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Non-thermal plasma as a new food preservation method, Its present and future prospect

Roya Afshari [1], Hedayat Hosseini[*,2]

[1]Research committee student. National Nutrition &Food Technology Research Institute, Faculty of Nutrition Sciences &Food Technology Shahid Beheshti University of Medical Sciences. Tehran, Iran.
[2]Department of food science and technology National Nutrition &Food Technology Research Institute, Faculty of Nutrition Sciences &Food Technology Shahid Beheshti University of Medical Sciences. Tehran, Iran.

*Corresponding Author: email address: Hedayat@sbmu.ac.ir (H.Hosseini)

ABSTRACT

Atmospheric pressure plasma (APP) is an emerging non thermal technology for the improvement of food safety. Non-thermal plasma (NTP) is a neutral ionized gas that comprises highly reactive spices including, positive ions, negative ions, free radicals, electrons, excited or non excited molecules and photons at or near room temperature. NTP can be generated at atmospheric pressure that makes it more applicable. Moreover, it could be employed in inactivation of microorganisms on the surface of fresh and processed foods. However, for the reason that there are few studies on the application of this technology in real food systems, the effects of non-thermal plasma on nutritional and chemical properties of food is not known well. Furthermore, the studies which explore the safety and cost aspects of this technology could help it become widespread in food industry. This paper will attempt to provide a review of atmospheric pressure cold plasma, its application in microbial inactivation,food preservation and future prospect of this new technology.

Keywords: Atmospheric pressure plasma; Food preservation; Non-thermal technology.

INTRODUCTION

Food safety is a major concern for food industry, regulatory agencies as well as consumers. Food-borne pathogens and spoilage microorganisms are problematic microbes in food industry due to its significant public health risks and economic impact [1]. There are a lot of sterilization method to eliminate these microorganisms. Some of these methods rely on lethal heat treatment such as steam pasteurization, autoclaving, ohmic heating, etc. Thermal technologies have side-effects on nutritional, sensory and functional properties of treated foods so alternative non thermal pasteurization methods such as high hydrostatic pressure, pulsed electric field, oscillating magnetic field, ionizing irradiation and high power ultrasound have been developed and studied in recent years. These processes retain quality of foods better than conventional methods but they are cost effective, required specialized equipment and trained personnel and also consumer acceptances and safety of these processes should be considered [2].

Non thermal plasma is a new discipline in food processing. Plasma is electrically energized matter in a gaseous state that can be generated by electrical discharge. Electrical discharges in atmospheric pressure and low temperature make this process practical, inexpensive and suitable for decontamination of products which heat is not desirable for[1].

This paper will attempt to provide a review of the fundamental aspect of plasma including plasma definition, generation, and classification and will focus specifically on atmospheric pressure cold plasma, its application in microbial inactivation and food preservation.

Fundaments of plasma

Plasma definition, generation and classification

Plasma is ionized gas, that consists of a large number of different species such as electrons, positive and negative ions, free radicals, gas atoms, molecules in the ground or excited state and quanta of electromagnetic radiation (photons). It is considered to be the forth state of matter in the world [3]. It can be generated in the large range of temperature and pressure by means of coupling energy to gaseous medium. This energy can be mechanical, thermal, nuclear, radian or carried by an electric current. These energies dissociate the gaseous molecules into collection of ions, electrons, charge – neutral gas molecules and other species [4]. Depending on the type of energy supply and amount of energy transferred to the plasma, density and temperature of the electrons are changed. These lead Plasma to be distinguished into two groups, high temperature plasma and low temperature plasma(given in table 1) [4].

High temperature plasma implies that electron, ions and neutral species are in a thermal equilibrium state. Low temperature plasma is subdivided to thermal plasma, also called local thermodynamic equilibrium plasmas (LTE) and non thermal plasma (NTP), also called non-local thermodynamic equilibrium plasmas (non-LTE) [3]. An equilibrium or near equality between electrons, ions and neutrals is the main characterization of thermal plasmas (TP). Frequently employed thermal plasma generating devices are those produced by plasma torches, and microwave devices. In generation of cold plasma most of the coupled electrical energy is channeled to electron component instead of heating entire gas stream so the temperature of heavy particle remains near the room temperature, these characteristics make it suitable to be used in processes which high temperature is not desirable [4].

