storage, but at the end of the sensory shelf-life of product were higher than those initially present in unprocessed avocado paste. Interestingly, ORAC-values followed a different trend than carotenoids; they decreased immediately after HPP and increased during storage, therefore indicating that carotenoids appear to be minor contributors to the total antioxidant capacity of the fruit [125].

1.2.11 PACKAGING REQUIREMENTS OF HHPP

Packaging technology for HHPP involves different considerations, based on whether a product is processed in-container or packaged after processing. For batch in-container process, flexible or partially rigid packaging is best suited. On the other hand, fluid products require continuous or semi-continuous systems, which are aseptically packaged after pressure treatment. The effectiveness of HHPP is greatly influenced by the physical and mechanical properties of the packaging material. The packaging material must be able to withstand the operating pressures, have good sealing properties and the ability to prevent quality deterioration during the application of pressure. At least one interface of the package should be flexible enough to transmit the pressure. Thus, rigid metal, glass or plastic containers cannot be used [170].

The most common packaging materials used for HP processed food are polypropylene (PP), polyester tubes, polyethylene (PE) pouches, and nylon cast PP pouches. Plastic packaging materials are best suited for HHPP packaging applications, because of reversible response to compression, flexibility and resiliency. The head-space must be also minimized as much as possible [169] in order to control the deformation of packaging materials while sealing the package in order to ensure efficient utilization of the package as well as space within the pressure vessel. Packaging materials for HHPP must be flexible to withstand a 15% increase in volume followed by a return to original size, without losing physical integrity, sealing or barrier properties. Sufficient headspace also minimizes the time taken to reach the target pressure. Film barrier properties and structural characteristics of polymer based packaging material were unaffected when subjected to pressures of 400 MPa for 30 min at 25°C [153].

1.2.12 LEGAL AND SAFETY CONCERNS OF HHPP FOODS

HHPP treated food items falls under the category of novel food as per the definition of Novel Food by European Union (EU) countries (Regulation (EC) No 258/97). The 'Novel Foods Regulation' defines novel food as a food that does not have a significant history of consumption within the EU before the 15th of May, 1997 [90] and such foods are subject to a pre-market safety assessment. Further, the legislations defines Novel foods as follows: foods and food ingredients to which has been applied a production process not currently used, where that process gives rise to significant changes in the composition or structure of the foods or food ingredients which affect their nutritional value, metabolism or level of undesirable substances. If a food falls under the definition of novel food, the person responsible for placing it on the market has to apply for an authorization. In EU countries for introducing novel foods to the market, food companies must have an approval that such products are in compliance with the food law. Food safety issues, the achievable extension of shelf-life and the legislative situation need to be inspected.

High pressure treated foodstuffs have been marketed in Japan since 1990, in Europe and United States since 1996. Information relating to the adverse effects of HHPP on toxins, allergens, and nutrients are rare. There are no published reports available on health and safety issues of HHPP foods. In the developing nations, where there is no such regulations established, for them supportive data on validation is required, and to be sorted out before the marketing of high pressure treated foods. Further, markers/indicators of the effectiveness of HHPP treatment needs to be worked out before the enforcement of legal requirements for such processed dairy foods.

1.3 PULSED ELECTRIC FIELD (PEF)

Non-thermal processes have gained importance in recent years due to the increasing demand for foods with a high nutritional value and fresh-like characteristics, representing an alternative to conventional thermal treatments. PEF are an emerging technology that has been extensively studied for non-thermal food processing. PEF processing has been studied by a number of researchers across a wide range of liquid foods.

Apple and orange juices are among the foods most often treated in PEF studies. The sensory attributes of juices are reported to be well preserved, and the shelf life is extended. Yogurt drinks, apple sauce, and salad dressing have also been shown to retain a fresh-like quality with extended shelf life after processing. Other PEF-processed foods include milk, tomato juice, carrot juice, pea soup [59], liquid whole egg [58], and enzymes in liquid foods such as milk [90]. The conventional HTST processing technique can affect the organoleptic and nutritional properties of milk to varying degrees [140, 190].

PEF is a non-thermal method of food preservation that uses short pulses of electricity for microbial inactivation and causes minimal detrimental effect on food quality attributes. PEF technology aims to offer consumers high-quality foods. For food quality attributes, PEF technology is considered superior than the traditional thermal processing methods, because it is energy efficient and avoids or greatly reduces detrimental changes in the sensory and physical properties of foods. PEF technology aims to offer high-quality foods [78, 102, 104].

1.3.1 TYPICAL COMPONENTS OF PEF EQUIPMENT

- **Power supply**: this may be an ordinary direct current power supply or a capacitor charging power supply (latter can provide higher repetition rates).
- **Energy storage element**: this can be either electric (capacitive) or magnetic (inductive).
- **Switch:** Either for closing or opening. Devices suitable for use as the discharge switch include a mercury ignitron spark gap, a gas spark gap, thyratron, a series of Switch Circuit diode, a magnetic switch or a mechanical rotary switch.
- **Pulse shaping and triggering circuit** in some cases is being used.
- **Treatment chamber:** in wide variety of designs.
- **Pump:** to supply a feed of product to the chamber.
- **Cooling system:** to control the temperature of the feed and/or output material.

1.3.2 PRINCIPLE OF PEF

The basic principle of the PEF technology is the application of short pulses of high electric fields with duration of microseconds to milliseconds and intensity in the order of 10–80 kV/cm. The processing time is calculated by multiplying the number of pulses times with effective pulse duration. The applied high voltage results in an electric field that causes microbial inactivation. When an electrical field is applied, electrical current flows into the liquid food and is transferred to each point in the liquid because of the charged molecules present [223]. The electric field may be applied in the form of exponentially decaying, square wave, bipolar, or oscillatory pulses and at ambient, sub-ambient, or slightly above-ambient temperature. After the treatment, the food is packaged aseptically and stored under refrigeration.

1.3.3 MECHANISMS OF MICROBIAL INACTIVATION

Two mechanisms have been proposed for the mode of PEF action on microbial membrane: electroporation (cell exposed to high voltage electric field pulses temporarily destabilizes the lipid bilayer and proteins of cell membranes); and electrical breakdown (normal resisting potential difference across the bacterial membrane is 10 mV which leads to the build-up of a membrane potential difference due to charge separation across the membrane). In both cases, the phenomena starts by electroporation, by which the cell wall is perforated and cytoplasm contents leak out resulting in cell death ([135, 200].

1.3.4 APPLICATION OF PEF IN MILK PROCESSING

It has been observed that raw skim milk under PEF treatment (intensity of 35 kV/cm; pulse with width 3 μs and time of 9 μs) did not show any significant difference in color, pH, proteins, moisture and particle size [141].

Application of PEF treatment (35 kV/cm; 2.3 μs of pulse width at 65°C for <10 s) immediately after HTST pasteurization extended the shelf life of milk to 78 days at 4°C [184]. PEF treatment of bovine immunoglobulin enriched soymilk (at 41 kV/cm for 54 μs) did not cause any significant change in bovine IgG activity but resulted in a 5.3 log reduction of initial microbial flora [126].

1.3.4.1 Microbial Inactivation and Shelf Life Enhancement of Milk

PEF treatment results in less flavor degradation of milk than equivalent heat treatments, and does not cause any chemical or physical changes in milk fat, protein integrity, and casein structure. Hence, PEF may be used to preserve heat-sensitive dairy products such as whey protein concentrates. An extension of shelf life of raw milk to 2 weeks at refrigeration temperature using PEF (two steps of seven pulses, and one step of six pulses at 40 kV/ cm) was noted. There was no significant difference in sensory quality of PEF treated and heat pasteurized milk. High intensity PEF (HIPEF) treatment of whole milk at 35.5 kV for 1000 μs with 7 μs bipolar pulses at 111 Hz reduced the mesophilic aerobic count from 3.2 log to 1 log cycle ensuring microbial stability for 5 days at 4°C without significant change in acidity, pH and FFA; proteolysis and lipolysis was not observed [156]. The combination of PEF and heat treatment reduced the *salmonella enteritidis* count in skim milk by 2.3 log cycle compared to 1.2 log cycle obtained by PEF treatment alone [156]. The shelf of skim milk under HIPEF treatment (40 kV/cm, 60 μs; 36 kV/cm, 84 μs) was enhanced to 14 days when stored at 4°C [68]. Whole milk processed with HIPEF (35.5 kV/cm, 1000 μs) had a shelf life of 5 days at 4°C and change in acidity was not observed during storage [156]. Subjecting chocolate milk to HIPEF (30 kV/cm, 45 μs) prior to heating at 105°C and 112°C for 31 s resulted in product having shelf life of 119 days at ambient (37°C) storage temperature [135].

