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Removal effect of the low-low temperature electrostatic precipitator on polycyclic aromatic hydrocarbons

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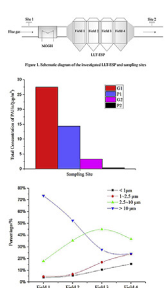
HIGHLIGHTS

- The low-low temperature electrostatic precipitator has effective removal effect on polycyclic aromatic hydrocarbons (PAHs).
- The flue gas cooling process significantly contributed to the elimination of both gas- and particulate-phase PAHs in flue gas.
- A few 4-ring or 5-ring PAHs may have regenerated in the particles due to the discharge process in the electric fields.

GRAPHICAL ABSTRACT



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ABSTRACT

The low-low temperature electrostatic precipitator (LLT-ESP) is one of the most used devices for pollutant control in ultra-low emission coal-fired power plants. This study investigated the influence of the LLT-ESP on polycyclic aromatic hydrocarbons (PAHs) distributions in flue gas from an ultra-low emission coal-fired power plant. The total gas-phase PAH concentration was reduced from 27.52 $\mu g/m^3$ to 3.38 $\mu g/m^3$. The total particulate-phase PAH concentration decreased from 14.36 $\mu g/m^3$ to 0.34 $\mu g/m^3$. The removal efficiency of the LLT-ESP for gas-phase and particulate phase carcinogenic higher molecular weight (HMW) PAHs was 85% and 99%, respectively. The total concentration of 16 selected PAHs in feed coal was 98.16 μg/g. The fly ash particle size successively decreased from Electric Field 1 (F1) to Electric Field 4 (F4). The total PAH concentration decreased from F1 to F2 but increased again from F3 to F4. The flue gas cooling process significantly contributed to the elimination of both gas- and particulate-phase PAHs in the flue gas. Presumably, most of the condensed PAHs were adhered to or absorbed in the fly ash and were scavenged in Field 1. Both gas- and particulate-phase 5- and 6-ring PAHs in the flue gas were completely removed in Field 1. The discharge process in the electric fields may promote the formation of several 4- or 5-ring PAHs. In this study, benzo[k]fluoranthene (BKF) and benzo[a]pyrene (BaP) were regenerated in the particles rather than in the flue gas during the discharge process in the electric fields.

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a series of organic pollutants with two or more fused benzene rings, which are important by-products of incomplete combustion and pyrolysis of fossil fuels(Li et al., 1999; Chow et al., 2006; Liu et al., 2008). PAHs

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emitted from stationary as well as mobile sources exist in both particulate and gas phases, which can be transported and deposited in the ambient over an extended time and distance(Kong et al., 2010; Mu et al., 2013; Mehdinia et al., 2015). With potential toxic, carcinogenic and mutagenic effects, the occurrence of PAH is an increasing concern during the emission and control of combustion processes in stationary sources.

Source identification studies regarding PAHs indicated that, coal-fired power plants are one of the major sources of PAHs in China(Chow et al., 2006; Xu et al., 2006; Kong et al., 2010). Tian et al. concluded that the main pollution sources of atmospheric PAHs in Dalian, China, can be identified as coal-fired boiler emissions (56%) during the heating period (Tian et al., 2009). Additionally, PAHs, particulate matter (PM), NOx, SOx, heavy metals and other organic pollutants are also produced during energy generation in coal-fired power plants. In China, progressively more coal-fired power plants apply ulota-low emission technology to control pollutant emissions(Hongyue, 2014; Zhang et al., 2016). The low-low temperature electrostatic precipitator (LLT-ESP), upgraded selective catalytic reduction(SCR) device, upgraded wet flue gas desulfurization (WFGD) system and wet electrostatic precipitator (WESP) are most used air pollution control devices (APCDs) in ultra-low emission coal-fired power plants(Zhang et al., 2015). However, most studies on ultra-low emission focused on the control of PM, NO_x and SO_x.

