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Investigation of inactivation process for microorganism collected in an electrostatic precipitator

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ABSTRACT

This study is aimed at investigating an inactivation process of microorganisms collected by a two-stage type electrostatic precipitator (ESP). The experimental system consisted of a discharging section and an electrostatic section. A bacterial culture of *Staphylococcus aureus*, as a model of airborne microorganisms, was put on the surface of grounded plate electrodes in these sections. Negative DC high voltages were applied to these sections. The gas flow velocity in the experimental system was 0.5 m/s. The survival ratio was calculated by the colony counting method, and the amount of 250-nm-absorbing substance, such as protein and minerals, was measured using a spectrophotometer. Living and dead microorganisms were distinguished using a fluorescence microscope, and their forms were observed using a scanning electron microscope (SEM). Reactive oxygen species (ROS) distribution on the surface of the grounded plate electrode was observed using a gel reagent. The collection efficiencies and the ozone concentrations were also measured in a single-stage ESP and the two-stage type ESP.

As a result, ROS concentration was the greatest under the wire electrode. The result of the colony count showed that microorganisms were inactivated by the corona discharge. The observation using the fluorescence microscope showed that the amount of dead microorganisms was greater than that of the living microorganisms after the inactivating treatment. The SEM observation revealed that the cell walls were destroyed, and the result obtained with the spectrophotometer showed an increase in the amount of 250-nm-absorbing substance. These results indicated ROS destroys cell walls and causes cell content to flow out, whereby microorganisms collected in an ESP are inactivated. It was also revealed that the collection efficiency can be improved without increasing ozone concentration and energy consumption in the two-stage type ESP.

1. Introduction

Electrostatic Precipitators (ESPs) have been extensively used for the cleaning of industrial process flue gases, combustion flue gases and ventilation flue gases for road tunnels, etc. A home air cleaner is also one application of an ESP. Such air cleaners which utilize corona discharge must be capable of eliminating and inactivating airborne microorganisms to improve indoor air quality as in a hospital room.

Microorganisms are inactivated by nonthermal plasma [1,2]. There are many pieces of literature describing the inactivation with ozone gas generated by nonthermal plasma. It is known that survival ratios of *B. subtilis* and *S. aureus* are proportional to CT [ppm·min], which is the product of ozone concentration C and exposure time T [3,4]. It was reported the value of CT needed to be 50 or 60 ppm·min to inactivate *S. aureus* at relative humidity between 60 and 65% [4,5].

The inactivation mechanism of corona discharge was also studied. Mizuno et al. reported that φX174 phage was inactivated as a result of the degradation of coat protein [6]. Ohshima et al. showed that the cell-surface and DNA of *S. epidermidis* on a plate electrode was damaged due to corona discharge [7]. Ye et al. observed the changes in morphology and microstructure of microorganisms using a scanning electron microscope and transmission electron microscope, and revealed defects in the morphology and internal sub-structure after treatment [8]. Sysolyatina et al. indicated that the neutral reactive species, which was $O_2(^1\Delta)$ + HO_2 had the highest inactivation efficiency among ultraviolet radiation (UV), electric field and charged particles [9]. Machala also showed UV radiation from plasma had no biocidal effects, and radicals and reactive oxygen species (ROS), which were O, OH and O_3, were

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dominant biocidal agents [10].

G. Mainelis investigated the applicability of an ESP as a method for bioaerosol collection [11]. Botvinnik et al. reported an experimental result carried out to investigate the elimination of *Serratia marcescens* in the air using an ESP employing corona discharge [12]. The microorganism concentration was measured using the fifth stage of an Anderson six-stage impactor. As a result, colonies on the Petri dishes decreased with ESP-operation time. Takimoto et al. suggested a bacteria collection system using negative ions and ozone with mist formation in an ESP [13]. Ohshima et al. investigated the influence of electrode form, voltage waveform and voltage frequency on electrostatic precipitation under airflow condition [14], and showed microorganisms collected on the grounded plate electrode were inactivated [15]. These reported that airborne microorganisms were collected on a collection electrode and the collected microorganisms were inactivated in the ESP. However, there are few studies for the inactivation of collected microorganisms and the process in a two-stage type ESP.

The authors had investigated an inactivation effect on microorganisms collected on the surface of a collection electrode in a DC energized two-stage type ESP which consisted of a discharging section and an electrostatic section [16]. A two-stage type ESP has the merits of low energy consumption, low ozone concentration and compact size compared with a single-stage type ESP. As a result, the inactivation effect in the electrostatic section was low, whereas the effect in the discharging section was high.

In this study, the aim is to investigate the inactivation process of microorganisms collected by the ESP. In particular, ROS distribution and the morphology were investigated to clear the reason why the inactivation effect in the discharging section was high. The experimental system consisted of a discharging section and an electrostatic section. A bacterial culture of *S. aureus*, as a model of airborne microorganisms, was put on the surface of grounded plate electrodes in the discharging and the electrostatic sections. The gas flow velocity in the experimental system was 0.5 m/s. The survival ratio was calculated by colony count, and the amount of 250-nm-absorbing substance was measured using a spectrophotometer. Living and dead microorganisms were distinguished using a fluorescence microscope, and their forms were observed using a scanning electron microscope (SEM). Reactive oxygen species (ROS) distribution on the surface of the grounded plate electrodes was observed using a gel reagent. The collection efficiencies and the ozone concentrations were also measured in a single-stage ESP and the two-stage type ESP.

