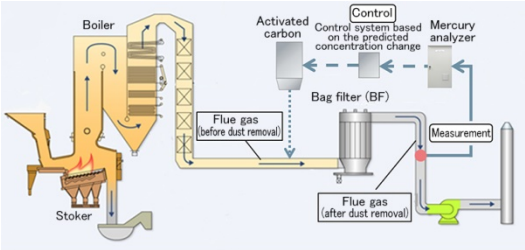
Mercury Removal System for MSW Incineration Flue Gas



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On August 16, 2017, the Minamata Convention on Mercury, a global treaty to protect human health and the environment from anthropogenic emissions and releases of mercury and its compounds, was enacted. On April 1, 2018, in Japan, the Amended Air Pollution Control Act and its related laws entered into force. Based on the aforementioned treaty and act, the Japanese government has been regulating mercury emissions, including those coming from waste incineration flue gas. Since then, both existing and newly constructed waste incineration plants have to comply with these regulations and meet the mercury emission standards. By considering this social need to reduce mercury emissions, Mitsubishi Heavy Industries Environmental & Chemical Engineering Co., Ltd. (MHIEC) developed a mercury removal system which is not only affordable, but also meets the strict emission standards imposed on existing and newly constructed plants.

1. Introduction

1.1 Types of mercury and measurement methods

Table 1 summarizes the Amended Air Pollution Control Act.

Table 1 Summary of the Amended Air Pollution Act (for waste incinerators)

	Item		Newly constructed	Existing
Waste incinerator	Applicable specification	Grate area of ≥2 m^2 Or Incineration capacity of ≥200 kg/d	○	○
	Emission standard (μg/m^3N) *Corrected to 12% O_2		30	50
	Date of enforcement		April 1, 2018	
	Frequency of measurement		Flue gas of 40000 m^3N/h, Above: ≥3 times/year Below: ≥2 times/year	
	Target measurement		Total mercury (particulate + gaseous)	

According to the Amended Air Pollution Control Act, it is mandatory to measure total mercury consisting of particulate mercury and gaseous mercury. Particulate mercury is defined as the mercury and its compounds bound in the dust. They can be easily captured by dust collectors (e.g., bag filter) prior to release.

On the other hand, gaseous mercury is defined as the mercury and its compounds which are present in a gaseous form. They cannot be simply removed just by using the dust collectors. As there is high potential risk for the release of gaseous mercury, new measures need to be taken to comply with the government regulations.

The mercury measurement methods, as described in Notification No. 94 of the Ministry of

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the Environment of Japan, are listed in **Table 2**. Accordingly, the suction gas flow rates and the gas quantities are specified for both particulate and gaseous mercury measurements. The measurement values are reported as the corrected average of mercury concentrations in gas samples taken in a given unit of time, not the instantaneous values.

Table 2 Mercury measurement methods (taken from Notification No. 94 of the Ministry of the Environment)

Parameter	Particulate mercury	Gaseous mercury
Suction gas flow rate	10～40 L/min	0.5～1.0 L/min
Suction gas quantity	≈1000 L	≈100 L

1.2 Waste incineration plant

Figure 1 shows the waste incineration process diagram. The produced flue gas was cooled by the cooling system and the Quench tower. In the next step, the acid gas and dust were removed by the bag filter. After deNOx, the flue gas is released to the atmosphere. The mercury can be removed by means of adsorption on activated carbon. In this method, the early detection of the mercury concentration and the adjustment of the activated carbon supply are the key factors to control the mercury emissions. Although the early detection of the mercury in the inlet of the bag filter is important, measurement using conventional mercury analyzers is difficult due to the high dust concentration in the inlet of the bag filter, and therefore, the mercury analyzer is installed in the inlet of the stack, which is mainly for monitoring purposes. From the perspective of control, it is difficult to promptly respond due to the slow response time of the mercury analyzer itself, in addition to the aforementioned issue of the measurement point location.

