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Technical note

Reduction of aerosol particulates through the use of an electrostatic precipitator with guidance-plate-covered collecting electrodes

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ABSTRACT

This paper presents a novel particle-trapping mechanism that enhances the filtration efficiency of an electrostatic precipitator (ESP). Collecting electrodes are covered with guidance plates that have patterned holes. Gaps are intentionally left in-between the guidance plates and the collecting electrodes, so that particles can travel through these holes and sit inside the gaps. Guidance-plate-covered ESPs have up to 20% higher filtration efficiencies than traditional ESPs. The parametric studies show that the number of holes in the guidance plates has more influence on filtration efficiency and power consumption than the diameter of the holes.

1. Introduction

Fine airborne pollutant particles, or particles smaller than 2.5 μm in diameter ($PM_{2.5}$), are considered as a source of risk for diseases, such as ischemic stroke and cardiovascular disease (Brook et al., 2010; Wellenius et al., 2012). Filtering these particles out of the air stream to improve air quality has gained considerable attention. For HVAC systems (heating, ventilation, and air conditioning), filters are used to improve indoor air quality and to protect components like fans and heat exchangers.

From an energy saving standpoint, a filtration system saves a significant amount of energy when using electrostatic precipitators (ESPs), rather than fiber-based filters. This is because electrostatic precipitators have much lower pressure drop than fiber-based filters. Fiber-based filters are obstructively placed into the path of the airflow, whereas electrostatic precipitators have most components placed along the path of airflow. In other words, fewer obstacles obstruct the airflow in electrostatic precipitators than in fiber-based filters. Furthermore, as more and more particles accumulate on the fiber-based filters, the accumulated particles increase the resistance to the airflow, causing the fans to require more power to maintain a specific airflow rate (Edelman, 2008; Fisk et al., 2002; Railio & Makinen, 2007; Xu et al., 2007). For ESPs, the collected particles do not increase the resistance to the airflow as much as they do for fiber-based filters, because the collecting electrodes and the airflow direction are in parallel, and the surface areas of the collected particles are relatively small.

ESPs can be generally grouped into two types, single-stage and two-stage. Single-stage ESPs charge and collect particles at the same time, whereas two-stage ESPs charge and collect particle at separated sections (Mizuno, 2000). When compared to

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single-stage ESPs, two-stage ESPs charge particles better, but are worse at suppressing particle re-entrainment (Mizuno, 2000). The ESPs presented in this paper are two-stage ESPs. When air flows into the system, particles in air are charged by gaining additional ions from the collision with other ions or charged particles. When charged particles move toward the collection region, the electric forces drive the charged particulates toward the collecting electrodes. These particles settle on the collecting electrodes.

The filtration efficiency of an ESP depends on various conditions, such as the corona charging efficiency, airflow rate, and the properties of particles (Alonso et al., 2006; Jiang et al., 2007; Marquard et al., 2005; Zhuang et al., 2000). The collected particles that return to the air stream because of external disturbances lower the filtration efficiency (Ferge et al., 2004; Tsai & Mills, 1995; Zukeran et al., 1999). To improve filtration efficiency by suppressing particle re-entrainment, our research group has presented foam-covered ESPs, where the collecting electrodes are covered with porous foam. Our group has successfully proven that foam-covered ESPs have high ratings in filtration efficiency (Krichtafovitch et al., 2013; Wen et al., 2014). Nevertheless, foam-covered ESPs may not be ideal for very dusty areas, because the foam has limited pores for storing collected particles; highly frequent replacements would be required.

This paper demonstrates a novel particle-trapping mechanism for ESPs to reduce the effects of particle re-entrainment, while accommodating for a large amount of particles. The collecting electrodes are covered with guidance plates that have patterned holes. Rather than attaching the guidance plates to the collecting electrodes directly, gaps are intentionally left in-between them by using the spacers in the peripherals of the guidance plates. The holes allow the particles to travel through the guidance plates and get trapped in the gaps. Because disturbances inside the gaps are relatively low when compared to the bare electrode structure, the collected particles have lower chances of returning to the environment. Thus, this new type of ESP is highly suitable for dusty applications, such as diesel engines used at sandy shorelines and deserts.

The experimental setups, as well as the design details for guidance-plate-covered ESPs (GPC-ESPs), are demonstrated at the beginning of this paper. Then, the baseline comparisons of the filtration efficiencies and the power consumption of GPC-ESPs and traditional bare-electrode ESPs (BE-ESPs) are presented. Next, the parametric studies of the patterns of the holes in the guidance plates are covered, where the parameters of interest are the number of the holes and the diameter of the holes. The effects of the operating conditions are also discussed, including corona voltage, repelling voltage, and free airflow velocity.

2. Experimental setup and prototype design

2.1. Experimental setup

Figure 1 shows the experimental setup. Air is drawn into the ESP under test using traditional rotary fans. The free airflow velocity, from 1.0 m/s to 3.0 m/s, is varied through adjustments to the input power of the fans. A particle counter (Haltech HPC600) is placed right after the ESP to measure the number of particles in the air. This paper only focuses on the fine particles, which are 0.3 μm, because they are the most difficult ones to capture. A high voltage DC power supply (Hipotronics) provides high positive voltage to the corona electrodes, and a separate power supply (Spellman SL150) supplies high positive voltage to the repelling electrodes. The collecting electrode is grounded.

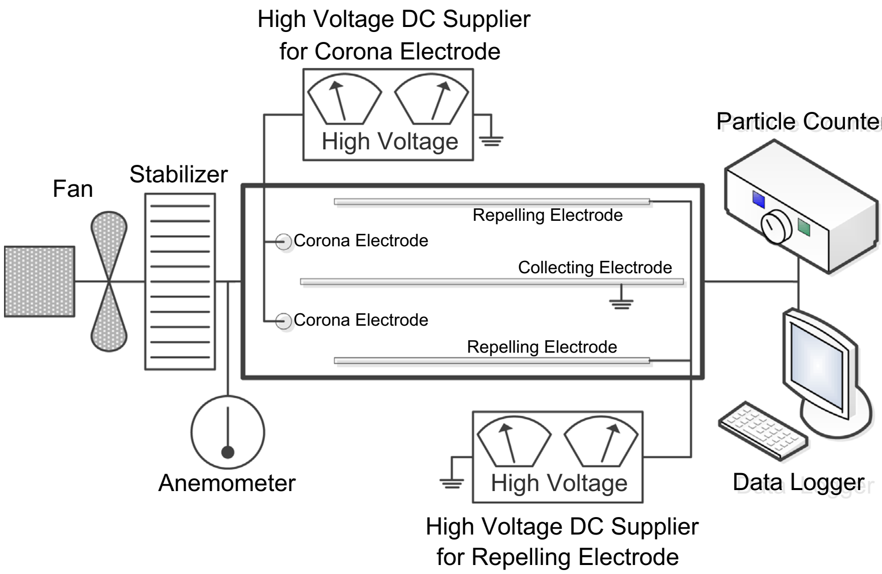

Fig. 1. A schematic of the experimental setup, including the fans and the ESP under test (BE- or GPC-ESP). A particle counter is placed right after the ESP. Not drawn to scale.