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Inactivation effect of dielectric barrier discharge plasma against foodborne pathogens on the surfaces of different packaging materials

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ABSTRACT

The usefulness of dielectric barrier discharge (DBD) plasma for surface disinfection of the common food packaging materials, namely glass, polyethylene, polypropylene, nylon, and paper foil was evaluated. DBD plasma was generated by applying a pulsed DC voltage of 10 kV and at a power of 208 W. The separation distance between the electrodes was 2.65 mm. On exposure of food pathogens-loaded packaging materials to the plasma, >4 log/cm^2 reduction (99.99%) in viable cell counts of *Escherichia coli* O157:H7 was observed in 10 min. The other two tested pathogen strains, *Salmonella typhimurium* and *Staphylococcus aureus,* were inactivated in the range 3.0–3.5 log/cm^2. The inactivation pattern of the pathogens fitted well to the log-linear and tail model. Compared to unexposed packaging materials, no significant ($p > 0.05$) changes in the surface temperatures, optical characteristics, tensile strengths, and strain-induced deformation were observed for the DBD plasma-exposed materials. Therefore, the DBD plasma can be used to disinfect surfaces of different food packaging materials harboring moderate levels of bacterial contaminants without adversely affecting their physicomechanical properties.

Industrial relevance: Traditionally, dry heat, steam, UV light and chemicals like ethylene oxide and hydrogen peroxide have been used as surface sterilants and disinfectants for packaging materials in the food industry. However, certain limitations have motivated the search for new approaches. Cold plasma technology is an emerging, green process for surface sterilization. The DBD plasma was found to be effective in reducing the bacterial food pathogens on different food packaging materials. As the technology is simple and scalable, it can be readily applied industrially.

1. Introduction

Glass, metal, plastic, wood and paper-based materials are widely used for the food packaging purposes (Raheem, 2012). Especially, thermo-plastic polymeric packaging materials have received greater attention in recent years owing to their flexibility, chemical inertness, transparency, low specific weight and low cost (Pankaj et al., 2014). Aseptic processing and packaging is a well-known technique to increase the shelf-life of foods without any preservatives. Sterilized package is a key component in aseptic processing and packaging of foods. Food packaging materials should meet microbiological requirements specified by different regulatory bodies as the packaging process is an important critical control point in a hazard analysis critical control point (HACCP) system (Mittendorfer, Bierbaumer, Gratzl, & Kellauer, 2002). The surface of packaging materials can be sterilized/disinfected by different methods including dry heat (>180 °C), saturated steam (130–150 °C), UV irradiation, infrared light, chemicals like hydrogen peroxide or peracetic acid and ethylene oxide, and combination of these methods (Ansari & Datta, 2003; Muranyi, Wunderlich, & Langowski, 2010). However, certain limitations associated with these methods have motivated the search for new approaches (Schneider et al., 2005; Pankaj et al., 2014). For instance, the chemical sterilants used for disinfection are known for their intrinsic toxicity and might leave toxic residues on surfaces (Samuel, Matthews, & Gibson, 1988). In recent years, cold or non-thermal plasma sterilization/disinfection methods are gaining popularity as attractive alternatives to conventional methods for the microbial decontamination of heat sensitive materials (Ehlbeck et al., 2011), and food packaging materials (Lee, Puligundla, & Mok, 2015).

Plasma is a partially ionized gas that consists of a variety of species such as electrons, free radicals, ions (both positive and negative), gas molecules in ground or excited state and quanta of electromagnetic radiation. Cold plasmas generated with different gases such as O_2, N_2, air, H_2, halogens, N_2O_3, H_2O_2, CO_2, SO_2, SF_6, etc., have been reported to exhibit sterilization effect (Ratner, Chilkotti, & Lopez, 1990). A wide

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range of microorganisms, including spores, can be inactivated by non-thermal plasma treatment (Feichtinger, Schulz, Walker, & Schumacher, 2003; Kelly-Wintenberg et al., 1999; Lee, Paek, Ju, & Lee, 2006). The mode of action of plasma is more complex in inactivation, and is still not fully understood.

Among different non-equilibrium atmospheric-pressure plasmas, dielectric barrier discharge plasma (DBDP) has a unique position. The prominent features of DBDP include simple scalability, plasma can cover large surface area, efficient, it can be shaped and cost-effective (Kogelschatz, 2003). These discharges require alternating voltages for their operation, and require simple equipment, in which a pair of conducting electrodes is separated by a solid dielectric material (e.g. glass, plastic). Originally, DBD has been used for different industrial applications such as surface modification, ozonizer, and degradation of environmental pollutants, and so on (Kogelschatz, 2003; Park, Moon, Lee, & Shin, 2006); and in recent times, it has also been employed for microbial decontamination purposes (Ma, Zhang, Shi, Xu, & Yang, 2008; Leipold, Kusano, Hansen, & Jacobsen, 2010; Misra et al., 2014).

DBD atmospheric cold plasma generated in air was shown to be effective against *Pseudomonas aeruginosa* biofilms (Ziuzina, Patil, Cullen, Boehm, & Bourke, 2014). In a study by Yong et al. (2015), encapsulated atmospheric pressure DBD plasma, which was generated in air at 250 W power and 15 kHz frequency, has been shown to exhibit significant inactivation effect against *Escherichia coli, Salmonella typhimurium* and *Listeria monocytogenes* on agar plates and cheese slices. Recently, our group has shown that DBD plasma in air can be used for microbial decontamination of thin sheets of dried laver (seaweed) (Kim, Puligundla, & Mok, 2015).