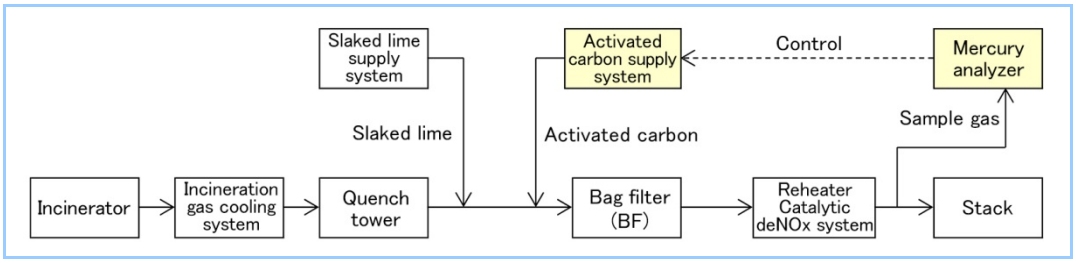

Figure 1 Main treatment process of waste incineration plant

2. Mercury removal system

2.1 System overview

Figure 2 shows the overall feed forward control system which measures the mercury concentration in the early stage of the inlet of the bag filter and it can adjust the activated carbon supply immediately. However, as shown in **Figure 3**, we have adopted a feedback control system which measures the mercury concentration in the outlet of the bag filter to adjust the activated carbon supply. The characteristics of each system and the mercury analyzer used therein, which are the core elements of the system, are described in the following section.

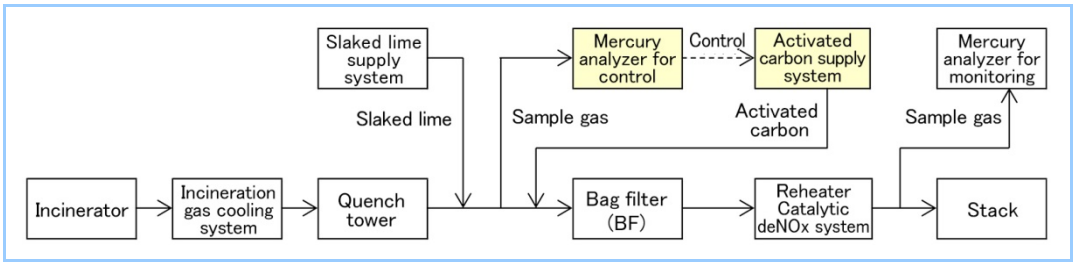

Figure 2 Feedforward control system

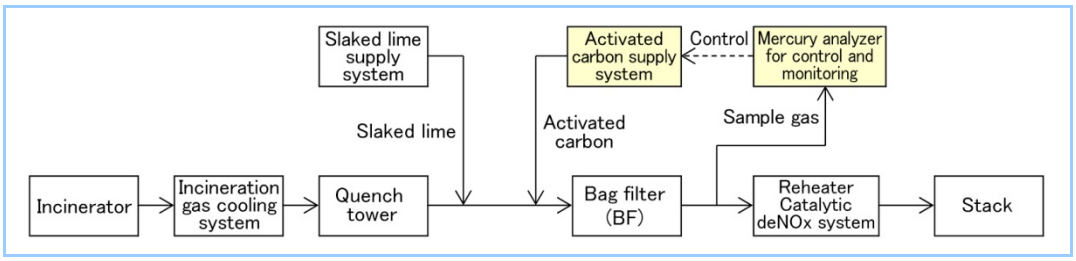

Figure 3 Feedback control system (MHIEC's system)

2.2 Characteristics of the mercury analyzers and the proposed system

Table 3 compares the specifications of the mercury analyzers. Type I is the common mercury analyzer used in the waste incineration plants. However, it is not suitable to be used in very dusty environments, such as in the inlet of the bag filter, because the dust can easily block the filters and the sampling lines. As a result, it is installed in the inlet of the stack for monitoring purposes. If it is utilized for control, there is still the other issue of the slow response time.