1.3.5 INACTIVATION OF ENZYMES BY PEF

The alkaline phosphatase enzyme activity was reduced by 65% in simulated milk ultra-filtrate (SMUF) subjected to electric field strength 22 kV/ cm and seventy pulses using static chamber [31]. The 90% reduction in plasmin activity in SMUF at 30 kV/cm after 50 pulses was observed [199]. Destruction of plasmin by non-thermal PEF is of significance since its activity can cause bitterness and gelation in UHT milk. PEF treatment at 21.5 kV/cm achieved 60% reduction in the milk lipase activity too. Inactivation of protease and lipases produced by psychrotropic microorganism such as *Bacillus* and *Pseudomonas* by use of PEF is of significance in dairy industry since these enzymes are heat-stable and some remain active even after high-temperature treatment. The inactivation of enzymes was increased with field strength, treatment time, input energy and pulse frequency and was dependent on the composition of milk. The inactivation of enzymes in skim milk was higher than that of whole milk. PEF treatment at 21.5 kV/cm and high-energy input reduced the lipase and peroxidase activity of raw milk by 65% and 25%, respectively with negligible effect on alkaline phosphatase activity [82].

1.3.6 APPLICATION OF PEF IN JUICE PROCESSING

Juice extraction from Chardonnay white grape using PEF with two pressure conditions was studied by Grimi [83]. A PEF treatment of 400 V/cm was applied. The PEF pre-treatment increased the juice yield by 67 to 75% compared to the control sample without any adverse effects. The juice volume, total phenolics, betacyanins, betaxanthins concentrations and antioxidant activity were increased ($p = 0.01$) for PEF treated beetroot juice compared to non-PEF treated. Whole beetroots were treated with 1.5 kV/cm electric field, 0.66 μF capacitance and 20 pulses [207].

1.3.7 EFFECT OF PEF ON OSMOTIC DEHYDRATION

Carrot slices (2 cm in diameter, 1 cm in thickness) were pre-treated with PEF at different levels with exponential pulses, 5 pulses and a total specific energy input range of 0.04–2.25 kJ/kg [170]. The electric field strength range was 0.22 to 16 kV/cm and pulse duration between 378 and 405 μs. Both PEF-treated and untreated samples were osmotically dehydrated (immersion in 50° B sucrose solution at 40°C for 5 h). PEF pre-treated samples showed the decrease in moisture content and the increase in solid content during osmotic dehydration.

1.3.8 APPLICATION OF PEF IN PROCESSING OF EGGS

The liquid whole egg with 0.15% citric acid processed at 35 kV/cm for 20 μs and at a maximum temperature of 45°C was preferred over a commercial brand in an acceptance test. Also, scrambled eggs under PEF were not distinguished from a control in a triangle test and did not detect significant changes in the viscosity, °Brix, and color parameters between untreated liquid whole egg controls and samples treated with PEF (25 kV/cm, 250 μs) plus a following heat treatment at 55°C for 3.5 min. These treatment conditions were chosen to obtain a product with a long shelf life in refrigeration temperatures (more than 60 days), since PEF alone resulted insufficient [164].

1.3.9 APPLICATION OF PEF IN EXTRACTION OF BIOACTIVE COMPOUNDS

Thirteen percent increase in total polyphenolic (TP) content in fresh pressed grape juice was reached in comparison to the referent sample simultaneously with 24% increase of TP content in grape residue, under treatment conditions of 0.5 kV/cm, 50 pulses, 0.1 kJ/kg 2.4 kV/cm, and 50 pulses 2.3 kJ/kg [10]. There was a higher juice yield (75%) of PEF-treated vine grapes in comparison to referent sample (70%). With 3 kV/cm and 50 pulses, total anthocyanin content was almost 3 times higher than that in the untreated grapes [197].

1.4 ULTRASOUND TECHNOLOGY

Use of ultrasound in food processing includes extraction, drying, crystallization, filtration, de-foaming, homogenization, meat tenderization and preservation. Ultrasound is one of the non-thermal methods that are used for foods in the last decades. It can be applied to solid, liquid and gas systems for different purposes. Its instrumentation can be fully automated to allow precise measurements [57]. The principle aim of ultrasound technology is to reduce the processing time, save energy and improve the shelf-life and quality of food products [37]. The advantages of ultrasound over the heat treatment include; minimization of flavor loss, greater homogeneity and significant energy savings [60, 202].

Ultrasound refers to sound waves, mechanical vibrations, which propagate through solids, liquids, or gases with a frequency greater than the upper limit of human hearing. The range of human hearing is from about 16 Hz to 18 kHz. When these waves propagate into liquid media, alternating compression and expansion cycles are produced. During the expansion cycle, high intensity ultrasonic waves make small bubbles to grow in liquid. When they attain a volume at which they can no longer absorb enough energy, they implode violently. This phenomenon is known as cavitation. During implosion, very high temperatures (approximately 5000 K) and pressures (estimated at 50 MPa) are reached inside these bubbles.

1.4.1 ULTRASOUND GENERATION

Ultrasonic wave producing system consists of generator, transducer and the application system. Generator produces electrical or mechanical energy; and transducer converts this energy into the sound energy at ultrasonic frequencies.

There are three main types of transducers: fluid-driven, magnetostrictive and piezoelectric [151]. The fluid-driven transducer produces vibration at ultrasonic frequencies by forcing liquid to thin metal blade which can be used for mixing and homogenization systems. The magnetostrictive transducer is made from ferromagnetic materials which change in dimension upon the application of a magnetic field and these changes produce mechanical vibrations. The efficiency of system is about for conversion into an acoustic energy [123]. The piezoelectric transducers produce acoustic energy by changes in size produced by electrical signals in piezo-ceramic materials such as lead zirconate titanate, barium titanate and lead metaniobate. The piezoelectric transducers are most commonly used devices and are more efficient (80–95% transfer to acoustic energy) [123, 151].

1.4.2 CLASSIFICATION OF ULTRASOUND APPLICATIONS

Methods of ultrasound applications can be divided: (i) direct application to the product, (ii) coupling with the device, and (iii) submergence in an ultrasonic bath [3]. Also, ultrasonic applications in the food industry are divided into two distinct categories according to the energy generated by sound field: Low and high energy ultrasounds, which are classified by the sound power (W), sound energy density (Ws/m^3) and sound intensity (W/m^2).

Low energy (low power, low-intensity) ultrasound applications are performed at frequencies higher than 100 kHz and below 1 W/cm^2 intensities. Small power level is used for low intensity ultrasound so that it is non-destructive and no change occurs in the physical or chemical properties of food. Low intensity ultrasound in the food industry is generally used for analytical applications to get information on the physicochemical properties of foods such as composition, structure and physical state [101].

High energy (high power and high-intensity) ultrasonic applications are performed generally at frequencies between 18 and 100 kHz and at intensities higher than 1 W/cm^2 (typically in the range 10–1000 W/cm^2) [138]. At this power, destruction can be observed due to the physical, mechanical or chemical effects of ultrasonic waves (e.g., physical disruption, acceleration of certain chemical reactions). High-intensity ultrasound has been used for many years to generate emulsions, disrupt cells and disperse aggregated materials. More recently, it is used for many purposes such as: modification and control of crystallization processes, degassing of liquid foods, enzyme inactivation, enhanced drying and filtration and the induction of oxidation reactions [138].

1.4.3 METHODS OF ULTRASOUND

Ultrasound can be used for food preservation in combination with other treatments by improving its inactivation efficacy. There have been many studies combining ultrasound with either pressure, temperature, or pressure and temperature, some of them are briefly discussed below:

1. Ultrasonication (US) is the application of ultrasound at low temperature. Therefore, it can be used for the heat sensible products. However, it requires longer treatment time to inactivate stable enzymes and/or microorganisms, which may cause high energy requirement. During ultrasound application, there may be a rise in

temperature depending on the ultrasonic power and time of application; and needs control to optimize the process [224].

2. Thermosonication (TS) is a combined method of ultrasound and heat. The product is subjected to ultrasound and moderate heat simultaneously. This method produces a greater effect on inactivation of microorganisms than heat alone. When TS is used for pasteurization or sterilization purpose, lower process temperatures and processing times are required to achieve the same lethality values as with conventional processes [137, 213].
3. Manosonication (MS) is a combined method in which ultrasound and pressure are applied together. MS provides to inactivate enzymes and/or microorganisms by combining ultrasound with moderate pressures at low temperatures. Its inactivation efficiency is higher than ultrasound alone at the same temperature.
4. Manothermosonication (MTS) is a combined method of heat, ultrasound and pressure. MTS treatments inactivate several enzymes at lower temperatures and/or in a shorter time than thermal treatments at the same temperatures [36]. Applied temperature and pressure maximizes the cavitation or bubble implosion in the media, which increases the level of inactivation. Microorganisms that have high thermos tolerance can be inactivated by MTS. Also some thermos – resistant enzymes (such as: lipoxygenase, peroxidase and poly-phenoloxidase and heat labile lipases and proteases from pseudomonas) can be inactivated by MTS [133].

