INTERNATIONAL UNION OF FOOD SCIENCE & TECHNOLOGY

IUFoST

IUFoST Scientific Information Bulletin (SIB)
May 2010

Emerging and New Technologies in Food Science and Technology

Introduction

During the final three decades of the last century consumer demands for natural, minimally processed, fresh like and safe foods led to the search for gentle processing and to the development of new ("emerging") processing concepts. Examples for these developments are the emergence of the hurdle concept (Gould, 1995) and of food biotechnology (Shetty et al, 2006; Knorr, 1987).

Within the last decade the request and necessity to provide - in addition to gentle processing and fresh like products - nutritional and sensory benefits, to integrate the food chain to achieve this and to aim for sustainability through out the food chain (ETP, 2007) was added and increased the complexity of process development

Below some of the most promising new and emerging technologies will be given.

For further information some key references include (Barbosa-Canovas et al, 2005; Hendrickx and Knorr, 2001; Raso and Heinz, 2006).

Pulsed electric fields (PEF)

Principle:

When exposed to high electric field pulses cell membranes develop pores which may be permanent or temporary, depending on the intensity and treatment conditions. Pore formation increases membrane permeability which results in the loss of cell content or intrusion of surrounding media. Low intensity treatment has the potential to induce stress reactions in plant cells resulting in the promotion of a defense mechanism by increased production of secondary metabolites. An irreversible perforation of the cell membrane reduces its barrier effect permanently and causes cell death. Applied to fruit and vegetable cells mass transfer processes like pressing, extraction or drying are more effective, in the case of meat brining and pickling mass transport and microdiffusion could be enhanced. The loss of cell vitality caused by electroporation is furthermore a capable tool for the inactivation of microorganisms used for a non-thermal pasteurization of liquid food.

Process description

Generally, high intensity electric pulses can be generated by the switched discharge of a suitable capacitor bank. The characteristics of the discharge circuit determine the shape of the time dependent potential at the treatment chamber where the product is exposed to the electric field (Raso & Heinz, 2006). Depending on the product and application, parallel plate electrode treatment chamber configuration or co-linear type treatment chambers are most commonly used. A comprehensive review on treatment chamber configurations can be found in (Huang & Wang, 2009).

Stage of development

Effective inactivation for most of the spoilage and pathogenic microorganisms has been shown and colony count reductions depending on treatment intensity, product properties and type of microorganism in the range of 4-6 log-cycles are comparable to traditional thermal pasteurisation. Bacterial spores and viruses are not affected by the PEF treatment (Lelieveld, Notermans & de Haan, 2007). Reports on the effects of PEF on enzymes are limited and different experimental setups and processing parameters make them difficult to compare (Van Loey, Verachtert & Hendrickx, 2002). But in most cases, enzyme inactivation during PEF treatment seems to be related to thermal effects. First industrial large scale applications have been realized for the treatment of sugar beet, olive mash and fruit mashes. Industrial equipment is available up to capacities of a single system of 2200 L/h for PEF processing of liquids for non-thermal pasteurisation with total treatment costs of 0.6 Cents per kg and 22 t/h for cell disintegration applications with related total treatment costs of 0.5 Euro/t (DIL, 2009).

Food safety

In pulsed electric field systems for preservation of liquid food working at higher treatment intensities, electrochemical reactions can occur in the treatment chamber at the electrode surface (Morren, Roodenburg & de Haan, 2003). Related unwanted effects can be limited or avoided by suitable selection of electrode and by adaptation of the electrical pulse shape and duration (Roodenburg, Morren, Berg & de Haan, 2005). Treatment homogeneity and the avoidance of over-processing of the product including the occurrence of local high temperatures are key aspects to guarantee predictable cell disintegration and microbial inactivation while maintaining heat-sensitive food constituents. Therefore, optimisation of the treatment chamber design is the major task to be solved for successful industrial application (Jaeger, Meneses & Knorr, 2009). Protective effects occurring in real food systems may limit the process effectiveness of PEF compared to inactivation studies conducted in model solutions and the occurrence of sublethally injured cells has to be taken into account with regard to food safety aspects (Jaeger, Schulz, Karapetkov & Knorr, 2009). A comprehensive statement concerning food safety aspects of PEF treatment can be found in (Knorr, Engel, Vogel, Kochte-Clemens & Eisenbrand, 2008)

Food modification:

PEF is affecting the cell membranes and thus can be expected to influence the texture of products in which the structure is largely dependent on the integrity of cells. Applied to plant or animal raw material, it can be used for tissue softening and improvement of extraction processes (Vorobiev & Lebovka, 2008). In contrast to heat treatments applied for pasteurisation, PEF does not cause protein coagulation or gelatinization of starch. Covalent chemical bonds are not affected so that nutrients remain intact.

