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# Cold Plasma as an Emerging Supplement for Food Industry

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**Abstract**

Food borne contamination continues to be a significant concern with illness and deaths. Thermal treatment can effectively inactivate pathogens, but this often induces side effects in the sensory, nutritional, and functional properties of foods, especially in fresh products. Cold plasma technology is an emerging non-thermal food processing technology for microbiological decontamination of food and bio-materials. The term 'Plasma' was first employed by Irving Langmuir in 1928 to define this fourth state of matter which is partially or wholly ionized state of gas and discovered plasma oscillations in ionized gas. The various approaches used for plasma generation includes the corona discharge, dielectric barrier discharges (DBD), radio frequency plasma (RFP) and the gliding arc discharge.

**Introduction**

Consumer demands food product that is safe to consume, premium quality, high nutritious and longer shelf life. Food borne illness associated with contaminated food continues to be a significant concern. Microorganisms are the major problem with regard to food processing as they produce undesirable impact on the health and economy of the public. An estimated as 600 million people almost 1 in 10 people in the world fall ill after eating contaminated food and 420000 die every year, resulting in the loss of 33 million healthy life. There are many reasons for food borne disease remaining a global public health challenge. In order to eliminate the various microorganisms' various thermal method such as pasteurization, sterilization, canning has been followed. But these conventional thermal methods are having side effects in the sensory, nutritional, and functional properties of foods, especially in fresh products. Conventional postharvest washing and sanitizing treatments are not highly effective for produce, often resulting in less than 2 log unit reductions of

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pathogens (U.S. FDA 2009).Conventionally, sterilization methods such as heat, chemical solutions are used for the surface disinfection of fruits, seeds, and spices etc., which are often time-consuming and damaging or have toxic residues. To overcome these disadvantages of the non-conventional methods, non-thermal methods, such as irradiation, high pressure processing, ultrasound etc have been developed. However, these technologies also have some drawbacks, including the high cost of application, requirements for specialized equipment, generation of undesirable residues and extended processing times and lower efficiencies. In the last two decades, non-thermal processing technologies have gained widespread attention from the food industry interested in mild and effective processes. These alternative technologies may increase functionality and shelf-life, reducing the negative impact on food nutrients and natural flavor. One such recent non-thermal technology which finds its application in food processing and packaging is cold plasma technology. Cold plasma (CP) technology is a new non-thermal food processing method that has piqued the interest of many scientists across the world. CP was first used to improve the printing and adhesion capabilities of polymers, as well as to increase the surface energy of materials and a range of other applications in electronics. Textiles, glassware, paper, and other materials are regularly treated with it. CP technology, according to a new research trend, is a powerful and profitable technology for the food business. Cold plasma (CP) induces several chemical and physical processes within the plasma volume and on the plasma polymer interface, which modify the surface properties. Due to the abundant number of reactive oxygen species (ROS) contained in the quasi-neutral plasma gas, non-thermal technology is particularly advantageous for microbial decontamination of food products, including sporulating and spoilage/pathogenic organisms.

**Plasma Chemistry and Sources**

Matter exists in 3 phase solid liquid and gas. When energy is supplied to any matter it changes its state example solid became liquid, liquid become gaseous if we give more energy to a gas beyond a certain level, it gets ionized and goes into the state called plasma state. Plasma is considered as the fourth state of matter. Being a fourth state of matter, plasma consists ions, free electrons, highly reactive species, atoms, molecules and UV photons with a net neutral charge. Plasma is a hot ionized gas into which sufficient energy is provided to free electron from atoms or molecules and to allow both ions and electrons to coexist. Ionization