Table 3 Comparison of mercury analyzers

Type of mercury analyzer	I	II	III
Measurement method	Reducing-vaporization ultraviolet absorption spectrometry	Dilution + reducing-vaporization ultraviolet absorption spectrometry	Reducing-vaporization ultraviolet absorption spectrometry
Target measurement	Gaseous mercury	Gaseous mercury	Gaseous mercury
Range of measurement ($\mu g/m^3N$)	0 to 1000	1 to 20000	0 to 1000
Reduction method	Dry reducing agent	Dry reducing agent	Dry reducing agent
Response time (90% response)	90 s *Starting point: analyzer inlet	30 s *Starting point: analyzer inlet	20 s *Starting point: analyzer inlet
Measurement accuracy	FS ± 1 %	FS ± 2 %	FS ± 1 %
Applicability for installation in the inlet of bag filter	N/A Preventive measures against dust are required	○	N/A Preventive measures against dust are required
Implementation cost (given as relative value)	1.0	4.0	1.1
10 years of maintenance cost (given as relative value)	1.0	3.1	1.0

In accordance with the mercury emission regulations, new dilution and dust removal auxiliary functions have been developed and added to the mercury analyzers. This kind of special type of mercury analyzer, defined as "type II," is capable even in very dusty environments (e.g., the inlet of the bag filter), thus, it can be used for the feedforward control system and an early response can be obtained. However, the implementation cost is much higher than that of type I, due to these auxiliary functions. Before the flue gas entered the bag filter, the acid gas components had not been removed completely, therefore, these acid gases can easily degrade the internal parts, resulting in high maintenance costs. Furthermore, this feedforward control system still needs an additional mercury analyzer installed in the outlet of the bag filter for monitoring. As a result, the implementation cost increased even more (Figure 2).

The aforementioned problems motivated us to develop the low-cost type III system with a shorter response time by improving the type I analyzer (Table 3). The type III mercury analyzer needs to be installed in the outlet of the bag filter and doesn't require additional functional devices for dilution and dust removal. This improvement only requires a minor additional cost, as low as 10% compared with the type I system (Table 3). Since most of the dust and acid gas have been removed by the bag filter and the exit gas was less harmful for the mercury analyzers, the type III system can have a long-term maintenance cost the same as type I. By installing an analyzer in the nearest point of the outlet of the bag filter, the proposed system can provide the controlling and monitoring ability without adding another mercury analyzer (Figure 3).

The adoption of the aforementioned type III system enabled us to obtain an earlier response, or at least the same response time as type I, while keeping the cost low. The results of the demonstration experiment of this system are reported in the following section.

3. Demonstration experiment

3.1 Outline of the experiment

The demonstration experiment was conducted in Plant A. Plant A is a waste incineration plant built before the Amended Air Pollution Control Act came into force, and uses continuous stoker-type incinerators with a non-permanently-installed activated carbon supply system. The proposed system (type III mercury analyzer and activated carbon supply system) was installed in No. 2 incinerator. The mercury concentration in the inlet of stack of No. 1 and No. 2 was measured by the existing mercury analyzer for confirmation. **Figure 4** illustrates the process diagrams for No. 1 and No. 2 incinerators. The one-hour moving average of the mercury concentration in the inlet of stack (corrected to 12% O_2) was used as an indicator (hereafter referred to as the "one-hour moving average"). The mercury concentration in the stack was examined as to whether it can meet our self-imposed standard of ≤30 μg/m^{3}N. Satisfying this standard means that the proposed system can be applied to both existing and newly constructed waste incineration plants. The effectiveness of the system was also evaluated by comparing the one-hour moving average results of No. 2 with those of No. 1.