1.4.4 APPLICATIONS IN DAIRY INDUSTRY

1.4.4.1 Applications in Cheese

When sonication was applied to milk to study the proteolytic activity of the enzymes related to curdling, the main observable effect was that ultrasound speeds up the hardening of the curd and the final product showed a better firmness because of the activity on the chymosin, pepsin and other related enzymes [214]. When ultrasound (20 kHz) was used to enhance the extraction not only the yield and enzyme activity were increased considerably, but also extraction times were much shorter than without sonication, due to the destruction of cellular structure because of the action of ultrasound, increasing the activity of the substances contained in the cells and the migration of proteins and minerals from the cells to the solution. The activity of the chymosin was increased with sonication and the nitrogen content of the extract was decreased at the same time. During cheese making, the methods used to test curd firmness are destructive methods (penetrometers, suspended bodies, torsion viscometers, and rotational viscometers) that are not easy to automate. A pulse-echo technique has been used to determine variations in ultrasonic attenuation and velocity during the coagulation process [12].

The changes during enzymatic coagulation were planned by ultrasound using 1-MHz transducer and the pulse-echo technique. Ultrasonic velocity did not show any variation during coagulation, but ultrasonic dilution was decreased when coagulation progressed, due to changes in viscosity, which increases the viscous attenuation of ultrasound [7]. Resonant techniques (sonic frequencies) have been used to classify defects in cheese based on the differences found in the spectrum of cheeses with and without defect. The pulse-echo technique was used to estimate the size and number of voids in kamaboko by counting the number of ultrasonic echo pulses on the oscillograms [195]. Using this technique, cracked cheeses can be identified. Furthermore, it is also possible to determine the distance of the crack from the surface by assuming a range of velocities that include the maximum and minimum values found for the particular type of cheese. The calculated range for the cheese was 1.84–1.98 cm (at velocity range 1620–1740 m/s), which coincided with the distance measured with a digital gauge (1.9 cm).

1.4.4.2 Applications in Lactose-Free Milk

Lactose-free milk without lactose can be produced by fermentation of lactose-hydrolyzed milk or by the simultaneous addition of β-galactosidase and lactic acid bacteria. These bacteria produce β-galactosidase, which hydrolyses the lactose in fermented milk. Ultrasound has the capability of raising the reaction activity of cells or to stimulate a new action into the cells, for example, in sterol synthesis with baker's yeast or in lactose hydrolyzed fermented milk. Using ultrasound in the processing of lactose-free milk, the lactose hydrolysis was around 55% compared to 36% with traditional methods to produce lactose-free milk (fermentation) [215].

1.4.4.3 Applications in Ice Cream

A narrow ice crystal size distribution is necessary for production of high quality ice-cream with smooth texture and desired sensory characteristics [176]. High power ultrasound treatment of ice cream inside the scraped surface freezer induces crystal fragmentation by cavitation bubbles and also prevents accumulation on the cold surface due to the high heat transfer rate [136]. Increasing the ultrasound pulse time significantly decreased the freezing process time of ice cream, and improved sensory flavor, texture and mouth feel [150].

1.4.4.4 Applications in Homogenization and Emulsification

Sonication of fresh cow milk at 20 kHz resulted in a reduction in the size of fat globules. Homogenization at a power level of 40 for 10 min was similar to conventional homogenization [213]. Ultrasonic emulsification is mainly driven by cavitation, wherein the bubbles collapse at the interface of two immiscible continuous and dispersed phases [136]. High amplitude homogenization also improved the water-holding capacity and viscosity and also reduced syneresis of yogurt produced from ultrasonicated milk [145].

1.4.4.5 Applications in Milk Adulteration

Milk adulteration has usually consisted of adding water. To detect this fraud, the variation of ultrasonic velocity in two types of milk, cow and buffalo, adulterated with different percentages of water was measured [18]. Ultrasonic velocity of cow and buffalo milk was found to be different due to the differences in composition. In both cases, velocity was decreased in line with the water addition and was dependent on temperature, density and viscosity of the samples [18].

1.4.4.6 Applications in Fouling Detection

When dairy products are processed in continuous high temperature processing plants, the internal walls of the plant can become fouled by burnt on or chemically deposited material. The fouling layer will affect the flow rate and also heat flow to or from the product. An ultrasonic sensor has been developed to detect and measure the thickness of these films in a dairy plant [217]. The sensor was operated by transmitting a pulse of ultrasound across the pipe being tested. The received signal was analyzed in the time domain to determine film presence and thickness. Thickness measurement was possible over a range of 0.5–6.0 mm. Product temperature compensation over a temperature range of 20–140°C was implemented. Changes in product flow rate from 0 to 25 l/min and pressure from 0 to 3 bars had no effect on the ultrasonic measurements.

1.4.5 EFFECT OF ULTRASONICATION ON MICROBIAL INACTIVATION

Combined effect of power ultrasound and heat (thermosonication) has proved to be more efficient method of microbial inactivation than either of the two methods alone [172]. Microbial inactivation of ultrasound treatment accounts for generation of acoustic cavitations, resulting in increased permeability of membranes, selectivity loss, cell membrane thinning [180], confined heating [194] and singlet electron transfer in cooling phase [124]. Ultrasonic power of 100 W was found to be optimal for maximum microbial inactivation [222] and US has been found to be effective method for microbial inactivation in *Escherichia coli*, *Listeria monocytogenes*, and other pathogens [73]. Efficiency of ultrasonic treatment as antimicrobial tool depends on the physical (size, hydrophobicity) and biological (gram-status, growth phase) characteristics of the micro-organisms. It has been demonstrated that micro-organisms with "soft" and thicker capsule are extremely resistant to ultrasonic treatment [76].

1.4.6 EFFECT OF ULTRASONICATION ON ENZYME INACTIVATION

Heat treatment to eliminate enzymes is the commonly used method but it also destroys nutrients and may cause loss of food quality. For this reason, non-thermal technologies are being tested as an option for reducing the enzymatic activities in foods [66]. Ultrasound is an effective method in the inactivation of enzymes when it is used alone or with temperature and pressure. There are many enzymes inactivated with ultrasound such as: glucose oxidase [84], peroxidase [49, 177], pectin methyl esterase [171], protease and lipase [208, 209], watercress peroxidase [45] and poly-phenoloxidase [168]. TS is used as a means for enzyme inactivation such as lipoxygenase, peroxidase, lipase, and protease, and tomato or orange pectin methylesterase [171].

The ultrasound stability of individual proteins varies between the enzymes [41, 132, 160, 210, 211] and also depends on ultrasound treatment conditions [172], the composition of treatment medium, treatment pH, and whether they are bound (e.g., membrane-bound proteins) or free (e.g., cytoplasmic proteins). Enzyme inactivation generally increases with increasing ultrasound power, ultrasound frequency, exposure time, amplitude level, cavitation intensity, processing temperature and processing pressure, but decreases as the volume being treated increases [172, 211].

1.4.7 ULTRASONICATION IN MEAT TECHNOLOGY

A large number of applications of ultrasonic treatment are reported in meat technology like, reduction of meat toughness due to large proportion of connective tissue [100], examining the composition of fish, poultry, raw, and fermented meat products by supporting genetic enhancement programs in case of livestock [75] and in the tenderization of meat products.

1.4.8 ULTRASONICATION IN FRUIT AND VEGETABLE PROCESSING

US is used to maintain both pre- and post-harvest quality attributes in fresh fruits and vegetables [75] and is considered a substitute for washing of fruit and vegetable in the food industry [14]. In an attempt to meet the consumers' needs of not only maintaining but also improving the nutritional value of fruit juices [15, 16], US has proved to be one such technique [1] and is described to retain fresh quality, nutritional value, and microbiological safety in guava juice [38], orange juice [205], and tomato juice [221].

Ultrasound treatment can also be used to recover the nutrient loss occurred during blanching, resulting in achieving the collaborative benefit of both the techniques [98]. US cleaners (20–400 kHz) have been efficiently used to produce fruits and vegetables free of contamination [129]. At 40 kHz, it has been applied on strawberry fruits, in which decay and infection were considerably reduced along with quality maintenance [29].

