



The simultaneous capture of mercury and fine particles by hybrid filter with powder activated carbon injection[☆]

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ABSTRACT

The hybrid filter (HF) was newly designed and operated with powder activated carbon (PAC) injection to capture mercury and fine particulate matter in the coal power plant. With PAC injection in HF operation, the capture efficiency of elemental mercury was clearly enhanced. When the injection rate of PAC increased from 0 to 20 mg/m³, the speciation fraction of elemental mercury significantly decreased from 85.19% to 3.76% at the inlet of the hybrid filter. The speciation fraction of oxidized mercury did not vary greatly, whereas the particulate mercury increased from 1.31% to 94.04%. It was clearly observed that the HF played a role in the capture of mercury and fine PM by leading the conversion of elemental mercury as particulate mercury and the growth of PM via electrode discharge in the HF operation with PAC injection.

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1. Introduction

In coal-fired power plants, various hazardous air pollutants (HAPs) are generated and released into the atmosphere by fossil fuel combustion. Among the HAPs, mercury is a major emission pollutant, which can be derived from anthropogenic sources. In the atmosphere, mercury is transported over long distances from its emission sources. The distance of transportation is related to the residence time of the species of mercury. Mercury is emitted as a species of elemental mercury, oxidized mercury, and particulate mercury (Pirrone et al., 2009; Keating et al., 1997; Air Pollution Prevention and Control Division, National Risk Management Research Laboratory, US Environmental Protection Agency, 2005; Srivastava et al., 2004; Pavlish et al., 2003). Depending upon the mercury species, the residence time of elemental mercury can be more than a year. Once elemental mercury is emitted from the emission sources, it cannot be destroyed, only transformed. After releasing into air, mercury is subjected to a series of complex cycles

in the environment. Elemental mercury can photo-chemically react with bromine or chlorine in the air, and it is then deposited in the ground, lakes and ocean as oxidized mercury aerosols. This oxidized form of mercury is transformed (partly) into methylmercury as a consequence of methylation reactions by microbes. This methylmercury is accumulated in fishes as a result of food chain. Peoples and the environment are affected by those reactions, transformation and deposition processes, potentially being the reason of adverse effects in both, the environment and health of human society (Pirrone et al., 2009; Keating et al., 1997). Coal-fired power plants are regarded as a major contribution source of anthropogenic mercury emissions (Pirrone et al., 2009; Keating et al., 1997; Air Pollution Prevention and Control Division, National Risk Management Research Laboratory, US Environmental Protection Agency, 2005). In coal-fired power plants, elemental mercury is partly converted to oxidized mercury and particulate mercury in a series of reactions. Moreover, mercury can be removed by particulate matter control devices, sulfur dioxide and nitric oxide control devices (Air Pollution Prevention and Control Division, National Risk Management Research Laboratory, US Environmental Protection Agency, 2005; Srivastava et al., 2004; Pavlish et al., 2003). There were numerous studies of the mercury removal mechanisms in control processes. Galbreath and

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Zygarlicke (2000) studied the mercury transformation mechanism in coal combustion. In coal combustion, mercury chlorination, as the reaction of elemental mercury with chlorine component for oxidized mercury, would be the dominant conversion mechanism in the process. In addition, the interaction on particle surface of fly ash with mercury chlorination could contribute the greatest impact for the conversion of elemental mercury to oxidized mercury and particulate mercury. Hower et al. (2010) studied mercury capture by fly ash in coal-fired power plants. In the combustion process of each plant, unburned carbon contents in fly ash had an important role in mercury capture. Unburned carbon as the loss on ignition (LOI) in fly ash would be various by combustion surroundings (IEA Clean Coal Centre, 2010; Mohebbi et al., 2015), and the conversion of elemental mercury to oxidized and particulate mercury mostly depended on the contents, surface area, size distribution, surface chemistry in unburned carbon of fly ash, and the flue-gas composition (Wang et al., 2016; Yang et al., 2016, 2017; Lee and Wilcox, 2017). Zhao et al. (2017) studied mercury transformation across air pollution control device (APCD) processes, which were followed by selective catalytic reduction (SCR), electrostatic precipitator (ESP), and wet flue-gas desulfurization (WFGD). In SCR, mercury oxidation could be affected by catalyst material, flue-gas temperature, residence time, and flue-gas chemistry. Across ESP, the decrease of flue-gas temperature and the increase of residence time could elevate mercury oxidation. In addition, charged particles, as fly ash, could easily adsorb oxidized mercury in the process. In WFGD, oxidized mercury was removed with sulfur dioxide by reacting with limestone slurry, whereas re-emission of elemental mercury could occur at the outlet of the process owing to the instability of mercury sulfate compounds in the slurry. Svoboda et al. (2016) studied mercury removal mechanisms in the combination of sorbent injection with APCD configuration as SCR/SNCR with a dry or semi-dry flue-gas cleaning device in waste incineration facilities. The removal efficiencies of mercury mostly depended on the sorbent materials, flue-gas temperature, and acid gas compositions. Kamato et al. (2008) investigated mercury oxidation by a commercial SCR catalyst. Mercury oxidation was strongly inhibited by ammonia and fly ash. Ammonia would compete with hydrogen chloride for the conversion of elemental mercury at the active surface site of the catalyst. Fly ash would deposit on the catalyst surface and would decrease the active site number. Zou et al. (2016) studied the inhibition of mercury release by the injection of additives in the gypsum from a WFGD device. After the injection of additives, mercury conversion to elemental mercury decreased, and the thermal stability of mercury increased in the gypsum. According to Deepak et al. (Pudasainee et al., 2017), the co-beneficial capture of mercury through control processes was enhanced by major factors such as mercury oxidation by SCR, ESP removal increase, WFGD removal increase, and inhibition of re-emission from WFGD. Although mercury was beneficially captured by the configurations and operation of various APCDs, it was anticipated that those technologies would not be promising for the capture of mercury because those capture mechanisms of mercury should depend on the various operation conditions of each process. To enhance the capture efficiency of elemental mercury in flue-gas, sorbent injection would be the most promising technology, equipped with particulate control devices in coal-fired power plants. The United States Department of Energy (DOE) demonstrated laboratory-, bench-, and pilot-scale tests for mercury removal from flue-gas by activated carbon. According the series of tests, activated carbon exhibited high performance for the removal of mercury (Brown et al., 2000). Zheng et al. (2012a) compared the technologies of mercury removal from flue-gas in cement production processes. This study indicated that sorbent injection would be the most promising technology for mercury removal. However,