Table1. Classification of plasma [4]

Plasma	**Properties**	**Example**
High temperature plasma (Equilibrium plasma)	$Te \approx Ti \approx Tg$, $Tp = 10^6 – 10^8$ K	Laser fusion plasma
	Low temperature plasma	
Thermal plasma (Quasi-equilibrium plasma)	$Te = Tg = T \leq 2 \times 10^4$ K $n_e \geq 10^{20}$ m^{-3}	Arc plasma
Non-thermal plasma (Non-equilibrium plasma)	$Te >> Ti \approx Tg = 300 – 10^3$ K $n_e \approx 10^{10}$ m^{-3}	Glow discharges

Atmospheric pressure plasmas (APP)

Low pressure glow discharge plasmas are of great interest in microelectronic industries but their vacuum equipment limits their application. Therefore one of the recent challenges was developing new plasma sources that can operate at or near 1 atmospheric pressure. Power sources of atmospheric pressure plasma generation can be microwave, RF (radio frequency), pulsed, AC (alternating current) or DC (direct current) [1].

Devices that have been used for plasma generation are the corona discharges, micro hollow cathode discharges, gliding arc discharge, one atmospheric uniform glow discharge, dielectric plasma needle barrier discharge (DBD), atmospheric pressure plasma jet (APPJ).

Among all. DBD and APPJ are commonly used in industrial application like lightening, surface modification, etching and deposition [1, 4].

Microbial inactivation mechanism of plasma

The use of plasma as a sterilization method was first patented in 1968 [5] and the plasma made from oxygen was first applied in 1989 after that considerable researches have been done on mechanisms of microbial inactivation by plasma agent. Interacting plasma agent with biological mater contributed to lethal action. Plasma treatment can effectively inactivate a wide range microorganisms including spores [6-8] and viruses [9]. Effect of plasma on different microorganisms can be completely selective, meaning that it can damage pathogenic microorganisms without damaging host or it can activate different pathways in different organisms [10].

The reactive spices in plasma have been caused the oxidative effects on the outer surface of microbial cells. Nitrogen and oxygen gas plasma are good sources of reactive oxygen- based and nitrogen-based spices such as $O^{\cdot}$, O_2, O_3, OH, $NO^{\cdot}$, NO_2. Chemical rate constant of atomic oxygen for oxidation at room temperature is so higher than molecular oxygen [11]. These act on the doubled bond of unsaturated fatty acid of membrane cell, thereby disturbing the transport of bimolecules across it [12].

In spite of oxidation of the lipids, amino acids and nucleic acids of cells and spores are vulnerable to the action of these spices and oxidation of them cause changes that lead to microbial death or injury

[11]. In addition to reactive spices, UV photons can modify the DNA of the microorganisms and as a result disturb cell replication. The role of UV photons in inactivation of microorganisms when they are subjected to plasma was reviewed in detailed by Boudam et al.[13]. Many studies have found that reactive spices had the most important role in inactivation of microorganisms and the role of UV photons in plasma was minor [14], but these studies demonstrated that more researches need to be done over the role of UV photons in plasma.

Contribution of each of the above mentioned mechanisms in inactivation microorganism depends on plasma characteristics and to the type of microorganisms. The former includes device set up (reactor geometry), voltage, gas pressure, gas composition, water content in the gas, and distance of the microorganism from the discharge glow, where the latter takes account of Gram-positive, Gram-negative, spores and other types[15-18]. To cite an example, Hury et al. [19], compared the destructive efficiency of different gas composition and temperatures on Bossilus spp. Spores. They found that oxygen-based plasma is more efficient than pure argon plasma. The other criterion that was considered is the direct exposure or remote exposure of substances from the plasma sources, The recent findings demonstrated that if the substrate which is sterelizied to be in indirect contact (remote exposure) with the plasma, the quantum of heat transmitted to a sample is reduced and many of the short-lived reactive spices do not reach the sample so the treatment cannot be efficient in microorganism inactivation [20].

