論文要旨

論文題目　Material flow analysis of mercury at an industrial coal-fired boiler and international comparison of mercury management.
（工業用石炭焚きボイラにおける水銀のマテリアルフロー分析及び水銀対策の国際比較）

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Mercury is a highly toxic trace element that has been recognized internationally as a global priority pollutant. Current inventories of mercury emissions indicate that anthropogenic activities are the major sources of mercury inputs to the environment, with coal combustion and solid waste incineration accounting for more than half of the total emissions. Once released, inorganic oxidized forms of mercury with relatively short atmospheric residence time would be deposited locally, then be converted by specific groups of anaerobic bacteria to methylmercury. In addition to control the release of mercury in the natural environment, mercury used in human life should also pay attention too, such as fluorescent lamps, dry batteries, amalgam, agricultural pesticides and paints. When these are used up, if proper processes are not followed for their disposal, mercury can be released into the environment leading to harm to human beings and other organisms.

From the 1950s to 1960s, Minamata disease, caused by organic mercury poisoning, resulted in severe damage to human health and the environment in Kumamoto, Japan. After this matter, countries in the world have begun to formulate preventive measures and policies. But as of now, only a few countries with relatively developed economies have complete laws and technology to manage mercury use and disposal. Taiwan is a neighbor of Japan and the second largest monitor producing country in the world. Therefore, in addition to the fluorescent lamps, other high-mercury lamps such as cathode fluorescent lamps and high-pressure mercury lamps, are discarded in large quantities every year. Now, Taiwan has its own complete policy to manage mercury and has proper equipment to handle mercury-containing waste. However, because Taiwan is not a member of the United Nations or the World Health Organization (WHO), some information regarding Taiwan has always been ignored in important reports or conferences by international organizations. For example, Taiwan cannot participate in the Minamata convention because it is not a member of the United Nations. Even so, Taiwan wishes to demonstrate willingness to actively protect the global environment. Taiwan intends to follow and synchronously implement the conditions of the Minamata Convention and share the corresponding experience and its achievements with the international community.

In this study, we focus on substance flow analysis of mercury from an industrial coal-fired boiler at a pulp factory and the treatment technologies for mercury-containing products (fluorescent lamps and dry batteries), which are most commonly use in human life. Finally, explore the recycling systems of fluorescent lamps and dry batteries in Taiwan and Japan.

In the first part of this study, in order to understand the overall distribution and flow of mercury in coal-fired industrial boiler. We conducted an investigation of substance flow analysis of mercury from a small-scale industrial coal-fired boiler at a pulp factory in China. Because China is the largest emitter of

atmospheric mercury, as well as the largest coal producer and consumer in the world. The results showed that approximately 99% of Hg in the feed coal turned into gaseous Hg after the combustion process. More than 90% of the Hg was enriched in fly ash removal by ESP and FF, which is higher than corresponding values previously reported for other coal-fired power plants. The Hg input and Hg output as per the substance flow analysis were found to be 12.12 kg (coal), 1.80 kg (limestone), 0.16 kg (bottom ash), 12.93 kg (fly ash), and 0.83 kg (stack) between 2016 to 2017. This result can be attributed to equipping the circulating fluidized bed boiler with an ESP and FF. On the other hand, it is very difficult to measure the exact contents of mercury in flue gas due to the complex process of mercury release from coal combustion and the instantaneous change of mercury emission in flue gas is severe. In order to save costs, three model, including Mass balance model (MB), Emission modification factors model (EMF) and Flue calculation model (FC), were employed to estimate the possible mercury emission from flue gas in this study. A comparison of the results from the different models indicated variability among the different models. The results showed that the mass balance model is the least error. The mass balance model was confirmed using previously published data, which showed an average error of -0.35% between the Hg output and Hg input. Using this ratio provided a result similar to the amount of Hg emitted from the stack. Therefore, the mass balance model is the most reliable method in the given context. Thus, the results proved that this model estimation remains a cost effective and quick way to study Hg emission from a coal-fired power boiler.

In the second, we investigated the current recycling status of fluorescent lamps and dry batteries in Taiwan and Japan. Assessed the situation in both countries through government research reports, literature collection and policies. In Taiwan, there is a unique recycling system called the four-in-one recycling system. Its main feature is the producer responsibility system. All manufacturers, importers, and retailers of regulated recyclable waste are obligated to accept them from customers by regulations of Taiwan EPA. In addition, the government requires manufacturers and importers to pay the regulated recyclable waste processing fee towards setting up the recycling subsidy foundation to promote improvement of the recycling rate by processing enterprises. In addition, the government requires manufacturers and importers to pay the regulated recyclable waste processing fee towards setting up the recycling subsidy foundation to promote improvement of the recycling rate by processing enterprises. The implementation of this system has enabled the recycling rate of fluorescent lamps and dry batteries to reach a high ratio in Taiwan. The recycling rates for fluorescent lamps and dry batteries are 88% and 45%, respectively. In Japan, fluorescent lamps and dry batteries are classified into general waste and industrial waste, which belong to general waste are not responsible for the manufacturers, only belong to industrial waste are producer responsibility. Most fluorescent lamps and dry batteries are belonging to general waste. Local governments and autonomous groups are responsible for recycling them. According to the literature, the recycling rate of fluorescent lamps and dry batteries, which belonging to general waste are not too high, only about 30% and 26%, respectively. In addition, because the producers do not need to be responsible for the spent of fluorescent lamps and dry batteries, the processing costs of the recycling industry are insufficient. Therefore, we propose to expand the producer responsibility system, whether it belongs to general waste or industrial waste, the manufacturers, importers or retailers should be responsible for it. In addition, the government should require manufacturers and importers to pay the processing fee towards setting up the recycling subsidy foundation to promote improvement of the recycling rate by processing enterprises.

Treatment methods for fluorescent lamps and dry batteries differ between Japan and Taiwan. In Japan, crushing and washing is used for fluorescent lamps and rotary kiln for dry batteries. In Taiwan, crushing

thermal desorption is used for fluorescent lamps and batch process distillation for dry batteries. The processing technologies of two countries have their own advantages and disadvantages.

In view of this study, using mass balance model to estimate the mercury release from stack is a cost effective and quick way for a coal-fired power boiler. For management of fluorescent lamps and dry batteries in Japan, as a country with a comprehensive mercury management system, Japan should expand the producer responsibility system of fluorescent lamps and dry batteries in general waste.