1.4.9 ULTRASONICATION IN EMULSIFICATION

US is relatively cheaper technique for emulsion formation with significant effect on emulsion droplet size and structure. In ultrasonic emulsification application of high energy, researchers observed viscosity decrease and lesser particle size distribution in sub-micron oil-droplets emulsions. However, change in sonication parameters caused remarkable change in stability and oil droplet size of the emulsion formed [108]. Ultrasonically produced W/O emulsions are used by emulsion liquid membrane for the separation and recapture of cationic dyes, and the stability is governed by operating variables such as emulsification time, carrier, ultrasonic power, surfactant and internal phase concentrations, volume ratios of internal phase to organic phase and of external phase to W/O emulsions, stirring speed, contact time, and diluents [56].

1.4.10 ULTRASONICATION IN OIL TECHNOLOGY

US stimulates the mixing and desired reaction for conversion of soybean oil to biodiesel and can achieve optimum yield using 9:1 oil to methanol ratio [181]. Ultrasonic irradiation is also used to increase the rate of transesterification [53].

1.4.11 ULTRASONICATION IN HONEY

Ultrasound applications in honey include use of velocity of ultrasonic wave propagation as a means to differentiate between different types of honey determination of adulteration in honey and evaluation of the type of protein, aggregation state, and size [75].

1.4.12 ADVANTAGES AND DISADVANTAGES OF ULTRASONICATION

- Ultrasound waves are non-toxic, safe, and environmentally friendly [112].
- US in combination with other non-thermal methods is considered an effective means of microbial inactivation [211].
- US involves lower running cost, ease of operation, and efficient power output.
- US does not need sophisticated machinery and wide range of technologies [75].
- Use of ultrasound provides more yield and rate of extraction as compared to other conventional methods of extraction [9].
- US involves minimum loss in flavor, superior consistency (viscosity, homogenization) and significant savings in energy expenditure [33].
- Ultrasound has gained huge applications in the food industry such as processing, extraction, emulsification, preservation, homogenization, etc. [36].

1.4.13 DISADVANTAGES OF ULTRASONICATION

- Ultrasound due to shear stress developed by swirls from the shock waves (mechanical effects) cause inactivation of the released products [122].
- Ultrasound application needs more input of energy which makes industrialists to think over while using this technique on commercial scale [222].
- Ultrasound induces physicochemical effects which may be responsible for quality impairment of food products by development of off – flavors, alterations in physical properties, and degradation of components.
- US leads to the formation of radicals as a result of critical temperature and pressure conditions that are responsible for changes in food compounds. The radicals (OH and H) produced in the medium deposit at the surface of cavitation bubble that stimulates the radical chain reactions which involve formation of degradation products and thus lead to considerable quality defects in product [46].

- Frequency of ultrasound waves can impose resistance to mass transfer [62].
- Ultrasonic power is considered to be responsible for change in materials based on characteristics of medium. So, this power needs to be minimized in the food industry in order to achieve maximum results [65].

1.5 OHMIC HEATING

Heating technologies for processing and preservation of foods have observed marvelous advancements with the development of technologies such as ohmic heating, dielectric heating (which includes microwave heating and radio frequency heating) and inductive heating. All the advanced methods of processing are highly energetic and efficient as the heat is generated directly inside the food. These are called novel thermal processing technologies.

Ohmic heating is also-called Joule heating, electrical resistance heating, direct electrical resistance heating, electro heating or electro conductive heating. It is a process where heat is internally generated due to electrical resistance, when electric current is passed through it [4]. Ohmic heating is distinguished from other electrical heating methods as the electrodes are in contact with the foods unlike in microwave and inductive heating where electrodes are absent, the applied frequency is lower as compared to radio or microwave frequency range and also the waveform is unrestricted, although typically sinusoidal. A successful application of electricity in food processing was developed in the 19th century to pasteurize milk called "electropure process" [81]. But this application was dejected apparently due to high processing costs [72]. Also, other applications were abandoned because of the short supply of inert materials needed for the electrodes [144]. However recent research has been carried out by various scientists worldwide on fruits, vegetables and meat products, flours and starches, etc. [32, 161, 216]. The ohmic heating system helps in the production of highly shelf-stable products with proper maintenance of the color and nutritional value of food. Ohmic heating is one of these alternative-processing techniques to emerge in the last 20 years [17].

1.5.1 FUNDAMENTAL PRINCIPLE OF OHMIC HEATING

Ohmic heating method is one of the several electromagnetic based methods such as capacitive dielectric, radiative, dielectric, inductive and radiative magnetic heating. Ohmic heating is somewhat similar to microwave heating but with very different frequencies [48]. Ohmic heating (direct resistance heating) is a process in which food liquids and solids are heated simultaneously bypassing an electric current through them.

The applicability of ohmic heating is dependent on product electrical conductivity. Most food preparations contain a moderate percentage of free water with dissolved ionic salts and therefore conduct sufficiently well for the ohmic effect to be applied. The ohmic heater column typically consists of seven-electrode housing machined from a solid block of polytetrduoroethylene and encased in stainless steel, each containing a single cantilever electrode. The electrode housings are connected using stainless-steel spacer tubes lined with a generally recognized as safe electrically insulating plastic. The column is mounted in a vertical or near-vertical position, with upward flow of product. A vent valve positioned at the top of the heater ensures that the column is always full. The column is configured so that each heating section has the same electrical impedance. Hence, the interconnecting tubes generally increase in length toward the outlet because the electrical conductivity of food products usually increases with increase in temperature. For aqueous solutions of ionized salts, there is a linear relationship between temperature and electrical conductivity, due to increased ionic mobility with increase in temperature and it applies to most food products. Exceptions could be products in which viscosity increases markedly at a higher temperatures, such as those containing un-gelatinized starches [162].

1.5.2 ADVANTAGES OF OHMIC HEATING

- Continuous production without heat-transfer surfaces;
- Rapid and uniform treatment of liquid and solid phases with minimal heat damage; and
- Nutrient losses (e.g., unlike microwave heating, which has a finite penetration depth into solid materials);

- Ideal process for shear-sensitive products because of low flow velocity;
- Optimization of capital investment and product safety as a result of high solids loading;
- Reduced fouling when compared to conventional heating;
- Better and simpler process control with reduced maintenance costs;
- Environmentally friendly system;
- Maintenance of the color and nutritional value of food;
- Less cleaning requirements;
- Heating of particulate foods and liquid–particle mixtures;
- Low risk of product damage due to burning;
- High energy conversion efficiency.

1.5.3 DISADVANTAGES OF OHMIC HEATING

The installation and operation cost of ohmic food processing systems was found to be more costly as compared to that of conventional retorting, freezing and heating in a conventional tubular heat exchanger and ohmic heating [6].

The food containing fat globules is not effectively heated during ohmic heating process, as it is non-conductive due to lack of water and salt [166]. If these globules are present in a highly electrical conductive region where currents can bypass them, they may heat slower due to lack of electrical conductivity. Any pathogenic bacteria that may be present in these globules may receive less heat treatment than the rest of the substance [182].

Also there is the possibility of ‘runaway’ heating [69]. As the temperature of a system rises, the electrical conductivity also increases due to the faster movement of electrons.

1.5.4 APPLICATIONS OF OHMIC HEATING

1.5.4.1 Applications of Ohmic Heating Extraction

The application of ohmic heating in conjunction with extraction processes increased the extraction efficiency of sucrose from sugar beets [110]. Diffusion of beet dye from beetroot into a carrier fluid was increased in ohmic heating and the amount of dye extracted was proportional to the strength of electrical field [128]. Ohmic heating improved the extraction of soymilk from soybeans [113].

1.5.4.2 Applications of Ohmic Heating Enzyme Inactivation

In addition to improvement food quality (e.g., texture and flavor) and for the recovery of by-products, enzymes may also have negative effects on food quality such as production of off –odors, tastes and altering textural properties. Therefore, control of enzymatic activity is required in many food processing steps to promote/inhibit enzymatic activity.

The effects of electric field on important food processing enzymes have been studied and reported in literature [33]. The tested enzymes were polyphenoloxidase (PPO), lipoxygenase, pectinase, alkaline phosphatase and β-galactosidase and the inactivation assays were performed under conventional and ohmic heating conditions. All the enzymes followed 1st-order inactivation kinetics for both conventional and ohmic heating treatments. The presence of an electric field did not cause an enhanced inactivation to alkaline phosphatase, pectinase, and β-galactosidase. However, lipoxygenase and PPO kinetics were significantly affected by the electric field, reducing the time needed for inactivation. Fresh grape juice was ohmically heated at different voltage gradients (20, 30, and 40 V/cm) from 20°C to temperatures of 60, 70, 80 or 90°C and the change in the activity of PPO enzyme was measured [97]. The critical deactivation temperatures were at 60°C or lower for 40 V/cm, and 70°C for 20 and 30V/cm. Various kinetic models for the deactivation of PPO by ohmic heating at 30 V/cm were fitted to the experimental data. The simplest kinetic model involving one step first-order deactivation was better than more complex models. The activation energy of the PPO deactivation at the temperature range of 70–90°C was 83.5 kJ/mol.