Although these studies show the antimicrobial efficiency of DBD plasma against different microorganisms, especially bacterial pathogens, there is a scarcity of information on the plasma application for sterilization/disinfection of food packaging materials. Sterilization efficiencies of different dielectric barrier discharges against spores of *Bacillus subtilis* and *Aspergillus niger* sprayed onto PET foils were investigated by Heise, Neff, Franken, Muranyi, and Wunderlich (2004). They reported a fast reduction in the viability by more than four orders of magnitude using cascaded dielectric barrier discharge (CDBD), which is a hybrid process by combination of UV light at 222 nm and reactive argon plasma. Moreover, the study also established that the sealing properties of commonly used PE-PET-laminate can be maintained in the CDBD treatment which was not observed using a single-gap DBD. DBDP disinfection of surface-borne microbes of other food packaging materials such as glass, polypropylene (PP), polyethylene (PE), nylon and paper foil is lacking. Therefore, this study was aimed majorly at determining the inactivation effect of DBD plasma against selected food pathogens, namely *Escherichia coli* O157:H7, *Salmonella typhimurium* and *Staphylococcus aureus,* which are bound to the surfaces of common packaging materials.

Physical and mechanical properties' testing is an essential step in quality control of a packaging material. Possible changes in the tensile strength, color and surface temperature of food packaging polymers upon DBD plasma treatment are unknown. Therefore, the present study was also aimed to determine the physicomechanical characteristics of DBD plasma-exposed food packaging materials.

2. Materials and methods

2.1. Microorganisms

Standard cultures of bacterial food pathogens were procured from Korean Culture Center of Microorganisms (KCCM). They include *Escherichia coli* O157:H7 ATCC 43894, *Salmonella typhimurium* ATCC 13311, and *Staphylococcus aureus* ATCC 25923. All the strains were cultured with tryptic soy broth (TSB) (BD Company, Le Pont de Claix, France) at 37 °C for 24 h prior to use in experiments.

2.2. Packaging materials

Packaging materials used for experimentation were procured from different suppliers. Glass slides (76 × 26 × 1 mm slide glass, Paul Marienfeld GmbH & Co. Lauda-Konigshofen, Germany) which represent glass (GL) packaging materials were used in this study. The films (LxW = 76 × 26 mm) of low-density polyethylene (PE, 65-μm film thickness) (Topchemical Co., Incheon, Korea), polypropylene (PP, 60-μm film thickness) and nylon (NL, 55-μm film thickness) (Sungwon plastic packaging, Seoul, Korea), paper foil or parchment paper (PF, 45 μm film thickness) (Cleanwrap Co., Gimhae, Korea) were also used.

2.3. DBD plasma generation

A DBD plasma-generating instrument that has been designed by Mok and Lee (2012) and fabricated by Plasma Life Co. Ltd., Incheon, Korea, was used in the present study. As shown in Fig. 1, plasma-generating electrode of the instrument was powered by a high-voltage pulsed DC power supply with a voltage range of 10–50 kV and an operation frequency range of 10–50 kHz. In the present study, the applied voltage was 10 kV DC and power consumed was 208 W. The length of the plasma-generating electrode was 15 cm and its width

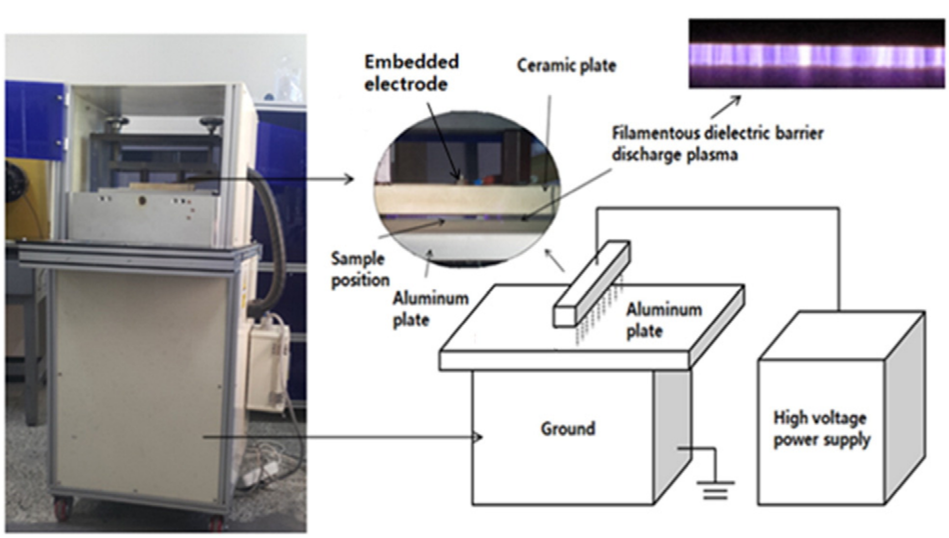

Fig. 1. Block diagram of dielectric barrier discharge plasma (DBDP) system used for the treatment of packaging materials.