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Use of an electrostatic precipitator with wet-porous electrode arrays for removal of air pollution at a precision manufacturing facility

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ABSTRACT

This study analyzed the concentrations and size distributions of ultrafine particles, as well as their chemical components and morphologies, in the context of manufacturing processes, focusing on injection molding and tool repair. The concentrations of water-soluble gases such as sulfur dioxide (SO_2), which is an undesirable emission, were measured during the manufacturing process. To remove particles and gaseous pollutants from manufacturing sites simultaneously, we improved the recently introduced electrostatic precipitator (ESP) system, in which wet-porous electrodes (WPEs) are used. The modified novel ESP consisted of an ionization part, for particle charging, and a collection part, installed in the working chamber of a manufacturing facility along with the WPE array to maintain a high-humidity environment using a water bucket. The proposed ESP could be also be coupled with laminar flow modules that are typically mounted in manufacturing facilities and used to maintain a clean environment during working processes. To evaluate the performance of the proposed ESP, the removal efficiencies of airborne particles and SO_2 gas were investigated under operating conditions, with an applied electric field strength in the collection part of the ESP and flow velocities in the working chamber. The collection efficiency of the WPE-ESP was improved by increasing the electric field strength of the collection plates, and the maximum total collection efficiency of the system was ~99.5% for a 13.3 kV/cm collection environment under 0.4 m/s conditions. The proposed system also removed SO_2 at 88.5–92.5% under flow conditions of 0.4–2.0 m/s. Furthermore, this system shows potential for increasing energy efficiency in workplaces due to the extremely low pressure drop.

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1. Introduction

Over the past two decades, many researchers have studied particle exposure in the workplace (Elihn, Berg, & Lidèn, 2011; Zhang, Kuo, Gerecke, & Wang, 2012), as well as its harmful effects on the cardiovascular system (Nemmar et al., 2001; Oprya et al., 2012). Moreover, there have been several studies investigating the characteristics of particles generated during manufacturing processes such as welding, molding and extrusion (Elihn & Berg 2009), which have found that the associated airborne particles significantly influence the quality of products, as well as the health of workers (Schulte, Geraci, Zumwalde, Hoover, & Kuempel, 2008). Numerous studies have investigated the mechanisms by which ultrafine particles are generated during manufacturing processes. Martin et al. (2015) studied the physicochemical and morphological properties of ultrafine particles and raw materials in commercial photocopying centers. Zimmer and Biswas (2001) and Sowards, Lippold, Dickinson, and Ramirez (2008) described how particles generated during manufacturing are usually classified into three types according to the mechanism of formation; i.e., ultra-fine particles (<0.1 μm), coarse fume particles (>1 μm), and agglomerates of various shapes (>0.1–0.2 μm). Hu et al. (2015) sampled metallic aerosol particles in various environments and observed the morphology and behaviors of the particles.

In particular, environmental concerns have developed regarding the manufacture of precision components due to the improvement in defect rates and the indoor air quality (IAQ) control processes for workplaces are more systematic than those in place in the industry in general. Furthermore, environmental regulations regarding the manufacture of medical devices have gradually been tightened (GMP, 2008; ISO 14644, 2001; ISO 13485, 2003). Therefore, additional research on removal technologies to control particles and toxic gases in manufacturing environments is needed.

Previously, Kim, An, Lee, Lee, & Jung (2015) developed an electrostatic precipitator (ESP) system using a non-metallic wet-porous electrode (WPE) array. The surface deviation of the water layer on the WPE (under ± 30 μm from the reference plane) was markedly enhanced compared with that of a traditional wet ESP (Dors, Mizeraczyk, Czech, & Rea, 1998; Saiyasitpanich, Keener, Lu, Khang, & Evans, 2006; Lin, Tsai, Chen, Chen, & Li, 2010), which resulted in improved electric field stability among the collection electrodes. In particular, the WPE array of the proposed ESP could maintain a high humidity environment, resulting in a greater collection efficiency, because the particle cohesiveness to the collecting plates was improved by water adsorption on the particle surface (Nouri, Zebboudj, Zouzou, Moreau, & Dascalescu, 2010; Chen, Tsai, Yan, & Li , 2014) and the electric field strength near the collection part was also increased by life extension of the electrons emitted from the corona discharge (Abdel-Salam, 1992; Bian et al., 2011; Wang & You, 2013). Furthermore, water-soluble gases were reduced rapidly by the WPE array in the collection part. However, to apply such a WPE-ESP system to the manufacturing environment that produces precision components and medical devices, research must examine high-flow-velocity conditions (>0.4 m/s) (ISO 14644, 2001; ISO 13485, 2003) and an improved system that can be mounted in manufacturing facility working chambers is also necessary.

This study investigated the physiochemical characteristics and concentrations of particles generated at a precision components manufacturing site. We also measured the concentration of sulfur dioxide (SO_2), which is a water-soluble gas that should be removed because it affects the health of workers and product quality, considering regulations pertaining to SO_2 emissions, such as those of the American Conference of Governmental Industrial Hygienists (ACCIH), National Institute for Occupational Safety and Health (NIOSH), and World Health Organization (WHO). Then, we propose an improved WPE-ESP system that was modified in consideration of manufacturing facilities, such that it can be mounted, for example, in an injection molding machine. Although existing collection systems equipped with high-efficiency particulate arrestance (HEPA) filters have been used to control air quality in the working chambers of manufacturing facilities, the issues of a high

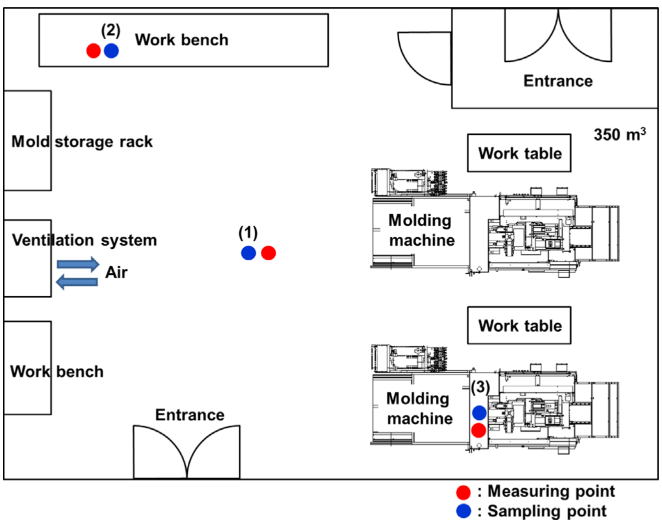

Fig. 1. Schematic diagram of the manufacturing site.