Ohmic heating using continuous alternating current electric field was applied to orange juice containing *Bacillus subtilis* spores to examine its inactivation. An effective inactivation of spores was achieved using a pressurized electric sterilization system, using a combination of high temperature and high electric field, in a shorter time. Also the loss in the ascorbic acid and development of peculiar smell was minimized in ohmic heating [201].

1.5.4.3 Applications of Ohmic Heating in Blanching

The peroxidize inactivation and color changes during ohmic blanching of pea puree were studied by application of four different voltage gradients in the range of 20–50 V/cm; the puree samples were heated from 30 to 100°C to achieve adequate blanching. The conventional blanching was performed at 100°C water bath. The ohmic blanching was applied by using 30 V/cm and above. Voltage gradient inactivated peroxidase enzyme in lesser time than the water blanching. The ohmic blanching at 50 V/cm gave the shortest critical inactivation time of 54 s with the best color quality. First order reaction kinetics adequately described the changes in color values during ohmic blanching. Hue angle is the most appropriate combination ($R^2 = 0.954$), which describes closely the reaction kinetics of total color changes of pea puree for ohmic blanching at 20 V/cm [96].

1.5.4.4 Applications of Ohmic Heating in Pasteurization and Sterilization

Ohmic heating is very often used in pasteurization/sterilization of food products resulting in excellent quality it also enhanced the air drying rate [128, 192]. In a recent study, the use of ohmic heating on sterilization of guava juice has reported [62]. The resistance heating technique was used for milk pasteurization in the early 20th century [165]. Ohmic heating can be used for ultra-high temperature (UHT) sterilization of foods. A reusable pouch with electrodes for long term space missions was developed [106]. The pouch permits reheating and sterilization of its internal contents. The 3-D model design ensured sterility and permitted identification of cold spots over the entire pouch. This 3-D model was observed to be useful tool to optimize electrode configurations and to assure adequate sterilization process.

1.5.4.5 Applications of Ohmic Heating in Fruit and Vegetable Products

The nutritional quality of most of the fruits and vegetable products is altered during conventional thermal processing. This necessitates the search for alternative processing technologies to achieve better quality of end products. Several strawberry based products were tested by ohmic heating. The results proved that high heating rates could be achieved for most of the products. Also, the increase of the applied electric field could increase the heating rate. The suitability of ohmic heating for strawberry products having different solids concentrations was also evaluated [33]. Electrical conductivity was observed to be decreased with the increase in solid contents in a mixture of particles, but the decrease was more significant for the bigger particles. The results also suggested that for higher solid content (> 20% w/w) and sugar contents over 40.0° Brix, electrical conductivity was too low to use in the conventional ohmic heaters and a new design is required.

1.5.4.6 Applications of Ohmic Heating in Milk Fouling

The influence of material (stainless steel. tin, and graphite electrodes), flow rate, electric current density (at constant frequency 50 Hz) and temperature (in a limited temperature range 65–75°C) on the fouling of skimmed milk during direct ohmic heating was studied and it was observed that the stainless steel electrodes are worst while the graphite electrodes, where no fouling was observed, are the best, thus confirming the significant role of corrosion and electrical phenomena [189].

While studying the hydrodynamic behavior of milk in a flat ohmic cell, it was found that fouling of fluid occurs due to greater quantity deposited in the zone where the temperature is lowest (entrance zone) and velocity is non-uniform. During continuous ohmic heating, there is a chance of slightest hydrodynamic disturbance which results in a thermal and electric disturbance and there by creates zones, which are subjected to fouling [8].

1.5.4.7 Applications of Ohmic Heating in Waste Water Treatment

Waste water treatment is one of the problems in surimi production due to high volume and high biological oxygen demand (BOD) of water. Protein coagulation by heating and subsequent separation is the method to reduce the BOD of waste water having high protein concentration. Ohmic heating is an efficient heating method to heat the fluid. Thus ohmic heating might be a viable alternative for waste water treatment in surimi production plants [182].

A continuous ohmic heating system to coagulate protein from surimi waste water to reduce the biological oxygen demand of the waste water were developed and a simple model, based on the energy conservation equation, was used to predict the temperature profiles of the waste water. Samples were diluted and NaCl solution (10% by wt.) was added to make them suitable for testing in the developed device. All samples were heated under different conditions (electric field strength of 20, 25 and 30 V/cm; flow rates of 100, 200 and 300 cc/min). After heating, the samples were centrifuged and the remaining protein in supernatants was measured and compared with the results from the previous batch experiments. Heating under higher electric field strength and lower flow rates resulted in higher temperatures of samples. The predicted temperature values agreed well with the experimental results. The amount of the remaining protein was also in agreement with that of the previous work. The lab scale ohmic heating system possessed good performance to coagulate protein (60%) from surimi waste water [109].

1.6 FOOD IRRADIATION

Food irradiation is a process in which food products are exposed to ionizing radiation in form of gamma radiation, X-rays and electron beams in a controlled amount to destroy pathogenic microorganisms in order to increase its safety and shelf life [219]. It can be used to replace chemical preservatives as well as thermal treatment. It is considered as cold pasteurization of food.

The use of gamma irradiation in dairy products is one of the most important peaceful application [218]. There was no hazard caused by irradiation up to 10 kilo gray which did not cause cancer, genetic mutation or tumors [139]. Therefore, hospitals use irradiated food for patients with severely impaired immune system [118]. In 1981, the United Nation Food and Agricultural Organization (UN-FAO-WHO) endorsed irradiation doses up to 10 k Gray as a major technology for the prevention of food borne illness and for the reduction in food losses due to spoilage by microorganisms and vermin. Ionizing radiation is now approved for use in more than 41 countries for over 35 specified foods, and the list is growing [30, 131, 198]. Approximately 26 countries currently employ radiation on a commercial scale for food application [191]. Many consumers are not adequately educated about the safety of irradiated foods. Investment for a commercial irradiator facility is high. As a result, it is very challenging for a food preserved with an unconventional technology to enter and compete in the market place [70].

1.6.1 FOOD IRRADIATION METHODS

Three principal types of radiation source can be used in food irradiation according to the *Codex Alimentations General Standard* [69].

Gamma radiation source is from radionuclides such as 60 Cu (copper) or 137 C_s (cesium), Machine sources of electron beams with energies up to 10 MeV, Machine sources of bremsstrahlung (X rays) with electron energies up to 5 MeV. Because of their greater penetrating capability, gamma rays and X-rays may be used for processing of relatively thick or dense products. Ionizing radiation for food processing is limited to high energy photons (gamma rays) of radio nuclides 60 Cu or C_s, X-rays from machine sources with energies up to 5 MeV and accelerated electrons with energies up to 10 MeV generated by electron accelerating machines [95]. These kinds of Ionizing radiation are preferred due to: the suitable food preservative effects do not generate radioactivity in foods or packaging materials and available at costs as commercial use of the irradiation process [64].

1.6.2 ADVANTAGES OF IRRADIATION

To ensure hygienic quality of food, the use of ethylene oxide fumigation for decontaminating the ingredients has been increasing restricted in recent years. The European community is used a directive, which prohibited the use of ethylene oxide on food starting effective January 1991 [55]. Most microorganisms and all insects cause damage to fresh commodities such as fish, meat, fruit, vegetable, etc., and their products are sensitive to low dose irradiation. Thus, irradiating the food with dose between 1 and 5 kGy resulted in insect's disinfestation and a several fold reduction of spoilage microorganisms, thereby extending the shelf life of the food [204].

1.6.3 LIMITATIONS OF IRRADIATION

Food treatment adds cost to the product. Like other physical food processes, irradiation has high capital costs and requires a critical capacity and product volume for economic operation. A number of market tests of irradiated food have been carried out in the past five years with interesting results [203], by consumer critical education.

1.6.4 PROCESS OF IRRADIATION

During the irradiation process, food is exposed to the energy source in such a way that a precise and specific dose is absorbed. To do that, it is necessary to know the energy output of the source per unit of time, to have a defined spatial relationship between the source and the target and to expose the target material for a specific time. The radiation dose ordinarily used in food processing ranges from 50 Gy to 10 kGy, and depends on the kind of food being processed and the desired effects [220].

The actual dose of radiation employed in any food processing application represents a balance between the amount needed to produce a desired result and the amount the product can tolerate without suffering unwanted change. High radiation dose can cause organoleptic changes (off-flavors or changes in texture), especially in foods of animal origin, such as dairy products. In fresh fruits and vegetables, radiation may cause softening and increase the permeability of tissue [219].