Sustainability:

Application of PEF technology as a short time continuous operation will improve sustainability of food processing, and/or reduce energy requirements while maintaining or improving food quality and safety. Even if PEF requires an additional input of electrical energy it has beneficial effects on total energy consumption of mass transfer processes such as extraction, pressing or drying. Processing times are reduced, utilization of production capacities is improved and water as well as raw material consumption is decreased (Toepfl, Mathys, Heinz & Knorr, 2006).

High pressure

The growing consumers demand of minimally processed, fresh tasting, microbiologically safe and additive-free food with an extended shelf life enables the high pressure (HP) technology to be successfully introduced into the food industry.

Principle

The pressures currently used range from tens of MPa in common homogenizers or supercritical fluid extractors to up to 350 or 800 MPa in ultra HP homogenizers or HP pasteurization units, respectively. These HP units are principally used for the inactivation of vegetative microorganisms to extend shelf life of the treated food, which was first reported by Hite (1899) for a pressure treatment of bovine milk.

Furthermore, Bridgman (1914) reported that HP can coagulate egg albumin producing gels different from those obtained by heat coagulation. Therefore HP treatment offers numerous other interesting food applications such as food structure engineering (Knorr, 2002; Rumpold, 2005; Diels et al., 2006; Knorr et al., 2006; Sharma et al., 2008), enhanced food quality (Ludikhuyze et al., 2002; Trejo Araya et al., 2007), stress response utilization (Ananta et al., 2004; Bothun et al., 2004; Kato et al., 2007; Pavlovic et al., 2008) or control of bioconversion reactions (Knorr et al. 2006; (Picard et al., 2006).

In industrial scale HP units consist of a horizontal high pressure vessel and an external pressure generating device. The simplest practical system of such an intensifier is a single-acting, hydraulically driven pump. For the HP treatment, the packed food is deposed in carrier and automatically loaded into the HP vessel and the vessel plugs are closed. The pressure transmitting media, usually water, is pumped into the vessel from one or both sides. After reaching the wanted maximum pressure the pumping is stopped and in ideal case no further energy input is needed to hold the pressure during dwell time. In contrast to thermal process where temperature gradients occur, all molecules in the high pressure vessel are subjected to the same amount of pressure at exactly the same time, due to the isostatic principle of pressure transmission (Rastogi et al., 2007; Heinz et al., 2009).

In order to inactivate bacterial and fungal spores, a combination of HP and elevated initial temperature (> 80 °C) seems to be a promising improvement to the traditional heat sterilization. Combined HP and heat treatments can result in a sterilized food product with reduced thermal load and consequently higher nutritional quality and functionalities (Mathys et al., 2009b).

Moreover, due to the research efforts in the last decade, the Food and Drug Administration (FDA) of the United States was enabled to certify a pressure assisted thermal sterilization (PATS) process in February 2009

Supercritical Water

The application of sub (SubCW)- and supercritical water (SCW) has been attracting worldwide attention due to the unique properties of water as a reaction medium at elevated pressures and temperatures (Mathys et al., 2009a). When water is exceeding its critical point (374 °C, 22.1 MPa), the values of the ionic product, density and the dielectric constant of water drop down drastically. Hence, SCW acts as a non-polar solvent with excellent transport properties and high diffusivity (Franck, 1984; He et al., 2008) Consequently, even non-polar organic compounds and gases like oxygen become completely miscible in SCW (He et al., 2008). If this process is conducted below the critical point of water it is denoted as hot compressed water or subcritical water process (Abdelmoez et al., 2006; Kruse et al., 2006). Due to the applied pressure, water remains in the liquid state its dielectric constant decreases (water partially shift to a polar solvent) and the ion product of water increases in dependence of the applied temperature. Hence, the conversion rate of many chemical reactions increases or the reactions can proceed without the addition of catalysts. Moreover, SubCW can be used to perform very selective extraction processes of e.g. of anthocyanins (King et al., 2003).

Furthermore, different organic pollutants and waste have been treated utilizing SubCW, including decomposition of hazardous organic material, municipal sewage sludge (Goto et al.) and marine waste (Daimon et al., 2001). Yoshida (2003) showed that a relatively large amount of oil, organic acids, and amino acids could be extracted from fish, squid entrails meat, and cow meat and bone meal wastes using SubCW. Moreover, many useful products were extracted from wood wastes and Rogalinski (2008) presented an extensive data set about the degradation kinetics of polysaccharides to monosaccharide as a possible feedstock for bio-ethanol production.

