Study on Fundamental Emission Characteristics of Trace Metal Compounds and their Control in Combustion Processes

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In coal combustion and waste incineration processes part of trace metal compounds, which are contained in coal and wastes, evaporates and/or concentrates in fine particulates during the combustion, and may be emitted, as a gaseous phase or fine particulates, to the atmosphere. When those trace metal compounds are released to the atmosphere, however, they may cause adverse effects in the ecological system. In boilers and incinerators, generally, particulates collection devices such as an electrostatic precipitator and bag house have been installed to reduce fine particulates emission from combustion processes. However, those control devices cannot always capture the sub-micron particulates effectively, in which trace metal compounds are easily enriched. Medical researches have suggested health risks involved when one inhales those trace elements from the exhaust systems. From these viewpoints, some of researches to control those trace elements in combustion processes have been studied worldwide.

Temperatures, combustion conditions, fuel compositions, types of metal, furnace structures and other factors influence behaviors of trace metal compounds during combustion. Therefore, in order to control the trace elements during combustion, it is necessary to study formation behaviors of trace elements as well as formation mechanisms of particulates matter. This study focuses first on fate of the species of trace metals, especially for Pb, Cd and Cr which are classified as semi-volatile metals, in isolated or mixed cases and trace metal in sludge combustion by the chemical thermo-equilibrium calculation. Then, the fundamentals of evolution of pure Pb, Cd and Cr compounds are experimentally discussed, using a thermo-balance. Next, the use of natural and waste materials as sorbents to capture Pb and Cd compounds is carried out at high temperature, using a thermo-balance. The main task is to optimize the use of those materials by screening them. Finally, the optimum sorbent is tested in burning dried sewage sludge at temperatures ranging from 1073 to1223K, using an electrically heated drop tube furnace. Both formation behaviors of particulate mater and capture characteristics of trace elements by the optimum sorbent are discussed under practical combustion conditions.

First, formation characteristics of particulate matter containing trace elements and its controlling technologies are summarized. For the formation characteristics of particulate matter, most trace metals with

high volatility exist in the gaseous phase and/or in the fine particulates released to atmosphere, according to some reports of mass balance of trace metals in commercialized coal-fired boilers and incinerators. For the controlling technologies, injection of sorbents is considered to be a good way to control trace metal emissions. However, detailed clarifications on the mechanisms of capture and screening of the sorbents have not been understood yet. Furthermore, effects of the sorbent injection in the practical combustion have not been elucidated deeply.

Second, the evolution of trace metals, effect of sorbent addition on the capture of trace metal compounds and that effect under sludge combustion conditions are predicted by thermo-equilibrium calculation under various reaction conditions. As a result, both Pb and Cd can easily evolves even at low temperatures in case for HCl presence. Addition of SO_2 contributes to depressing the evolution of the compounds. In the case for sludge combustion most of Pb and Cd exist as a gaseous phase because they could react with chlorine, which exists in sludge with a high concentration. While, the calculation results of Cr do not show this phenomenon. The sorbents with SiO_2 may have capture potential of the metal compounds.

In order to experimentally confirm the chemical equilibrium calculations, the thermo-balance experiments on evolution characteristics of several trace metal compounds are conducted .It is observed that the evolution of the metal compounds depends on their respective melting points. The presence of HCl enhances the evolution of metal compounds, while co-existence with SO_2 inhibits the evolution tendencies of Pb and Cd compounds. All of the Cd compounds evolves under the reducing conditions. Cr compounds show no evolution tendencies even at the presence of HCl. Those experimental results obtained agree well with the calculation results above-mentioned.

Additionally, the screening tests of the optimum sorbents to capture the trace metal compounds at high temperature are also performed, using the thermo-balance. Pb and Cd compounds are selected due to low volatility. Silica, zeolite (3 types), kaolin (6 types), mullite, bauxite, alumina, limestone, waste seashell, and apatite are tested as sorbents to capture Pb and Cd. Natural alumino-silicate materials like kaolin and zeolite are found to be effective in capturing lead and cadmium chemically, owing their high specific surface area. The presence of HCl decreases capture efficiencies when using kaolin and zeolite. Calcium-based sorbents can capture trace metals a little, but on the presence of HCl. In reducing atmosphere, all sorbents show low capture abilities since the products may be reduced. Types of kaolin and zeolite have a little influence on the capture efficiency owing to different specific surface area. By analyzing the by-products of Pb- and Cd-kaolin systems, it is found that alumino-silicate compounds are detected. This suggests that kaolin can capture Pb and Cd chemically.

Based on those fundamental results obtained, finally, both formation behaviors of particulate mater and

capture characteristics of trace elements by the optimum sorbent are experimentally discussed under practical combustion conditions of dried sewage sludge at temperatures ranging from 1073 to1223K, using an electrically heated drop tube furnace. The particulates are collected and shifted by a low pressure impactor, and the element compositions in each stage are analyzed to study the fundamental formation characteristics and its mechanisms. The capture characteristics are elucidated, mixing kaolin with the sludge to capture trace metal compounds during combustion. The results show that the sub-micron particulates produced are enriched with Pb and Cd. Enrichment mechanisms depend on the particle size. Addition of kaolin can control Pb and Cd emission, where the particles size distributions appear to shift from sub-micron to coarse particles. With increase of temperature the capture efficiencies also increase both for Pb and Cd. Those results are expected that the sorbent addition technology is one of candidates to control emissions of trace metal compounds during combustion, and that this technology will be applied to practical boilers and incinerators.