1.6.5 IRRADIATION OF DAIRY PRODUCTS

Shelf life extension and/or sterilization of dairy products for making it shelf stable using radiation treatment are not a widely accepted practice. The reason for its limited use is that ionizing energy, through the formation of radiolytic products especially in high lipid-based foods, generates unacceptable off-odors and flavors via oxidation, or complementary with use of other preservation techniques including refrigeration and/or preservatives such as sorbic acid. Cheddar cheese developed off-flavors when irradiated at 0.5 kGy. However, none was detected when the dose was reduced to 0.2 kGy [21]. A dose > 1.5 kGy when applied to Turkish Kashar cheese, not only resulted in off-flavor development but also contributed to color deterioration [103]. By decreasing the dose to 1.2 kGy, the sensory problems were eliminated and the mold-free shelf life was extended 12 to 15 days when stored at room temperature. In contrast, non-irradiated cheese became moldy within 3 to 5 days. When combined with refrigeration storage, radiation increased the shelf-life period of the cheese five-folds. With Gouda cheese, however, no taste difference was reported between irradiated (3.3 kGy) and non-irradiated samples [175]. In order to stabilize the cheese by preventing additional growth of *Penicillium roqueforti*, a minimal dose of 2.0 kGy was recommended. Results from a subsequent study, however, reported that full fat Camembert cheese suffered no off-flavor development up to a dose of 3 kGy [39] and treatment at 2.5 kGy was sufficient to eliminate initial populations of 103 to 104 colony forming units (cfu)/g of the pathogen *Listeria monocytogenes* [15]. In contrast, flavor changes were quite noticeable when radiation treatment was applied to cottage cheese, the minimal threshold dose being 0.75 kGy. At this dosage, the cheese was described as having a slight bitter, cooked, or foreign taste. However, in order to reduce spoilage by psychrotrophic bacteria by at least three logs, the applied dose would have to be nearly doubled [103]. This resulted in cheese with a definite burnt off-flavor. Using electron beam irradiation and doses of 0.21 and 0.52 kGy, the shelf life of vacuum packaged cheddar cheese at 10°C containing 101 cfu/cm^2, *Aspergillus ochraceus* spores was extended by approximately 42 and 52 days, respectively [20].

Sterilization of yogurt bars, ice cream, and non-fat dry milk by gamma irradiation using a dose of 40 kGy at –78°C resulted in an overall decrease in acceptance [103]. Although the use of MAP or the inclusion of antioxidants appeared to reduce the level of off-flavors, yet the effects were product specific. Irradiation of fluid milk also resulted in unacceptable flavor scores. Off-flavors and browning originating from chemical reactions involving lactose were identified. Irradiation preservation of yogurt was similarly investigated. Left at room temperature, plain yogurt reached a population of 109 cfu/g by 6 days and was judged unacceptable. However, when treated with gamma irradiation using a dose of 1 kGy, this population level was not reached until 18 days of incubation. Irradiation combined with refrigeration further extended the shelf life of yogurt to 30 days. In comparison, the shelf life of the refrigerated controls was only 15 days [120].

1.7 DEGREES OF FOOD PROCESSING

1.7.1 MINIMALLY PROCESSED FOODS

Not all foods undergo the same degree of processing. In this section, processed foods are classified in three categories: minimally processed food, processed food ingredients, and highly processed food [147].

Fruits, vegetables, legumes, nuts, meat and milk are often sold in minimally processed forms. Foods sold as such are not substantially changed from their raw, unprocessed form and retain most of their nutritional properties. Minimal forms of processing include washing, peeling and slicing, juicing and removing inedible parts [157].

1.7.2 PROCESSED FOOD INGREDIENTS

This group includes flours, oils, fats, sugars, sweeteners, starches and other ingredients. High fructose corn syrup, margarine and vegetable oil are common examples. Processed food ingredients are rarely eaten alone; and these are typically used in cooking or in the manufacture of highly processed foods [146].

1.7.3 HIGHLY PROCESSED FOODS

Highly processed foods are made from combinations of unprocessed food, minimally processed food and processed food ingredients. They are often portable, can be eaten anywhere (while driving), working at the office and watching TV and require little or no preparation. Highly processed foods include: snacks and desserts, such as cereal bars, biscuits, chips, cakes and pastries, ice cream and soft drinks; as well as breads pasta, breakfast cereals and infant formula [187].

1.8 MICROWAVE HEATING

Microwave heating refers to the use of electromagnetic waves of certain frequencies to generate heat in material. For food applications, most commonly used microwave frequencies are 2450 MHz and 915 MHz. When a microwavable container with food is placed in a microwave oven, a temperature gradient develops between the center and the edges. Meat, fish, fruit, butter and other food-stuffs can be tempered from cold store temperature to around −3°C for ease of further processing (i.e., grinding of meat in production of burgers, blending and portioning of butter packs). Food products, such as bread, precooked foods have been processed using microwaves for pasteurization or sterilization or simply to improve their digestibility.

1.8.1 BASIC COMPONENTS OF MICROWAVE HEATING

These include: power supply and control; magnetron; waveguide; stirrer; turntable; cooking cavity; and door with choke.

1.8.2 PRINCIPLE OF MICROWAVE HEATING

Microwave heating in foods occurs due to coupling of electrical energy from an electromagnetic field in a microwave cavity with the food and its subsequent dissipation within food product. This results in a sharp increase in temperature within the product. Microwave energy is delivered at a molecular level through the molecular interaction with the electromagnetic field, in particular, through molecular friction resulting from dipole rotation of polar solvents and from the conductive migration of dissolved ions. Water in the food is the primary dipolar component responsible for the *dielectric heating*. In an alternating current electric field, the polarity of the field is varied at the rate of microwave frequency and molecules attempt to align themselves with the changing field. Heat is generated rapidly as a result of internal molecular friction.

The second major mechanism of heating with microwaves is through the *polarization of ions* as a result of the back and forth movement of the ionic molecules trying to align themselves with the oscillating electric field [52].

1.8.3 ADVANTAGES OF MICROWAVE TECHNOLOGY

- Microwave penetrates inside the food materials and therefore, cooking takes place throughout the whole volume of food internally, uniformly and rapidly, which significantly reduces the processing time and energy.
- Since the heat transfer is fast, nutrients and vitamins contents, as well as flavor, sensory characteristics, and color of food are well preserved.
- Minimum fouling depositions, because of the elimination of the hot heat transfer surfaces, since the piping used is microwave transparent and remains relatively cooler than the product.
- High heating efficiency (80% or higher efficiency can be achieved).
- Suitable for heat-sensitive, high-viscous and multiphase fluids.
- Low cost in system maintenance.

1.8.4 DISADVANTAGES OF MICROWAVE TECHNOLOGY

The rather slow spread of food industrial microwave applications has a number of reasons: there is the conservatism of the food industry [52] and its relatively low research budget. Linked to this, there are difficulties in moderating the problems of microwave heating applications. One of the main problems is that, in order to get good results, they need a high input of engineering intelligence. Different from conventional heating systems, where satisfactory results can be achieved easily by perception, good microwave application results often need a lot of knowledge or experience to understand and moderate effects like uneven heating or the thermal runway. Another disadvantage of microwave heating as opposed to conventional heating is the need for expensive electrical energy, high initial capital investment, more complex technology devices and microwave radiation leakage problem.

1.8.5 APPLICATIONS OF MICROWAVE TECHNOLOGY IN THE FOOD INDUSTRY

1.8.5.1 Applications of Microwave Technology in Thawing-Tempering

By using microwaves mostly with 915 MHz due to their larger penetration depth, the tempering time can be reduced to minutes or hours and the required space is diminished to one sixth of the conventional system [82]. Another advantage is the possibility to use the microwaves at low air temperatures, thus reducing or even stopping microbial growth.

Without a doubt, thawing and tempering are the most industrially widespread applications of microwave heating. There are about 400 systems in use in the United States for vegetables and fruits; and at least four in the United Kingdom for the tempering of butter. Most of the studies carried out [6, 13] have analyzed the behavior and final characteristics of diverse types of meat during microwave tempering. Tempered meat shows good final characteristics with less process time. This technology was attempted for stretching Mozzarella curd was not successful [28].

Recently, other possible applications of this technology to products such as rice balls [105] mashed potatoes [91] or cereal pellets or pieces [183] have been studied, with a few encouraging results in terms of the good physical and sensory properties. On the other hand, some studies [34, 107] were mainly focused on reaching a better understanding of the relationship between the equipment (applied powers and cycles of work) and the product (dielectric properties, loads, and geometry).