However, due to the unique properties of SCW, it becomes also extremely active and corrosive, which is actually the biggest problem for an industrial batch or continuous application of SCW.

Ultrasound

Ultrasound is the energy generated by sound waves of frequencies above the human hearing and is roughly defined by a frequency range from 18 kHz up to 1GHz. Ultrasonic waves are created by magnetostrictive or piezoelectric transducers, which transform electrical energy into mechanical oscillations, and transferred into the treatment medium either directly via sonotrodes or indirectly in case of ultrasonic baths.

The longitudinal sound waves can be transmitted into gases, fluids or foodstuff causing cyclic compressions and rarefactions of the respective material. High-intensity, low-frequency (16 – 100 kHz) ultrasound can lead to cavitation, the creation, growth and violent collapse of gas bubbles (Patist & Bates, 2008). The bubble collapse is accompanied by high pressure and temperature peaks (up to 100 MPa and 5000 K) as well as intense local shear (Clark, 2008). Such high power ultrasound treatments have the potential to improve a large range of key processes in food production such as emulsification and homogenization, crystallization, mass transfer processes and heat transfer. Furthermore, food structure can be altered leading to tissue softening or disruption and migration as well as alteration of proteins. Viscosity reduction can contribute to improved characteristics during heat transfer or extrusion processes (Patist & Bates, 2008). While the majority of these processes is still optimized at laboratory scale, ultrasonic defoaming and sieving are already standard applications at industrial level.

In contrast, low intensities and high frequencies in the MHz-range lead to sonication treatments with acoustic streaming as the main mechanism (Patist & Bates, 2008). Such low energy ultrasound is used for non-destructive testing as well as for the stimulation of living cells.

In terms of food safety ultrasound can contribute to higher hygienic standards in food production. Cavitation and associated phenomena can loosen impurities and improve cleaning processes with shortened application times and reduced use of chemicals. In respect of microorganism inactivation the singular use of ultrasound is generally rated insufficient for food industry standards (FDA, 2000). However, ultrasound application is rated promising in combination with other preservation processes, such as heat, mild pressure or ozone, as sonication induced cell damage leads to a higher sensitivity towards other treatments (IFT, 2006).

The versatile application of ultrasound in food technology and its characteristics allowing the improvement of a large variety of processes shows its potential to improve sustainability in food production. Depending on each single application ultrasound can contribute to savings in energy or water consumption as well as in the use of chemicals and other resources.

Plasma treatment

Principle

The term *plasma* was introduced by Irving Langmuir in 1928 (Langmuir, 1928). When gas is heated sufficiently for atoms to collide with each other and displace their electrons in the process, a plasma is formed. Plasma, an ionized gas, is also called the 4th state of matter since more than 90% of the material in the universe exists as plasma. In the field of plasma research we can find a complex nomenclature considering the temperature of the electrons and the bulk gas and/or the surrounding pressure (Roth, 1995; Goldston and Rutherford, 1997). Since a vacuum will support liquid to gaseous phase changes in high-moisture food products, the most suitable system for food processing is an atmospheric-pressure plasma device where no extreme conditions are required, low temperatures occur. However, such lower process pressures are mainly suitable for dried food materials or packaging materials.

Process description

Atmospheric-pressure plasma is commonly generated by corona discharge, dielectric barrier discharge or plasma jet. For the treatment of non-uniformly shaped products, the application of plasma jets offers advantages due to various options regarding design and construction. Radio-frequency (rf)-driven plasma jets can be used for studies on treatment of food related materials. Such a plasma source consists of a needle electrode in the centre of a ceramic nozzle and a grounded outer electrode. The rf voltage (f=27.12 MHz, P=20 W) is coupled via a matching network to the needle electrode. The gas flows between the electrodes, is ionized and then ejected from the source (Brandenburg et al., 2007). The generated plasma contains chemical species, charged species, radicals, heat, and UV in different concentrations. The concentrations of the reagents are depending on the process parameters and the gas used. To operate plasmas in this pressure regime, several generation methods are available. Most commonly used are radio frequency (rf) or microwave (mw) excited plasma sources.