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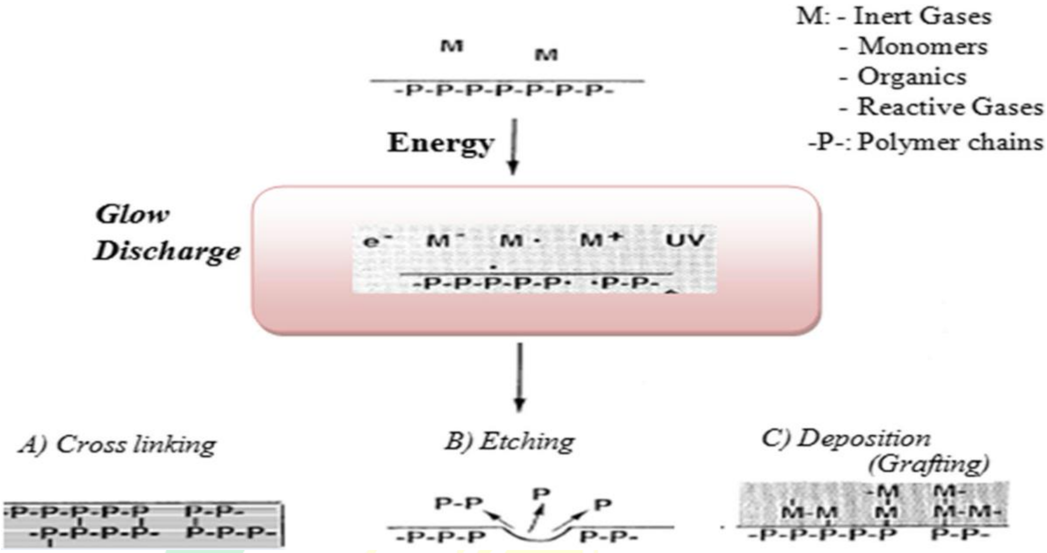
is always considered first important element in plasma processing followed by other characteristics such as reaction rate, electron energy distribution, rate constants, and the mean free path. Based on reactions, there are two types of plasma chemical reactions (i) Gas-phase reaction in a homogeneous state (for example, the production of N3 from N2), and ii) heterogeneous reaction (when plasma comes into contact with the be solid or liquid medium. Further, the heterogeneous reaction is classified into three subcategories. In the first subcategory, material is removed from the surface by etching or ablation; in the second subcategory, material is added to the solid surface in the form of a thin film observed during plasma polymerization by a process called plasma enhanced chemical vapour deposition; and in the third subcategory, no material is added or removed but the substrate surface is physically and chemically modified during exposure to plasma by a process called plasma enhanced chemical vapour deposition. Plasma is classified based on the relative temperature of ions and electrons; they are hot plasma cold plasma. The plasma that is at high temperature is called hot plasma. Hot plasma is also called as thermal plasma, have electrons and the heavy particles at thermodynamics equilibrium in nature. Cold plasma also called as non-thermal plasma is well ionized. Non- thermal or near ambient temperature plasma is generated under atmospheric or vacuum at temperature of 30-60$^{0}$c requiring low energy. Plasma is generated under atmospheric or vacuum at ambient temperature so requiring low energy. This cold plasma is used for food application.

**Working Principle**

Cold plasma is generated at atmospheric pressure by passing a process gas through an electric field. Electron arising from ionization processes accelerated in this field, trigger impact ionisation processes. Free e- colliding with gas atoms transfer their energy, thus generating highly reactive species that can interact with the food surface. The e- energy is sufficient to dissociate covalent bonds in organic molecules. Plasma can be produced by subjecting a gas to an electric field (between two electrodes), either of constant (direct current field) or alternating amplitude (usually high frequency field). Plasma state can be attained by the application of energy in several forms including; thermal, electric or magnetic fields and radio or microwave frequencies, which increase the kinetic energy of the electrons resulting in increased number of collisions in the gas forming plasma products like electrons, ions, radicals and radiation of varying wavelengths including that in the UV ranges. The various approaches used for plasma generation includes the corona discharge, dielectric barrier discharges (DBD), radio frequency plasma (RFP) and the gliding arc discharge




**Factors Influencing the Efficiency of Cold Plasma**

The effectiveness of cold plasma is dependent on several factors, which is primarily connected to the fact that various plasmas and the techniques used for their induction have distinct characteristics. For example, the type of processing gas employed principally determines the nature and quantities of reactive species produced in the discharge as well as the efficacy of the treatment procedure.An additional process variable affecting CP efficiency is the mode of exposure, with direct exposure as a preferable approach for process improvement, in contrast to indirect or remote exposure; as the latter decreases the amount of heat

**Cold Plasma generation approaches**

Cold plasma can be generated in 4 ways.

