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Short communication

Physical and microbial collection efficiencies of an electrostatic precipitator for abating airborne particulates in postharvest agricultural processing

Shoji Koide [a], Akira Nakagawa [b], Katsuhiko Omoe [c], Koichi Takaki [b,*], Toshitaka Uchino [d]

[a] Department of Agro-bioscience, Iwate University, 3-18-8 Ueda, Morioka 020-8550, Japan
[b] Department of Electrical and Electronic Engineering, Iwate University, 4-3-5 Ueda, Morioka 020-8551, Japan
[c] Department of Veterinary Medicine, Iwate University, 3-18-8 Ueda, Morioka 020-8550, Japan
[d] Faculty of Agriculture, Kyushu University, 6-10-1 Hakozaki, Fukuoka 812-8581, Japan

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ABSTRACT

We constructed a single-stage, laboratory-scale electrostatic precipitator (ESP) and evaluated its physical and microbial collection efficacies. Ground rice husk was examined as a representative model of airborne particles carrying microorganisms (bacteria, molds and yeasts). Physical and microbial collection efficacies were evaluated at different voltages applied to the negative discharge electrode without ozone generation. The best collection efficiencies were observed at an applied voltage of −6.0 kV, resulting in collection efficiencies of over 90% for the physical sample and 99.95% for bacteria. No molds or yeasts in the ground rice husk passed through the ESP operating at −6.0 kV applied voltage.

1. Introduction

Airborne dust in postharvest processing environments for agricultural crops is of increasing concern, especially because it is associated with biological, chemical and physical hazards. Airborne dust includes bacteria, fungi, pollen, algae, dusts, endotoxins, mycotoxins, and viruses [1–3]. Thus, air cleaning in dusty environments such as in rice postharvest facilities is of key importance, because airborne particles that contain microorganisms may pose environmental risks to public health and possibly increase microbial and mycotoxin contamination of agricultural products [4,5].

Recently we reported very high airborne concentrations (>4.2 $\log_{10}$ CFU/m^3 for aerobic bacteria and >3.7 $\log_{10}$ CFU/m^3 for molds and yeasts) during rice harvest season [6]. Thus, it is vital to develop advanced engineering systems for air cleaning to eliminate airborne particles that carry airborne microorganisms in the postharvest environment. In this study we focused on the electrostatic precipitator (ESP), a particulate collection device that removes particles from flowing air using the force of an applied electric field acting on a charged particulate; that charge imparted by air-ion attachment during passage of the particulate through an ionized field region of space near an electric-discharge electrode such as a high-voltage “corona” wire. ESPs are highly efficient filtration devices that minimally impede the flow of gases yet can easily remove fine particulate matter such as dust and smoke from the air stream. ESPs are considered to be compact, safe, and energy-efficient, and can be operated for long periods without maintenance [7]. Thus, ESPs have been used widely indoors and in industry to reduce air dust, biomass and mold spores [8–10]. However, there has been no application of ESP to date for air cleaning in a rice postharvest facility to remove airborne particles that carry airborne microorganisms.

The aim of this study was to investigate the feasibility of using ESP to control airborne dust and microorganism contamination in postharvest processing environments. We used ground rice husk as a model sample for airborne particles with airborne microorganisms (bacteria, molds and yeasts), and determined the physical and microbial collection efficacies of ESP under various voltages applied to the negative discharge electrode.

* Corresponding author. Tel./fax: +81 19 621 6941.
E-mail address: takaki@iwate-u.ac.jp (K. Takaki).

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2. Material and methods

2.1. Sample preparation

Milled rice dust was collected from a rice storage facility in the Iwate Prefecture in 2010. The dusts were transferred to the laboratory and ground using a blender to a particle size of <210 μm. The particle size distribution of ground rice husk samples was measured using a laser diffraction particle size analyzer (Shimadzu, SALD-2100, Japan).

2.2. Experimental setup

A diagram of the laboratory-scale experimental setup is shown in Fig. 1. The sample generator consisted of a sealed 100 ml glass flask that was autoclaved before receiving a 10.0 g sample of ground rice husk. The ESP was comprised of four parts: a cylinder consisting of acrylic plastic (36 mm inner diameter and 300 mm length), inlet and outlet funnels consisting of polypropylene attached between the cylinder and an inlet or outlet vinyl tube, a metal (316 stainless steel) high-potential wire (negative discharge electrode, 0.2 mm diameter and 280 mm length) connected to a DC power supply (Towa Keisoku, ATK, Japan), and metal (316 stainless steel) ground electrode mesh (36 mm inner diameter and 220 mm length). The negative discharge electrode was placed along the axis of the cylinder and the ground electrode was coaxially attached to the inner wall of the cylinder. A current sensing resistor (5 MΩ) was placed between the ESP and ground. The dust sample collection impinger consisted of a 500 ml glass flask with a silicone lid and Teflon tubes for inlet and outlet. The impinger was filled with collecting fluid (200 ml of sterile 0.85% sodium chloride solution). A stabilized 0.22 μm filter (Advantec, Tokyo, Japan) was connected to the outlet Teflon tube, and air was vented from the apparatus.