Potential application in food

NTP has been applied in the food industry including decontamination of raw agricultural products (Golden Delicious apple, lettuce, almond, mangoes, and melon), egg surface and real food system (cooked meat, cheese,). In one study on *E. coli* 12955 a non-pathogenic surrogate for *Salmonella spp*. inoculated onto almonds, Deng et al. [21] reported a reduction of more than 4 log CFU/ml after 30 s treatment at 30 kV and 2000 Hz. Similarly, Niemira and Site [22] reported the reduction of *Salmonella* and *E. coli 0157:H7* that inoculated onto apple surfaces for 2.9 – 3.7 and 3.4 – 3.6 log CFU/ml respectively, and they reported the highest flow rate of the air (40 liters/min) in discharge medium would be the most effective In this study cold plasma was generated in a gliding arc .Perni et al. [23] studied decontamination effect of NTP generated by an AC voltage (variable 12 – 16 kV) on pericurp of melon and mangoes that inoculated by *Sacchearomyces cerevisae, Pantoea agglomerans, Gluconacetobacter liquefacien* and *Ecoli*. It was observed that *S.cervisie* was the most resistant. *P. agglomerans* and *G. liquefaciens* were reduced below the detection limit (corresponding to 3 log) after only 2.5 s on both fruits, whereas *E. coli* required 5 s to reach the same level of inactivation.

Salmonella spp. has been reported largely as a potential hazard for egg consumers. Decontamination of egg surface using barrier discharge plasma was studied by Ragni et al. [1]. The results showed that maximum reduction of 2.2–2.5 log CFU/eggshell in *Salmonella enteritidis* levels achieved after 60 – 90 min treatment at 35% RH. Further, higher RH lead to higher effectiveness of treatment, at 65% RH, reduction of 3.8 and 4.5 log CFU/eggshell were achieved after 90 min of exposure. Similar result was observed for *Salmonella typhimurium,* with an overall reduction of 3.5 log CFU/eggshell.

Montenegro et al. [24] employed direct current corona discharges for reduction of *E. coli O157:H7* in apple juice. After 40 s treatment at a frequency of less than 100 Hz with 4000 pulses of 9000 V peak voltage, the number of cell reduction was more than 5 log CFU/g.

One of the factors that influence the effectiveness of NTP is the type of food which is being treated. Song et al. [25] investigated the influence of this factor. In this study sliced cheese and ham inoculated by 3- strain cocktail of *Listeria monocytogenes* (ATCC 19114, 19115, and 19111, LMC) and exposure to barrier discharged plasma (75, 100, 125, and 150 W) for 60, 90 and 120s. Microbial log reduction increased with increases of input power and exposure time. The results indicated that, reduction after 120s at 75, 100, 125, 150 W ranged from 1.7 to 8 log CFU/g in sliced cheese and those in sliced ham were 0.25 to 1.73 log CFU/g. These result confirmed that type of food has strong effect on inactivation of LMC.

The Limitations of APP process for food sterilization are that, in treatment of bulky and irregularly shaped food, restricted volume and size of the food should be considered and also microbial inactivation occur on the surface of the food being treated since plasma reactive species are limited to penetrate into foods [25].

A discussion on the future prospect of atmospheric pressure plasma

Atmospheric pressure plasma is proved to have specific potential for treatment of foods. Combining APP with other non thermal processes could be a possible future breakthrough in this field. In this case, synergistic effects may be more considerable however scaling up this technology remains a challenge to be solved. One of the dark aspects of experimental work on APP is that, treatment must be proven not to have negative impact on the organoleptic and nutritional properties of food; nevertheless, there has been limited investigation on this aspect of treatment. Hence, it is a necessary for further studies to specify the extent in which APP affect the chemical and nutritional properties of foods and its shelf life. In addition, risk assessment of toxic residues should be carried out in future works. The last but not the least, evaluation of the projected cost of treatment and safety of applied gas for scaling up this technology in food industry should be addressed to determine the applicability of this method [26].

CONCLUSION

APP is an emerging non-thermal technology for reducing microbial population on the surface of fresh and processed foods. Various reactive spices of plasma interact to biological cell to cause changes on cell wall and morphology of the microorganisms that lead to death. Because of the limit information about the nutritional and chemical changes in food products treated with this technology, specially, sensitive food which has high amount of lipid and vitamins additional issues concerning food quality and safety must be considered.

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