- Corona discharge
- Dielectric barrier discharge
- Radio frequency discharge
- gliding arc discharge

**Corona discharge**

In this method plasma is produced by an electric charge that is produced by high voltage when in close contact of metal electrode possibly an asymmetric electrode pair. This method generates plasma at atmospheric pressure. In a highly non- uniform electric field, the

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high electric field near the point electrode exceeds the breakdown strength of the gas and produces weakly ionized plasma. Corona is fundamentally non- uniform discharge that develops in the high field region near the sharp electrode spreading out towards the planar electrode. Corona is a stream of charged particles such as electrons and ions that is accelerated by an electric field. At least one of the electrodes has to have a small curvature diameter; this electrode is usually known as a point electrode. The plasma is created at near point electrode and then it spreads towards the planer electrode, creating a non-uniform crown around the wire: that is why this discharge is called ''Corona''. The current discharge is very low: $10^{-10}$ to $10^{-5}$A.

**Dielectric barrier discharge**

The dielectric barrier discharge is also known as silent discharge or barrier discharge. This method provides strong thermodynamic, non- equilibrium plasma at atmospheric pressure and at moderate gas temperature. This consists of two electrodes with at least one covered with dielectric layer placed in their current path between the metal electrodes. The dielectric layer may be made of glass, quartz, ceramic material or polymers. Discharge operates at atmospheric pressure. An a.c voltage is applied to the discharge. When a potential difference is applied between cathode and anode, a continuous current will flow, which gives direct glow discharge.

**Radio frequency plasma**

This is also known as Atmospheric-pressure plasma jet (APPJ), which produces a stable, homogenous plasma flume. This is most widely used method for plasma generation with which a varying electric field is established. The inner electrode is coupled to 13.56 MHz radio frequency power at a voltage between 100-250V and the outer electrode is grounded. These are produced when alternating voltage is applied between the two electrodes so that each electrode will act alternately as the cathode and anode. The frequencies generally used for these alternating voltages are in the radio frequency range. To produce radio frequency plasma, vacuum system is required. Stable plasma is generated when the rate of electrons generated is equal to loss rate of electrons.

**Gliding arc discharge**

These are more applicable to industry than other alternatives such as corona discharge. At least two electrodes diverging with respect to each other are placed in fast

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(typically 10 m/s) gas or vapor flow. The arc initiates at the shortest gap between the two electrodes, after which it elongates by transverse gas flow. At this point of time, the current in the arc is at its maximum value and the voltage at the lowest, then the discharge disappears after a certain path and the cycle is repeated.