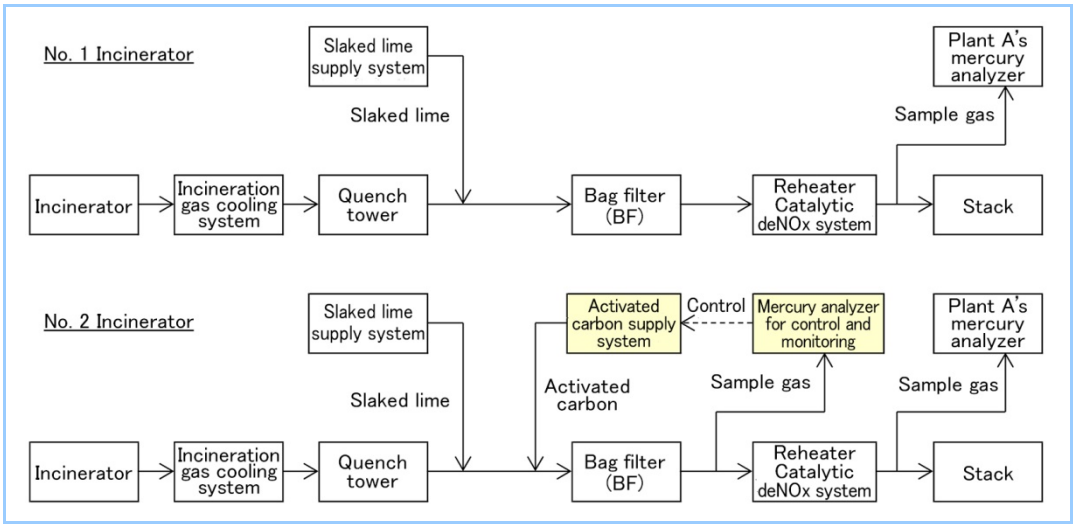

Figure 4 Major treatment processes of verification test (upper: No. 1 incinerator, and lower: No. 2 incinerator)

3.2 Experimental conditions

Table 4 summarizes the experimental conditions.

Table 4 Experimental conditions

Test condition	Activated carbon (General carbon)				Test period	Note
	Supply quantity		Mercury concentration when the supply starts	Mercury concentration when the supply stops		
	Constant	Peak				
(—)	(mg/m^{3}N)	(mg/m^{3}N)	(μg/m^{3}N)	(μg/m^{3}N)	(Day)	(—)
I	—	X	a	b	19	
II	—	Y	a	b	7	Change of activated carbon supply amount (X > Y)
III	—	Z	a	b	6	Change of activated carbon supply amount (Y > Z)
IV	—	X	a /2	b /2	11	Change of ON-OFF setting
V	—	X	a	b	6	
VI	Z /5	X	a	b	25	Combined use of slaked lime containing a small amount of activated carbon

Test conditions I, II, III, and V: The supply of the activated carbon was regulated by an on-off control. If the mercury concentration reached or exceeded a μg/m^{3}N, the supply of activated carbon was started. Meanwhile, if the mercury concentration fell below b μg/m^{3}N (where a > b), the supply of activated carbon was stopped. The feeding rates of activated carbon were fixed (X >

Y > Z mg/m^{3}N).

Test condition IV: Similar to test condition I, on-off control was applied, but the criteria for starting and stopping the supply of activated carbon were changed to a/2 μg/m^{3}N and b/2 μg/m^{3}N, respectively.

Test condition VI: In the slake lime supply system, a small amount of activated carbon (equivalent to Z/5 mg/m^{3}N) was added to the slake lime and they were fed constantly. This setup was applied to both No. 1 and No. 2 incinerators. In addition, only for No. 2 incinerator, it also had a separate activated carbon supply system (similar to that of test condition I) that was working during the mercury peak condition. If the mercury concentration reached or exceeded a μg/m^{3}N, the feeding rate of X mg/m^{3}N was started, and if the mercury concentration fell below b μg/m^{3}N, it stopped.

The experimental results and a comparison of No. 1 and No. 2 are provided in the following section.

3.3 Experimental results

The maximum one-hour moving average values and the number of startups of the activated carbon system for No. 2 incinerator are given in **Table 5**. For each test condition, the one-hour moving average values in No. 1 and No. 2 incinerators are compared in **Figure 5**. For No. 2 incinerator, the only test with the maximum one-hour moving average value exceeding 30 μg/m^{3}N (e.g., 67 μg/m^{3}N) was test condition II. At this test condition, flue gas with a high mercury concentration was continuously produced for several hours while the supply of activated carbon was insufficient. On the other hand, a satisfactory result (≤30 μg/m^{3}N) of test condition III was obtained with the lowest supply of activated carbon. This is because the mercury concentration in the incineration flue gas was lower than that in the other test conditions.