In previous studies, the LLT-ESP showed a good removal efficiency for filterable and condensable PM(Shou et al., 2016; Qi et al., 2017). The LLT-ESP demonstrated excellent performance in eliminating PM due to the low temperature of the inlet flue gas, which was reduced from approximately 140 °C to less than 100 °C by the gas-gas heat exchange (MGGH) that is located before the LLT-ESP. This temperature is below the acid dew point, which leads to the condensation and adhesion of condensable compounds, such as SO_3 and PAHs. Furthermore, the decrease in the electric resistivity of the dust, which is caused by the low temperature, increases the removal efficiency of the LLT-ESP. The filterable PM can absorb gas-phase compounds, which can then be eliminated by the LLT-ESP. Therefore, the LLT-ESP may have a good removal effect on all PAHs, especially gas-phase PAHs. Few investigations are available regarding PAH emission and control of ultra-low emission coal-fired power plants. One former study(Li et al., 2016) investigated the influence of both the WFGD and WESP systems on the PAH distribution in flue gas from an ultra-low emission power plant. The total concentration and total toxic equivalent (TEQ) of 16 selected PAHs in the flue gas at the outlet of the WESP were reported as low as 0.870 and 0.293 $\mu g/m^3$, respectively. Furthermore, the study showed that the total PAH concentration in the flue gas at the outlet of the LLT-ESP was low, too, which was partially attributed to the control effect of the LLT-ESP.

In this study, the LLT-ESP in an ultra-low emission coal-fired power plant was chosen to investigate the removal of particulate- and gas-phase PAHs in flue gas. The fly ash in the 4 hoppers of the 4-field LLT-ESP and the feed coal of the boiler were collected, and the PAH distribution characteristics were analyzed. The goals of this work are threefold: (1) to investigate the variation characteristics of PAH in the LLT-ESP; (2) to study the PAH distribution characteristics in fly ash and (3) to investigate the removal mechanism of the LLT-ESP for the PAHs in flue gas. The results can provide useful information on the pollutant control characteristics of the LLT-ESP by investigating the removal effect of the equipment on the PAHs.

2. Materials and methods

2.1. Facility

The studied LLT-ESP is one of the APCDs in the same ultra-low emission coal-fired power plant that was mentioned in a former study(Li et al., 2016). The power plant is equipped with a 1000 MW ultrasupercritical pressure one-through operation boiler. A non-leakage media gas-gas heat exchanger (MGGH) is located before the LLT-ESP, which can accurately reduce the temperature of the flue gas entering the LLT-ESP to less than 100 °C. The LLT-ESP includes a six-room four electrical field scheme, and the specific dust collection area is 93.9 $m^2/(m^3/s)$ (Shou et al., 2016).

There were two sampling sites used in this study. Site 1 was located upstream of the MGGH, and Site 2 was located at the outlet of the LLT-ESP. The schematic diagram of the LLT-ESP and the sampling sites are shown in Fig. 1. There was one sampling point at the cross section of the flue at each sampling site. The boiler was maintained at 500 MW while burning the same type of coal during sampling. The operation temperature of the LLT-ESP was maintained at 95 ± 1 °C. The properties of the coal blends are shown in Table 1.

2.2. Sampling and devices

Particulate- and gas-phase PAHs in the flue gas were sampled at Sites 1 and 2. Each site was sampled three times. For a single sample, the sampling time was 20 min at Site 1 and 90 min at Site 2, respectively. The PAH sampling equipment was an isokinetic system (model KNJ 23, KNJ, Korea) that complied with the U.S. EPA method 23A (Fig. 2) (Li et al., 2016). The filter membrane, which was fixed in the filter, collected the particulate-phase PAHs.

Table 1
Properties of the coal blends during testing.

Parameter	Basis	Value
Moisture, %	As received	14.13
Moisture, %	Dry	3.50
Ash, %	As received	12.64
Volatile matter, %	As received	27.20
Fixed carbon, %	As received	46.04
Sulfur, %	As received	0.44
Qgr, MJ/kg	As received	23.66
Qnet, MJ/kg	As received	22.59

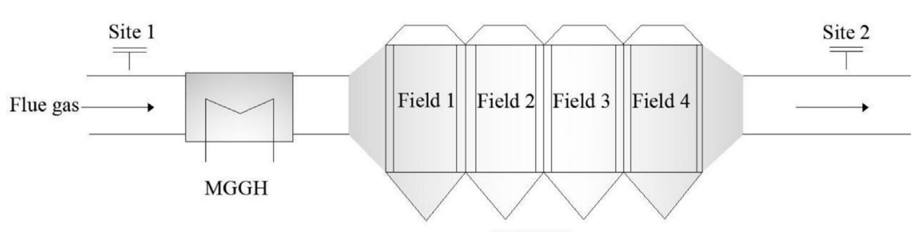

Fig. 1. Schematic diagram of the investigated LLT-ESP and sampling sites.