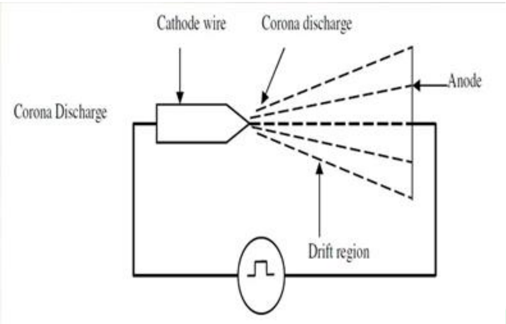


Fig 1 Corona discharge

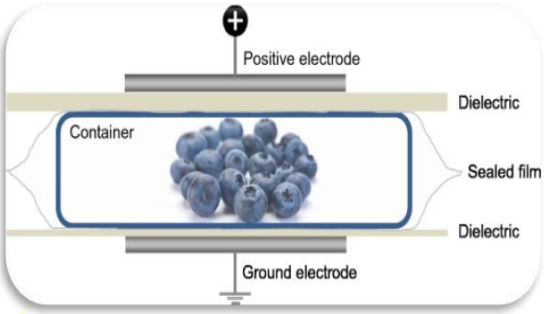


Fig 2. Dielectric barrier discharge

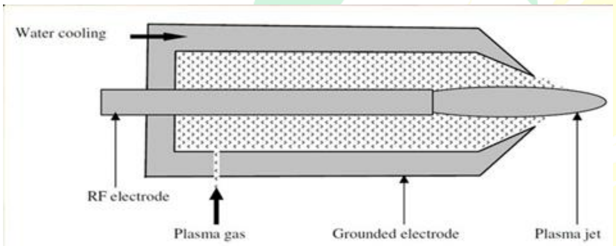


Fig 3. Radio frequency plasma

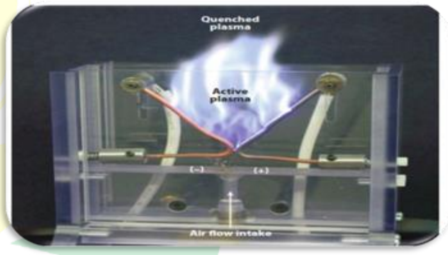


Fig 4. Gliding arc discharge

## Current Applications of Cold Plasma in Food Processing

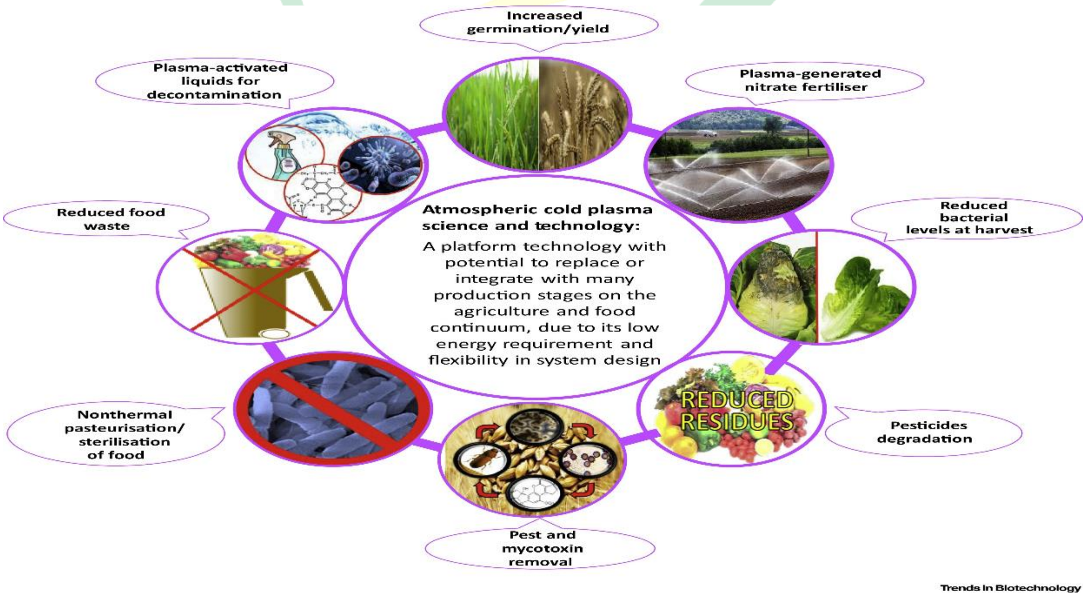


Fig.5 The Potential of Cold Plasma for Safe and Sustainable Food Production

- It is used in the area of microbial inactivation,
- Surface decontamination in product such as poultry, meat, diary, and fresh produce
- Modification of properties enhancement of mass transfer and decontamination of packing materials food decontamination,

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