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Effects of thermophoresis, vapor, and water film on particle removal of electrostatic precipitator

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ABSTRACT

The effects of thermophoresis, vapor, and water film on the collection efficiency of wet electrostatic precipitators (wet ESPs) were experimentally investigated. The results showed that the fractional collection efficiency curve on the influence of thermophoresis, vapor, and water film was similar to that of traditional ESPs, which exhibited the minimum value at particle diameters of about 0.5 μm. Thermophoresis was beneficial to the collection efficiency of ESPs but the promotion of collection efficiency was not obvious due to the suppression of the ion current caused by lower gas temperature. Vapor significantly improved the collection efficiency of small particles (with diameters smaller than 0.2 μm). However, it had little effect on the removal of large particles (those with diameters over 2 μm). When water was injected into the wet ESP, water film formed on the surface of the collection electrode greatly improved the collection efficiency of submicron particles and it also promoted the removal of large particles significantly. The effect of the water film on the collection efficiency of wet ESPs was a combined result of thermophoresis, vapor, and water flushing.

1. Introduction

Electrostatic precipitators (ESPs) were widely used as devices for removing particles from the flue gas exhausted in various industrial processes. ESPs were durable, cost-effective and easy to operate. The overall mass-based collection efficiency for modern ESPs exceeded 99% (Jaworek et al., 2007). However, the traditional dry electrostatic precipitators still had some issues to be improved. Dry ESPs exhibited reduced fractional collection efficiency for fine particles, especially in the 0.1–1 μm diameter range (Jaworek et al., 2007; Mizuno, 2000). Dust with higher resistivity formed a tight layer on the collection electrodes, causing accumulation of electrical charge which led to a back-corona discharge and reduced the collection efficiency of ESPs (Böhm, 1982; Jaworek et al., 2007; Krupa, 2009a, 2009b). The mechanical rapping resulted in re-entrainment losses. Particles that were captured were “knocked” back into the gas stream as a result of rapping, which reduced the collection efficiency of ESPs (Kim & Lee, 1999; Varonos et al., 2002).

Extensive experimental and theoretical works were conducted to improve the performance of ESPs. Wet electrostatic precipitators exhibited good control on fine particles in industrial applications. Bayless et al. (2004, 2005) proposed a membrane-based wet ESP to maintain an even distribution of water on collection electrodes and compared the collection efficiency with traditional metal wet ESPs. Bologa et al. (2009) introduced a novel wet ESP that had a high velocity of gas flow in the ionizing section and the collection efficiency was acceptable. The temperatures of the flue gas and water were

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usually different in wet ESPs, which led to the thermophoresis and water vaporization. The thermophoresis was a phenomenon in which particles migrated in the opposite direction of a temperature gradient under the influence of the thermophoretic force. The mechanisms of thermophoretic deposition of particles in laminar and turbulent flows were studied by many researchers (Romay et al., 1998; Sagot et al., 2009; Talbot et al., 1980; Wang et al., 2011). They found that thermophoresis could effectively remove the particles from the gas, especially for submicron particles. The combined effects of thermophoresis and electrophoresis on particle deposition were investigated (Chen & Chan, 2008; Opiolka et al., 1994; Tsai et al., 1998). It was found that thermophoresis played an important role on particle deposition in low electric field. But in a strong electric field, such as in ESPs, the effect of thermophoresis on particle removal was not clear. The corona discharge was affected by many factors, including temperature and water vapor. Noll (2002) considered the temperature dependence of the corona discharge and found that high temperature could reduce the corona onset voltage and intensify the corona current. The effect of relative humidity on the current–voltage characteristics of ESPs was studied (Fouad & Elhazek, 1995; Nouri et al., 2012) and they found that the discharge current was strongly affected by the relative humidity of the gas.

These studies mainly focused on the applications of wet ESPs and/or the influences on the electrical characteristics of ESPs. Particle removal in wet ESPs was a complex process and was affected by many factors, including electrostatics, thermophoresis, vapor, and water film. The influences and weights of these factors on the collection efficiency of ESPs were quite complicated and needed to be further studied. In this study, a thermophoretic ESP system (including a vapor generator) and water film ESP system were set up. The effects of thermophoresis, vapor, and water film on the collection efficiency of ESPs were studied separately and comparatively.

2. Experimental systems

The experimental system mainly consisted of an aerosol generation system, an ESP system and a measurement and data acquisition system. They were schematically shown in Fig. 1.

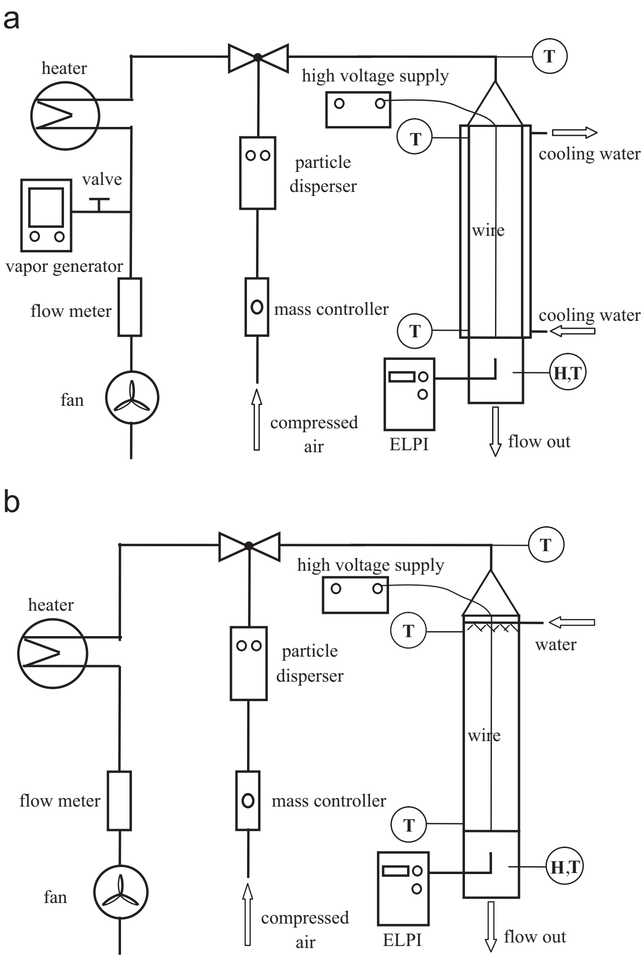

Fig. 1. Schematic diagram of the experimental system. (a) Thermophoretic ESP and (b) water film ESP.