2. Methodology

The schematic diagram of the experimental ESP system is shown in Fig. 1. The system consisted of ducts and an ESP. The electrode arrangement of the ESP is shown in Fig. 2. It has a two-stage structure of a discharging section and an electrostatic section. The discharging section (single-wire-type) has a wire-and-plates configuration composed of a high-voltage application wire electrode (ϕ: 0.45 mm, L: 70 mm, SUS304) placed between grounded plate electrodes (70 × 270 mm)

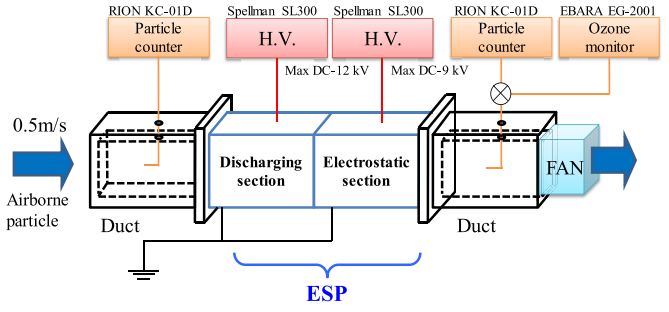

Fig. 1. Schematic diagrams of experimental ESP system.

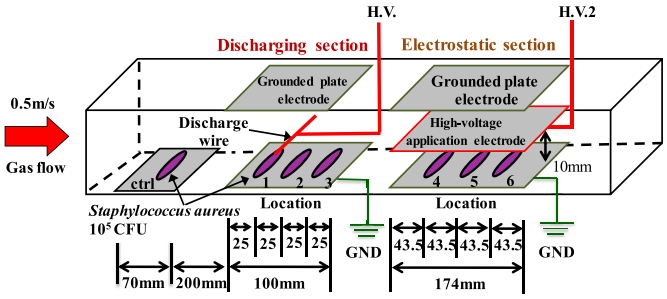

Fig. 2. Electrode arrangement of ESP.

with a gap of 10 mm. The electrostatic section has a parallel-plate electrode structure composed of a high-voltage application electrode (70 × 174 mm) sandwiched between grounded plate electrodes (70 × 174 mm) with a gap of 10 mm. All plate electrodes are made of stainless steel with a thickness of 0.8 mm. Room air was used, and the gas flow velocity was adjusted to 0.5 m/s by a fan located on the downstream side of the ESP. Maximum voltages of DC -12 kV and DC -9 kV were applied to the discharging and the electrostatic sections using high voltage generators (Spellman, SL 300) as shown in Fig. 1, and discharge current was measured. Ozone concentration was measured using an ozone monitor (EBARA, EG-2001) at the downstream side of the ESP. The size of suspended microorganisms is between 0.3 and 3 μm. Therefore, the number concentrations for the particle size between 0.3 and 5 μm at the upstream and downstream sides of the ESP were measured using particle counters (RION, KC-01D), and the collection efficiency was calculated by equation (1). However, this measurement cannot distinguish between microorganisms and suspended particulate matter. The discharge current and the ozone concentration in the double-wire-type discharge section shown in Fig. 3 were also measured.

$$\eta_p = \left(1 - \frac{N_{Dd}}{N_{Ud}}\right) \times 100\ \% \tag{1}$$

where, N_{Ud} and N_{Dd} are the number concentrations [part/m^3] for the particle diameter of d at the upstream and downstream sides of the ESP.

Gram-positive bacteria are stronger for drying, and the life time is longer than gram-negative bacteria. Furthermore, *Staphylococcus aureus*, which is gram-positive bacteria, are widely used for estimating inactivation effect in many studies for sterilization technology [16], and the inactivation effect in the ESP was investigated in our study [15]. Therefore, a solution of bacterial culture of *S. aureus* (NBRC13276, 10^4 CFU) diluted with pure water was put at six locations on the surface of the two grounded plate electrodes in the discharging and electrostatic sections to simulate collected microorganisms as shown in Fig. 2. The three samples in the discharging section were respectively located under the wire electrode as well as at 25 mm upstream and downstream from the wire electrode (Locations 1–3). The three samples in the electrostatic section were respectively located at the center of the electrode as well as at 43.5 mm upstream and downstream from the center (Locations 4–6). The control was located at 200 mm upstream from the grounded electrode in the discharging section.

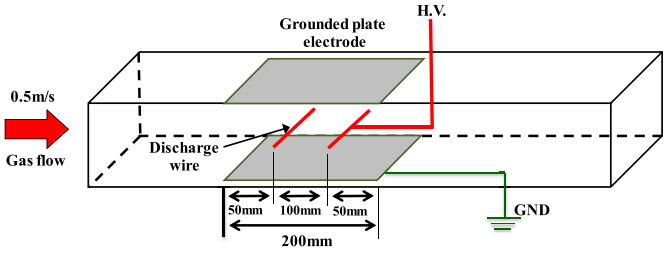

Fig. 3. Electrode arrangement of double-wire-type discharging section.