Table 5 The maximum one-hour moving average value and the number of startups of the activated carbon system of No. 2 incinerator

Test condition			I	II	III	IV	V	VI
Maximum one-hour moving average value		(μg/m^{3}N)	26	67	8	8	9	10
Test Period		(days)	19	7	6	11	6	25
Activate carbon supply system	No. of startups	(No.)	39	19	22	31	22	9
	Daily average	(No./day)	2.1	2.7	3.7	2.8	3.7	0.4

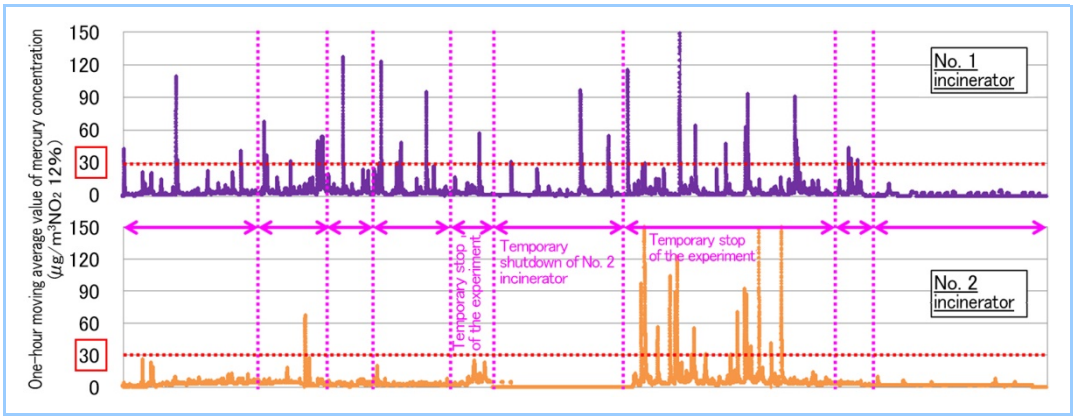

Figure 5 Comparison of one-hour moving average values for No. 1 and No. 2 incinerators

These results indicated that the excessive supply of activated carbon can be minimized by adjusting the activated carbon supply in accordance with the mercury concentration in the flue gas.

In test condition VI, a small amount of activated carbon was constantly supplied, and therefore it significantly reduced the one-hour moving average values (both No. 1 and No. 2 incinerators) and the number of activated carbon system startups. The combination with the constant supply of activated carbon can improve the stability of the treatment process. It should be noted that if a constant supply of activated carbon is applied, not only will the cost for activated carbon increase, but the burden of processing the flue gas (dust collectors) and the cost of fly ash treatment will also increase, which leads to higher operating costs. In order to reduce the cost, it is important to minimize the amount of the constant supply of activated carbon which may vary

depending on the plant.

Our proposed system was installed in the No. 2 incinerator and during the experiment period, the one-hour moving average values of ≤30 μg/m^{3}N could be achieved. Moreover, a comparison with No. 1 incinerator results and a comparison during the temporary stop of the experiment (No. 2 incinerator) also confirmed the effectiveness of the proposed system.

A blank test that did not use activated carbon was also carried out. The relationship between the maximum instantaneous mercury concentration and its increase rate is shown in **Figure 6**. As expected, the higher the maximum instantaneous mercury concentration is, the higher the increase rate of the mercury concentration is. In other words, it is possible to adjust the supply of activated carbon in advance by estimating the maximum instantaneous mercury concentration based on the increase rate of the mercury concentration.

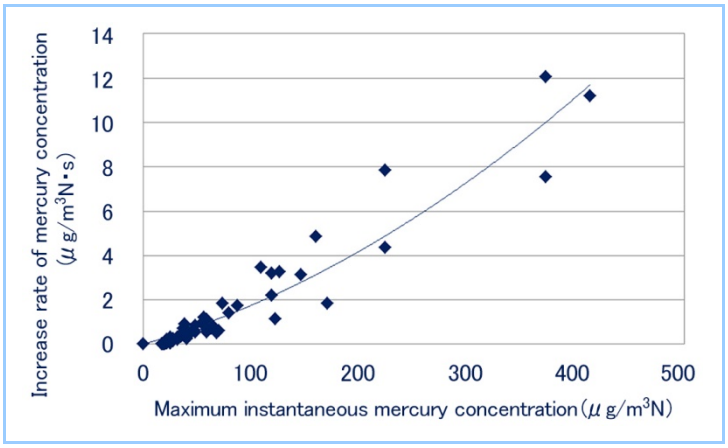

Figure 6 Relationship between maximum mercury concentration and increase rate of mercury concentration

4. Conclusion

We have improved the mercury removal system and evaluated it through demonstration experiments in a waste incineration plant. Now, we can offer a stable system that also has low operating cost. We will continue to promote this technology in Japan and overseas to satisfy the need to reduce mercury emissions.