1.8.5.2 Applications of Microwave Technology in Heating of Precooked Products

The heating of precooked products is the principal practical application of microwave ovens, both in domestic use and in the catering industry, since a rapid, safe, and hygienic heating of the product is obtained [26]. The objective of pre-cooking operations is to reduce preparation time for the consumer. In the case of cereals, these operations consist basically of treating starch to reduce its gelatinization time during the final preparation of the food product. Pre-cooked rice and wheat flour with good sensory and nutritional characteristics can be prepared with microwave [35]. The precooking process can be accelerated with the help of microwaves as has been established for precooking of poultry, meat patty and bacon [22, 52].

1.8.5.3 Applications of Microwave Technology in Cooking

Microwave ovens are now being used in about 92% of homes in the United States. Microwave ovens are very popular home appliances for the food processing applications. Cooking is one of the major applications of microwave. Microwave heating is so rapid; it takes the product to the desired temperature in such a short time that product cooking does not take place; the product is hot, but has the appearance and flavor of the raw product.

There are several products used in the continuous study of this technology, such as fish [178], beans [154], egg yolk [152], and shrimp [85]. The nutritious characteristics of the food are quite well retained, but it does not reach the typical flavor of the cooked dish; thus it is necessary to combine microwave treatment with conventional technologies [41]. It is reported that there was no significant change on the loss of B-complex vitamins during microwave boiling of cow and buffalo milk in comparison to conventional heating [115]. Microwave cooking reduces cooking times of common beans and chickpeas [134]. In addition microwave treatment reduced cooking losses, increased the soluble to insoluble and soluble to total dietary fiber ratio, but did not modify in-vitro starch digestibility. A higher protein concentration in soya milk was obtained by microwave heating of soya slurry than by the conventional methods of heating such as the use of boiling water [2]. Microwave oven heating of soya slurry, which was effective for protein extraction, also made the prepared tofu more digestible.

1.8.5.4 Applications of Microwave Technology in Baking

Baking process includes three phases: expansion of dough and moisture loss initiates in the first phase; the second phase, in which expansion and the rate of moisture loss becomes maximal. The changes that continue to take place in the third phase of baking include rise in product height and decrease in rate of moisture loss because the structure of the air cells within the dough medium collapses as a result of increased vapor pressure. Baking using microwave energy has been limited due to poor product quality compared to products baked by using conventional energy sources, which can be a reflection of the differences in the mechanism of heat and mass transfer [179]. In products such as breads, cakes and cookies, microwave baking can affect texture, moisture content and color of the final product, which represents a great challenge for research. Some researchers suggested adjustments in formulation and alterations in the baking process, while others studied the interactions between microwave energy and the ingredients of the formulation [163]. A process was patented to obtain a sponge cake free from bake shrinkage and good-looking voluminous appearance, through a batter prepared by adding a thermo-coagulation protein to a sponge cake premix containing main ingredient as a cereal powder consisting of starch and a pre-gelatinized starch cooked under heat with a microwave oven [196].

1.8.5.5 Applications of Microwave Technology in Blanching

Blanching is generally used for color retention and enzyme inactivation, which is carried out by immersing food materials in hot water, steam or boiling solutions containing acids or salts. Blanching has additional benefits, such as the cleansing of the product, the decreasing of the initial microbial load, exhausting gas from the plant tissue, and the preheating before processing. A moderate heating process such as blanching may also release carotenoids and make them more extractable and bio-available.

Blanching with hot water after the microwave treatment compensates for any lack of heating uniformity that may have taken place, and also prevents desiccation or shriveling of delicate vegetables. And while microwave blanching alone provides a fresh vegetable flavor, the combination with initial water or steam blanching provides an economic advantage. This is because low-cost hot water or steam power is used to first partially raise the temperature, while microwave power, which costs more, does the more difficult task of internally blanching the food product. Microwave blanching of marjoram and rosemary was carried out by soaking the herbs in a minimum quantity of water and ex-posed to microwaves [186].

1.8.5.6 Applications of Microwave Technology in Food Sterilization and Pasteurization

Pasteurization and sterilization are done with the purpose of destroying or inactivating microorganisms to enhance the food safety and storage life [52, 51]. Solid products are usually sterilized after being packed, so no metallic materials should be used in packaging when microwaves are used in this process. This factor limits the use of this technique in food sterilization. Possible non-thermal effects on destruction of microorganisms under microwave heating has been reported: The polar and/or charged moieties of proteins (i.e., COO– and NH_4+) can be affected by the electrical component of the microwaves [52]; and the disruption of non-covalent bonds by microwaves is a more likely cause of speedy microbial death [119]. Academic and industrial approaches to microwave pasteurization or sterilization cover the application for precooked food like yogurt or pouch packed meals as well as the continuous pasteurization of fluids like milk [51, 52].

1.8.5.7 Applications of Microwave Technology in Food Dehydration

In drying of food materials, the goal is to remove moisture from food materials without affecting their physical and chemical composition. It is also important to preserve the food products and enhance their storage stability which can be achieved by drying. Dehydration of food can be done by various drying methods such as solar (open air) drying, smoking, convection drying, drum drying, spray drying, fluidized-bed drying, freeze drying, explosive puffing and osmotic drying [42].

The application of microwaves to food drying has also received widespread attention recently [52, 80]. The heat generated by microwaves induces an internal pressure gradient that involves vaporization and expelling of the water toward the surface. This greatly accelerates the process, when compared to hot air or infrared dehydration [190], in which the drying rate is dependent on the diffusion of water inside the product toward the surface.

1.8.6 APPLICATIONS OF MICROWAVE TECHNOLOGY IN DAIRY INDUSTRY

Milk is traditionally pasteurized in a heat exchanger before distribution. The application of microwave heating to pasteurize milk has been well studied and has been a commercial practice for quite a long time. The success of microwave heating of milk is based on established conditions that provide the desired degree of safety with minimum product quality degradation. Since the first reported study on the use of a microwave system for pasteurization of milk [87], several studies on microwave heating of milk have been carried out. The majority of these microwave-based studies have been used to investigate the possibility of shelf-life enhancement of pasteurized milk, application of microwave energy to inactivate milk pathogens, assess the influence on the milk nutrients or the non-uniform temperature distribution during the microwave treatment [121].

Microwave application allows pasteurization of glass, plastic, and paper products, which offers a useful tool for package treatment. The food products that best respond to MW pasteurization treatment are pastry, prepared dishes, and soft cheeses [27]. The technique has also been tested on milk [79] and fruit juices [71] in devices suitable for continuous treatment and domestic microwave. It is reported that the microwave pasteurization has no effect on amino acid composition [2].

1.9 COLD PLASMA

CP is a novel non-thermal food processing technology that uses energetic, reactive gases to inactivate contaminating microbes on meats, poultry, fruits, and vegetables. This flexible sanitizing method uses electricity and a carrier gas, such as air, oxygen, nitrogen, or helium; antimicrobial chemical agents are not required. The primary modes of action are due to UV light and reactive chemical products of the CP ionization process [155]. Reductions of greater than 5 logs can be obtained for pathogens such as *Salmonella, Escherichia coli O157:H7, Listeria monocytogenes, and Staphylococcus aureus*. Effective treatment times can range from 120 s to as little as 3 s, depending on the food treated and the processing conditions. Key limitations for CP are the relatively early state of technology development, the variety and complexity of the necessary equipment, and the largely unexplored impacts of CP treatment on the sensory and nutritional qualities of treated foods.

Plasma is often called the "*Fourth State of Matter*," the other three being solid, liquid and gas. Plasma is a distinct state of matter containing a significant number of electrically charged particles, a number sufficient to affect its electrical properties and behavior. In an ordinary gas each atom contains an equal number of positive and negative charges; the positive charges in the nucleus are surrounded by an equal number of negatively charged electrons, and each atom is electrically "neutral." A gas becomes plasma when the addition of heat or other energy causes a significant number of atoms to release some or all of their electrons. The remaining parts of those atoms are left with a positive charge, and the detached negative electrons are free to move about. Those atoms and the resulting electrically charged gas are said to be "ionized." When enough atoms are ionized to significantly affect the electrical characteristics of the gas, it is called plasma.

Physical plasma is defined as a gas in which part of the particles are present in ionized form. This is achieved by heating a gas which leads to the dissociation of the molecular bonds and subsequently ionization of the free atoms. Thus, plasma consists of positively and negatively charged ions and negatively charged electrons as well as radicals, neutral and excited atoms and molecules. Plasma not only occurs as a natural phenomenon as seen in the universe in the form of fire, in the polar aurora borealis and in the nuclear fusion reactions of the sun but also can be created artificially which has gained importance in the fields of plasma screens or light sources.

