Cold Plasma: An Emerging Technology for Food Processing and Preservation

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The concern for food safety and its nutritional integrity has increased manifold among consumers in the recent years. Traditional methods of food preservation such as pasteurization and sterilization, involve extensive heating of the foods, which alters their nutritional and organoleptic qualities. Use of chemical preservatives has constantly been under scrutiny for their ill-effects on health. These factors have shifted the focus on to non-thermal technologies. Cold plasma technology has become popular in food industry recently. Cold plasma technology is an effectual substitute of other technologies used for shelf-life enhancement and food decontamination. Cold plasma therapies have demonstrated negligible effects on the physical, chemical, nutritional, and sensory characteristics of different items because of their non-thermal nature. Because of its unique characteristics, this technology has gained more attention in recent years than others. There are distinct advantages to Cold Plasma over conventional processing technologies because of its versatile design, non-thermal nature, affordability, and environmental friendliness.

What is cold plasma?

Plasma is the fourth state of matter and 99% of the perceptive universe is made up of it. Plasma is generally made up of atoms, free electrons and partially ionized gases that contain charged particles, free radicals, and various reactive species. Plasma can be classified into two main types based on temperature. Thermal plasma, referred to as equilibrium plasma, is characterized by all plasma particles having a uniform and elevated temperature. Conversely, non-thermal plasma, often referred to as non-equilibrium or cold plasma, is characterized by a state in which the temperatures of the lighter electrons are substantially greater than those of the heavier atoms and molecules, which stay at ambient temperature (25–60°C). Cold plasma has been found to deactivate microbes and enzymes by creating Nitrogen Species and Reactive Oxygen (RON, ROS) and damaging the macromolecules.

Methods of cold plasma generation:

1. **Glow Discharge Plasma**: An electric field is applied to a low-pressure gas to produce this kind of cold plasma. It produces a visible glow and is commonly used in various applications, including material surface treatments, cleaning, and thin film deposition in electronics and semiconductor industries.
2. **Dielectric Barrier Discharge (DBD):** DBD plasma is formed between two electrodes separated by an insulating dielectric material. It's used in applications like ozone production, surface modification, and sterilization due to its ability to generate reactive species without direct exposure to electrodes.
3. **Corona Discharge:** This type of cold plasma occurs at the surface of a conductor or in a gas gap when high voltage is applied, leading to the formation of ionized species. Corona discharge finds applications in air purification, ozone generation, and electrostatic precipitation.
4. **Atmospheric Pressure Plasma Jet (APPJ):** APPJ operates at atmospheric pressure and generates a plasma jet that can be directed towards specific targets. It's used for various applications, including surface treatment, sterilization, and wound healing in the medical field.
5. **Microwave Plasma:** Microwave plasma is generated by introducing microwaves into a low-pressure gas. This type is often used in material processing, surface modification, and thin film deposition due to its ability to produce uniform and controlled plasma.
6. **Capacitive Coupled Plasma (CCP):** CCP involves two electrodes separated by a dielectric, allowing the creation of plasma by applying an alternating current. It's used in semiconductor processing, surface cleaning, and modification due to its uniform and high-density plasma generation.

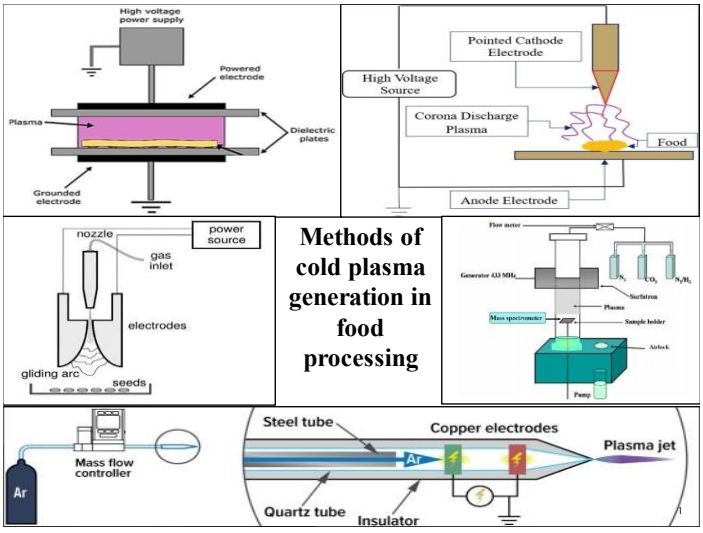
7. **Floating Electrode Dielectric Barrier Discharge (FE-DBD):** This form of DBD plasma involves an additional floating electrode which allows for specific control of the discharge. It's used in surface treatment, modification, and sterilization applications.

Cold plasma has shown significant potential for applications in food processing industries. The industries employ a variety of cold plasma generation techniques, including corona discharges, microwave plasma, gilded arc plasma, jet type plasma, radio frequency plasma, and dielectric barrier discharge plasma. Due to their straightforward, adaptable, and versatile designs and operating procedures, dielectric barrier discharge and jet plasma are the two techniques that are most frequently utilised for food research. In the former, cold plasma was often utilised in the polymer, sterilising, and electrical sectors, among other industries. However, in topical years, cold plasma's uses have rapidly extended to include the treatment of biological materials, biomedical devices and even food. Each type of cold plasma has its unique advantages and is suitable for particular applications based on factors such as the required level of energy, types of reactive species produced, scalability, and the specific properties of the targeted surface or material. The selection of the type of cold plasma is determined by the intended application and the desired outcomes.

Applications in Food Industry

The unique properties of cold plasma make it suitable for a variety of applications in food processing and preservation. The following are a few significant uses of cold plasma in the food industry:

1. **Surface decontamination:** Cold plasma is effective in decontaminating surfaces of food products, equipment, and packaging materials. It can destroy bacteria, viruses, and molds present on the surface of fruits, vegetables, and meat products without altering the food quality or characteristics.
2. **Extension of shelf life:** Treatment with cold plasma can help extend the shelf life of various food products. By targeting and eliminating spoilage microorganisms, it prevents or slows down microbial growth, thereby reducing the rate of spoilage and maintaining the quality of perishable foods.



3. **Packaging sterilization:** Cold plasma technology can be used to sterilize food packaging materials. It helps in disinfecting the packaging to ensure that the food remains uncontaminated throughout its shelf life.
4. **Improvement of food safety:** Cold plasma treatment is a non-thermal process that can enhance food safety by reducing pathogens and contaminants on the food surface without altering its nutritional content or sensory attributes.
5. **Enzyme inactivation:** Cold plasma treatments can also be used to deactivate enzymes that cause food spoilage, thereby extending the product's freshness and quality.
6. **Modification of food properties:** Cold plasma treatment can alter the surface properties of food, leading to changes in wettability, adhesion, and other characteristics. This can be useful for applications like improving the effectiveness of coatings or modifying the texture of certain food products.
7. **Reduction of chemical additives**: Using cold plasma in food processing can potentially reduce the need for chemical preservatives, as it offers a non-chemical method to maintain food safety and quality.

However, while cold plasma technology holds significant promise, there are still some challenges to

be addressed, such as scalability, cost-effectiveness, and standardization for widespread industrial adoption.

To sum up, cold plasma technology has a lot of promise for the food business. It provides creative, non-thermal methods for processing and preserving food, which enhances food safety, lengthens shelf life, and lessens the need for chemical preservatives. It has been observed that the processing of cold plasma affects the quality characteristics of food products both during handling and storage. The further exploration and advancement in this domain will probably enhance and broaden the uses of cold plasma in food technology.

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