2.3. ESP measurement procedure

Before and after each experiment, the moisture content of the ground rice husk sample was determined using the air oven method (105 °C, 24 h). In this study, the individual weights of milled husk sample in the glass flask, in the outlet tube from the sample generator, and in the laboratory-scale ESP were expressed as dry matter.

Before measurements all equipment was decontaminated and the individual masses of the glass flask containing the ground rice husk sample, the outlet tube from the sample generator, and the laboratory-scale ESP were measured with an electronic balance. The concentration of ozone produced from the ESP was monitored with an ozone meter (Dylec, DY-1500, Tokyo, Japan). No ozone was produced in the measurements until the discharge electrode voltage reached −6.2 kV.

ESP measurements were performed for 30 min at discharge electrode voltages of 0, −1.5, −3.0, −4.5 and −6.0 kV. During measurement, dry air was supplied to the sample generator from a fresh-air gas cylinder at a constant rate of 2.0 l/min, controlled by an air flow meter. The ground rice husk sample was suspended in the air within the flask by stirring with a magnetic stirrer. The sample was pneumatically transferred to the impinger via the ESP. The temperature of dry air in the ESP was approximately 20 °C. The energy used over 30 min for discharge in the ESP was 0.016, 0.066, 0.180 and 0.192 J at −1.5, −3.0, −4.5 and −6.0 kV, respectively. These energies correspond to 0.009, 0.037, 0.100 and 0.507 mW mean power consumed in the ESP and to −6, −12.3, −22.2 and −84.5 nA mean discharge current, respectively. Therefore, the current densities upon the outer grounded mesh cylinder were estimated as 0.24, 0.49, 0.89 and 3.39 $\mu A/m^2$ at −1.5, −3.0, −4.5 and −6.0 kV, respectively. The pressure within the sealed ESP during operation was 101.7 kPa, where atmospheric pressure was 101.3 kPa. Thus the pressure existing within the sealed ESP during operation can be considered negligible in this study.

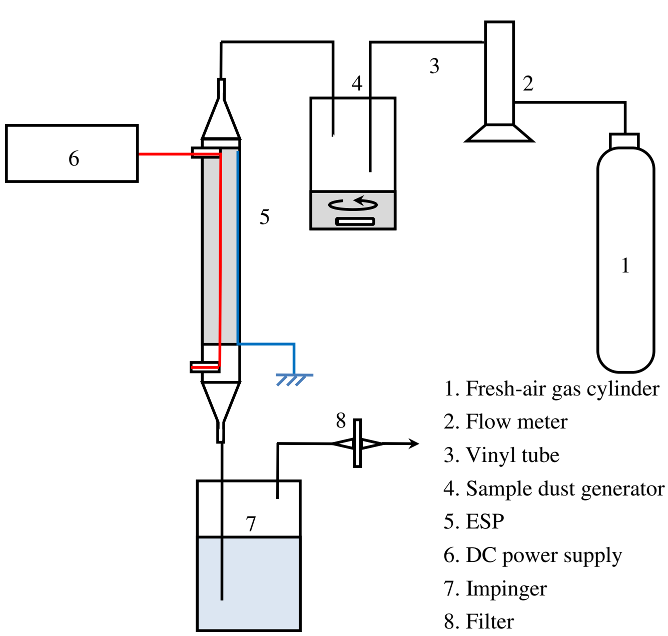

Fig. 1. Laboratory-scale experimental setup of electrostatic precipitator for collection of airborne particulates in postharvest agricultural processing facilities.

2.4. Determination of physical collection efficiency

To determine the physical collection efficiency of the ESP, the final post-experiment masses of the glass flask containing the milled husk sample, the outlet tube from the sample generator, and the laboratory-scale ESP were recorded. The total difference of the flask and outlet tube masses before and after the experiment was determined as the initial mass input to the ESP (W_{ini}). The mass difference of the laboratory-scale ESP before and after the measurement was taken as the mass collected in the ESP (W_{ESP}). In this study, an ESP measurement for 30 min with a zero negative discharge electrode condition was used as a control.

The physical collection efficiency, η% (w/w dry basis), of the ESP was calculated as follows:

$$\eta = 100\cdot\left(\frac{W_{ESP}}{W_{ini}}\right) \tag{1}$$

2.5. Sampling of microorganisms

Sampling of airborne microorganisms was performed by the impinger method [11]. After measurement the fluid collected in the impinger was used as a sample for counting the microorganisms. The fluid collected in the impinger was also serially diluted with sterile 0.85% sodium chloride solution and used as samples for counting the microorganisms for high concentration. The bacterial counts were determined by plating 0.1 ml of each sample onto a plate count agar (Difco Laboratories, USA) [12]. The plates were incubated at 37 °C for 48 h and the colonies then counted. The detection limit of this method was 1 $\log_{10}$ CFU/ml of sample. Mold and yeast counts were determined by plating 0.1 ml of each sample onto potato dextrose agar (Nissui, Japan) with 0.1 g/l