Stage of development

Plasma technologies in food processing are not yet established, but the world of applied plasma technology is diverse (e. g. plasma switches for power networks, cost-effective light sources, high-definition large area flat panel displays, plasma-improved printability of foils, etc.). In the last decade, concerted research efforts were expended to understand and to apply atmospheric pressure plasmas as sterilisation method. Modular and selective plasma sources were developed. These combine the technological advantages of atmospheric pressure plasmas (avoidance of vacuum devices and batch processing) with the flexibility and handling properties of modular devices (Ehlbeck et al., 2008). However, further investigations are required to characterize the plasma applied and to better understand the interactions of reactive species with organic surfaces as well as vital bio-systems (Mastwijk & Nierop Groot, 2010). This will allow us to control the effects of plasma and to design highly specified and efficient plasma processes.

Food safety

The presence of UV emitting species, charged particles, and free radicals is associated with the antimicrobial effect of the plasma (Moisan et al., 2002; Laroussi, 2005). The capability of non-thermal atmospheric plasmas to inactivate vegetative cells, including gram-negative and gram-positive bacteria, yeast, fungi, biofilm formers, and endospores was shown in various studies (Moreau, 2008). Recent interest is mainly focused on the inactivation efficiency of cold plasma with respect to contaminated pericarps of mangos, melons (Perni et al., 2008), bell pepper (Vleugels et al., 2005), fresh cut fruit surfaces (Perni et al., 2008a) or almonds (Deng et al., 2007). However, the inactivation mechanisms of different plasmas are not yet fully understood. Depending on the plasma source, process parameters and process gases the reactive species vary within the plasma, which makes inactivation mechanisms difficult to compare.

Food modification
Recent research activities focus mainly on inactivation of microbes but little is known about the effect of plasma on food matrices. Since emitted reactive species do not only react with bacteria, they may also affect food components such as water, lipids, proteins, and carbohydrates (Keener, 2008). Grzegorzewski et al. (2010) presented results on plasma effects on phenolic compounds. Recently, a joint research project has been launched in Germany to further elucidate the effects of plasma on heat sensitive food matrices (FISA database, 2010).

Sustainability
Besides the application in food processing, progress in germ reduction technologies is important for medical and biomedical application, biotechnology, the pharmaceutical industry and the packaging industry. The treatment of components with complex geometry demands the development of plasma sources for 3D surface treatment and of cavity-penetrating plasmas. Since energy transfer of a low-temperature plasma to a surface is small, the treatment of heat-sensitive materials is feasible. In environmental applications, plasma technologies can be applied to flue gas cleaning and can substitute wet-chemical processes that generate waste water by environmentally desirable dry processes (Weltmann et al., 2008).

Conclusions

The emerging and new technologies presented are at different stages of development with high hydrostatic pressure technology for food preservation and quality retention being the most advanced. Pulsed electric field applications are on the verge of industrial use. Ultrasound has some non-food safety applications and supercritical water and low temperature plasma treatment are in their developmental stage.

Combinations of the above processes with either mild heat, with each other or with other means of food preservation agents (e.g. antimicrobials) are also being developed and tested. Currently, these technologies are mainly used and developed as alternatives to conventional thermal preservation methods such as pasteurization.

However, they possess a great potential for food modification purposes and are generally more sustainable technologies than conventional thermal ones.

For all the processes described more research is needed regarding the fate of toxins, nutrients and allergens during processing and subsequent storage of food products. In addition, further knowledge on mechanisms of inactivation of microorganism, enzymes, allergens, toxins, etc. by the various processes still need to be generated.

Some recent attempts to re-introduce antimicrobial systems such as the use of ozone, UVC light, pulsed light or oxidized water still need to be validated regarding their feasibility and effectiveness.

Acknowledgements

EFFoST has been giving much attention to research and development of novel technologies also in cooperation with the Nonthermal Processing Divison of IFT. Parts of the data given are based on work supported by European Commission (projects HELP, SAFE ICE, Novel Q).

Despite many efforts, the application of technologies that apparently are capable of meeting the consumer requirements, only very slowly find application in the industry. Since 2005, EFFoST participates in the EU supported project “Novel Q”. This project aims to provide a sound science base to novel technologies, to demonstrate the potential industrial applications and to create more awareness among the industry.

The editorial assistance of Huub Lelieveld is highly appreciated.

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The International Union of Food Science and Technology (IUFoST) is the global scientific organisation representing over 200,000 food scientists and technologists from more than 65 countries. It is a federation of national food science organisations linking the world's food scientists and technologists. IUFoST has four regional groupings: ALACCTA representing Central and South America, EFFoST representing Europe, WAAFoST representing Western Africa and FIFSTA representing the countries in the ASEAN region.
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