those technologies usually had an economical problems in continuous operation due to high pressure drop and rapping problems, and it caused fatal operation problems to the capture of fine particulates. To solve these operation and economic problems, our research team has newly developed and tested a hybrid fabric filter (HF) system that combines FF and ESP in the one unit. In the previous study, the capture efficiency of mercury was preliminary investigated by the operation of the HF. Although mercury concentration was somewhat decreased by the HF operation, the speciation of elemental mercury in the flue-gas at the outlet of the HF was still dominant (Sung et al., 2017). In this study, the research team focused on the simultaneous capture of mercury with fine particulate matter (PM) by the PAC injection with HF operation. Mercury speciation changes and capture mechanisms by flue-gas compositions were investigated during the PAC injection tests with HF operation. Finally, PAC injection rate was optimized to enhance the capture efficiency of mercury with fine PM and to decrease operation costs when operating the HF.

2. Facility and experimental methods

2.1. Tested facility

Specifications of the tested facility in this study are shown in Table 1. The facility was a bituminous coal-fired power plant with the electric capacity of 200 MW. The gas mass flow rate at the inlet of ESP and HF were 1,200,000 m³/hr and 240,000 m³/hr, respectively. The configuration of APCDs and sampling points of the tested facility are shown in Fig. 1(a). The facility consisted of ESP, FGD, and HF which was newly designed and developed to enhance the capture efficiency of mercury. The basic characteristics of bituminous coal-fuel, which was mainly utilized in the tested facility, are shown in Table 2. Calorific value ranged from 5966 to 6469 kcal/kg. Mercury and chlorine contents were 0.160 and 160 ppm, respectively. Mercury speciation change with chlorine in flue-gas from coal-fired power plants would be important because the chlorine content would be strongly related with mercury oxidation. Low chlorine content would cause high portion of elemental mercury in flue-gas. A high portion of oxidized mercury was typically generated from the combustion of bituminous coals.

2.2. Hybrid filter

Fig. 1(b) shows a cut-away schematic drawing of the top and side views of the hybrid filter. The HF was designed to be combined with the ESP and FF into a single chamber for simplification of structure and minimization of installation area. FF was composed of empty space filters that were designed to cause low pressure drop. As the first collecting plate that was tightened to the baffle plate at each side was inclined, it has the advantages of durable performance and wide collection area. The first collecting plate was installed at the inlet of flue-gas, and the second collecting plate was installed between the first collecting plate and the outlet of flue-gas. Therefore, the pressure drop of FF decreased by effectively capturing particulate matter. The first collecting plate was a discharging type, and the second collecting plate was combined type of ESP and FF. Therefore, it has an advantage of stable operation by effective capture of suspended particles which were departed during rapping operation. It has an advantage of economical operation and effective capture of fine PM. Because the first collecting plate was designed to be located near the inlet of flue-gas, the pressure drop of the FF was definitely decreased by preventing accumulation of particles. It has an advantage of collecting fine particles by first removing of most coarse particles when the flue-gas was entering to the inlet point. As much coarse particles were

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