There are two types of plasma: thermal and non-thermal or cold atmospheric plasma. Thermal plasma has electrons and heavy particles (neutral and ions) at the same temperature. Cold Atmospheric Plasma (CAP) is said to be non-thermal because it has electron at a hotter temperature than the heavy particles that are at room temperature. CAP is a specific type of plasma that is less than 104°F at the point of application.

1.9.1 METHODS OF CP GENERATION

CP can be produced by a variety of means, some of which have been the subject of research since the earliest years of inquiry into electrical phenomena [11]. There are three basic forms of CP discharge systems: The *glow discharge* has electrodes at either end of a separating space, which may be partially evacuated or filled with a specific gas. The *radio frequency discharge* uses pulsed electricity to generate CP within the center of the electrical coil. The *barrier discharge* uses an intervening material with high electrical resistance (the dielectric material) to distribute the flow of current and generate the plasma.

A simple form of the barrier discharge systems is shown here as an example. These systems may use one or two layers of dielectric material, arranged in various configurations [92]. These may also be arranged in an annular or tubular form, with one electrode entirely within the other. In those designs, the CP is generated in the space between the electrodes. These designs allow for gas movement across the zone of plasma generation and delivery of the CP to the target [93].

1.9.2 ACTION OF PLASMA ON MICROORGANISMS

The reactive species in plasma have been widely associated to the direct oxidative effects on the outer surface of microbial cells. As an example, commonly used oxygen and nitrogen gas plasma are excellent sources of reactive oxygen-based and nitrogen-based species, such as O, O_2, O_3, OH•, NO•, NO_2, etc. Atomic oxygen is potentially a very effective sterilizing agent, with a chemical rate constant for oxidation at room temperature of about 106 times that of molecular oxygen [44]. These act on the unsaturated fatty acids of the lipid bilayer of the cell membrane, thereby impeding the transport of biomolecules across it. The double bonds of unsaturated lipids are particularly vulnerable to ozone attack [86]. Membrane lipids are assumed to be more significantly affected by the reactive oxygen species (ROS) due to their location along the surface of bacterial cell, which allows them to be bombarded by these strong oxidizing agents [148]. The proteins of the cells and the spores are equally vulnerable to the action of these species, causing denaturation and cell leakage. Oxidation of amino acids and nucleic acids may also cause changes that result in microbial death or injury [44].

1.9.3 APPLICATIONS OF COLD PLASMA

CP can be used to coat the surface of foods (dairy or non-dairy) with a film of vitamins or sensitive bioactive compounds. Equally known as the fourth state of matter, CP can be used to disinfect, but it does not penetrate deeply. It effectively disinfects the irregular surfaces of equipment and packaging.

1.9.3.1 Applications of CP in Surface Decontamination

CP can be used for decontamination of products where micro-organisms are externally located. Unlike light (UV decontamination), plasma flows around objects, ensuring all parts of the product are treated.

1.9.3.2 Applications of CP in Mild Surface Decontamination

For products like cut vegetables and fresh meat, there is no mild surface decontamination technology available currently; CP could be used for this purpose.

1.9.4 CP USE IN FOOD PACKAGING TECHNOLOGY

- It was originally developed to increase the surface energy of polymers, enhancing adhesion, printability and sealability.
- It has recently emerged as a powerful tool for surface decontamination food packaging materials. Gas plasma reactions establish efficient inactivation of micro-organisms (bacterial cells, spores, yeasts and molds) adhering to polymer surfaces within short treatment times. *Packaging materials such as plastic bottles, lids and films can be rapidly sterilized using CP,* without adversely affecting their bulk properties or leaving any residues.
- New trends aim to develop in package decontamination, offering non-thermal treatment of foods post packaging. (active packaging technique) it is effective and quick method to destroy microbes.

1.9.5 IN-PACKAGE PLASMA TECHNOLOGY

Recently DBDs have been employed for generation of plasma inside sealed packages containing bacterial samples [43, 143], fresh produce [114], fish [40] and meat [143]. The in-package plasma decontamination of foods and biomaterials relies on use of the polymeric package itself as a dielectric and has been studied using several packaging materials such as LDPE, HDPE, polystyrene (PS), etc. [111]. All these works have demonstrated significant reduction in microbial population on food products. Moreover, this approach is easy to scale-up to continuous industrial processing and could prevent post-packaging contamination [142]. For a complete assessment of the technology, it is essential to quantify all possible changes to the packaging, induced by the CP. For example, the migration limits of additives, monomers, oligomers and low molecular weight volatile compounds from the packaging material into the food (following in-package plasma) should be evaluated for food safety reasons, as well as water vapor and oxygen permeability.

1.9.6 ADVANTAGES OF USING COLD PLASMA

- Flexible sanitizing method uses electricity, for example, plasma torch.
- Antimicrobial chemical agents are not required to inactivation process.
- Cost effective method compared to other chemical and thermal decontamination methods.
- Less time consuming method (need few seconds to inactivate microbes within the food surface and mild surface).
- Green technology (since harmful effects to environment has not identified yet).

1.9.7 LIMITATIONS OF USING COLD PLASMA

CP are the relatively early state of technology development, the variety and complexity of the necessary equipment, and the largely unexplored impacts of CP treatment on the sensory and nutritional qualities of treated foods. Also, the antimicrobial modes of action for various CP systems vary depending on the type of CP generated. Optimization and scale up to commercial treatment levels require a more complete understanding of these chemical processes.

1.10 HIGH VOLTAGE ARC DISCHARGE (HVAD) TECHNOLOGY

The arc discharges have been used in many areas such as biochemistry, biology, medicine, microbial inactivation of food and also for biocompounds extraction from different products [23]. The arc discharge leads to a multitude of physical and chemical effects. The high pressure shock waves can induce bubble cavitation, which can create strong secondary shocks with very short duration. These shocks can interact with structures of the cells. The phenomena result in mechanically rupture of the cell membranes that accelerate the extraction of intracellular compounds [130]. The voltage arc discharge prompts the formation of highly reactive free radicals from chemical species in foods, such as oxygen. The free radicals are toxic compounds that serve to inactivate certain intracellular components required for cellular metabolism. The bacterial inactivation was not due to heating, but mainly to irreversible loss of membrane function as a semipermeable barrier between the bacterial cell and the environment. Moreover, the formation of toxic compounds (oxygen radicals and other oxidizing compounds) was noticed. The major drawbacks of this method are the contamination of the treated foods by chemical products of electrolysis and disintegration of food particles by shock waves. The method based on continuous HVADs may be unsuitable for use in the food industry [99].

1.11 CONCLUSIONS

The concern behind the thermal processing of food is loss of volatile compounds, nutrients, and flavor. To overcome these problems, innovative methods are being developed in food industries to increase the production rate and profit. The non-thermal processing is used for all foods for its better quality, acceptance, and for its shelf life also reduces the operational cost. Innovative methods have better potential than other conventional methods and still is an evolving challenging field. The cost of equipment used in the non-thermal processing is high when compared to equipment used in thermal processing. After minimizing the investment costs and energy saving potential of non-thermal processing methods, it can also be employed in small scale industries.

1.12 SUMMARY

Preservation is the most important process related to all food products. Preservation of food products can be achieved by various ways like addition of salt, sugars, preservatives, antioxidants, naturally occurring antimicrobial substances and also by the processes like drying, freezing, refrigerated storage and Hurdle technology. Novel technologies like microwave heating, PEF technology, HPP, PL technology, ohmic heating, ultrasonics, pulsed X-rays are also applied for the preservation of food products. The main problem with the thermal processing method is loss of color, flavor, vitamins and other nutrients in food products. A detailed review is presented for different non-thermal processing methods and its merits and demerits are analyzed and illustrated for applications in various industries. This chapter investigates different non-thermal processing methods and its suitability to different food processing industries which deal with foods like meat, milk, fish, egg and ready-to-eat foods.

KEYWORDS

- **atmospheric pressure**
- **baking**
- **blanching**
- **cold plasma**

- **cooking**
- **emulsification**
- **enzyme inactivation**
- **food dehydration**
- **fruit and vegetable processing**
- **high pressure processing**
- **high voltage arc discharge**
- **honey**
- **irradiation**
- **isostatic**
- **meat technology**
- **microscopic ordering**
- **microwave heating**
- **milk fouling**
- **monosonication**
- **non thermal**
- **ohmic heating**
- **oil**
- **pasteurization**
- **plasma**
- **preservation**
- **pulsed electric field**
- **pulsed light**
- **sterilization**
- **tempering**
- **thawing**
- **thermosonication**
- **ultra sonication**
- **ultrasonic**
- **ultrasound**
- **ultraviolet light**

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