

# Atmospheric Pressure Plasma Technology: A New Tool for Food Preservation

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**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 species 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.

**Keywords:** atmospheric pressure plasma, food preservation, non-thermal technology

## 1. Introduction

Food safety is a major concern for food industries, regulatory agencies and consumers. Food-borne pathogens and spoilage microorganisms are problematic microbes in food industry due to their significant negative impact on public health and economy [1]. There are a lot of sterilization methods 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; however, they have their own drawbacks. They are costly and required specialized equipment and trained personnel. Moreover, consumer acceptance and safety issues 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 where heat is not desirable [1].

This paper aims at providing 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.

## 2. Fundamentals of plasma

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## 2.1. 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, and gas atoms, molecules in the ground or excited state and quanta of electromagnetic radiation (photons). It is considered to be the fourth 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, radiant or carried by an electric current. These energies dissociate the gaseous molecules into collection of ions, electrons, charged – 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 [4]. (given in table 1)

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 channelled 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].

## 2.2. . 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 applications like lightening, surface modification, etching and deposition [1, 4]

Table 1. Classification of plasma

Figure	Properties	Example
High temperature plasma (Equilibrium plasma)	$T_e \approx T_i \approx T_g$ , $T_p = 10^6 - 10^8$ K $n_e \geq 10^{20} \text{ m}^{-3}$	Laser fusion plasma
Low temperature plasma		
Thermal plasma (Quasi-equilibrium plasma)	$T_e = T_g = T_i \leq 2 \times 10^4$ K $n_e \geq 10^{20} \text{ m}^{-3}$	Arc plasma
Non thermal plasma (Non-equilibrium plasma)	$T_e \gg T_i \approx T_g = 300 - 10^3$ K $n_e \approx 10^{10} \text{ m}^{-3}$	Glow discharges

## 3. Microbial inactivation mechanism of plasma

Several mechanisms are considered to be responsible for microbial inactivation. During plasma treatment, killing microorganisms are result of direct contact to antimicrobial active species. Accumulation of charged particles at the surface of the cell membrane can rupture the cell membrane. Oxidation of the lipids, amino acids and nucleic acids with reactive oxygen and nitrogen species cause changes that lead to microbial death or injury. In addition to reactive species, UV photons can modify DNA of microorganisms and as a result disturb cell replication. Contribution of mentioned mechanisms depends on plasma characteristics and to the

type of microorganisms. The former includes voltage, working gas, water content in the gas, distance of the microorganism from the discharge glow, etc. where the latter takes account of Gram-positive, Gram-negative, spores and other types [5-8].

#### 4. 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. [9] reported a reduction of more than 4 log CFU/ml after 30 s treatment at 30 kV and 2000 Hz. Similarly, Niemira and Site [10] reported the reduction of *Salmonella* and *E. coli O157: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 (40liters/min) in discharge medium would be the most effective. In this study cold plasma was generated in a gliding arc. Perni et al. [11] studied decontamination effect of NTP generated by an AC voltage (variable 12 – 16 kV) on pericarp of melon and mangoes that inoculated by *Saccharomyces cerevisiae*, *Pantoea agglomerans*, *Gluconacetobacter liquefaciens* and *E. coli*. It was observed that *S. cerevisiae* 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. [12] 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. [13] 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 [13].

#### 5. 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 [14].

## 6. Conclusion

APP is an emerging non-thermal technology for reducing microbial population on the surface of fresh and processed foods. Various reactive species 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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