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Estimation of optimal biomass fraction measuring cycle for municipal solid waste incineration facilities in Korea

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ABSTRACT

This study estimates the optimum sampling cycle using a statistical method for biomass fraction. More than ten samples were collected from each of the three municipal solid waste (MSW) facilities between June 2013 and March 2015 and the biomass fraction was analyzed. The analysis data were grouped into monthly, quarterly, semi-annual, and annual intervals and the optimum sampling cycle for the detection of the biomass fraction was estimated. Biomass fraction data did not show a normal distribution. Therefore, the non-parametric Kruskal-Wallis test was applied to compare the average values for each sample group.

The Kruskal-Wallis test results showed that the average monthly, quarterly, semi-annual, and annual values for all three MSW incineration facilities were equal. Therefore, the biomass fraction at the MSW incineration facilities should be calculated on a yearly cycle which is the longest period of the temporal cycles tested.

1. Introduction

Recently, incineration of municipal solid waste has advantages such as waste volume reduction, energy recovery, hygiene control, and is widely used as an alternative to waste management (Ange et al., 2012; Haihui et al., 2017).

In 2014, greenhouse gas emissions from wastes in Korea reached 15.4 million tons CO_2eq. About 6.3 million tons CO_2eq of this amount were from waste incineration that accounted for 41.1% of the total greenhouse gas emissions from wastes and the majority of CO_2 emissions (GIR, 2016). The development of reliable greenhouse gas emission inventories for waste incineration is critical for the management of the national emissions inventories and the greenhouse gas emissions trading which has been in effect since 2015. The "Paris Agreement" adopted in the COP21 (the 21st meeting of the Conference of the Parties of the UNFCCC) made it mandatory to report the greenhouse gas emission inventories and the emission reduction performance through quinquennial evaluations.

In Korea, the national emissions inventory is currently being developed to estimate the greenhouse gas emissions from waste incineration. A significant part of the inventory needs further work; thus, the default values suggested by the Intergovernmental Panel on Climate Change (IPCC) are typically used in practice. The inventory for the biomass fraction of the CO_2 emissions from waste incineration has not yet been developed. The IPCC requires that greenhouse gas emissions originating from biomass should be reported separately from the total emissions for carbon neutrality purposes (IPCC, 2006). Korea applies the default values provided by the IPCC for the biomass fraction to calculate the greenhouse gas emissions from waste incineration in the whole country. However, this approach may not reflect the national characteristics of Korea. A previous study reported the differences between the IPCC values as applied to Korea and the actual biomass fraction measured at MSW incinerator (Seongmin et al., 2016; Seungjin et al., 2016). Therefore, biomass sampling methods reflecting the national characteristics should be developed and methods for detecting the biomass fraction should be explored. Currently, such studies have not been much furthered and the analysis cost for estimating biomass is still high. Therefore, this study estimates the optimum sampling cycle using a statistical method for biomass fraction.

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2. Method

This study estimated the optimum cycle for biomass sampling for three MSW incineration facilities in Korea using a statistical method. The optimum sampling cycle was determined by dividing the sampling data into monthly, quarterly, semi-annual, and annual intervals for comparison and estimation.

2.1. Selection of MSW incinerator

Three MSW incineration facilities were selected in this study. The daily average incineration volume was more than 150 tons as of 2014 that was the highest rate of waste generation among those located in the capital region. The selected facilities employed the Stoker method for waste incineration. Stoker method is the most frequently used methods at waste incineration facilities in Korea (Sangwon et al., 2011). More than ten samples for 24 consecutive hours collected at each facility from June 2013 to March 2015 were analyzed for the biomass fraction. The overview of the facilities is shown in Table 1.

2.2. Sampling method of flue gas at MSW incinerator

The properties of gas generated by the incineration of municipal solid waste vary depending on the properties of the solid waste. Countries such as Australia, US, Europe, and Japan recommend the use of Continuous Emission Monitoring Systems (CEMS) for measuring greenhouse gases to reflect the properties of the incineration gas (EPA, 2011; European Commission, 2012; DOE, 2012).

The guidelines of the Greenhouse Gas Energy Target Monitoring Program implemented in Korea also suggest CEMS for estimating greenhouse gas emissions (MOE, 2014).

The Mandatory Reporting of Gas Rule of the U.S. recommends sampling the incineration gas for 24 consecutive hours or securing a sufficient number of samples to satisfy American Society for Testing and Materials (ASTM) D 6866-08 for the estimation of greenhouse gas emissions from waste incineration facilities. Some studies reported that sampling the incineration gas emitted from the incineration facilities has simpler procedures with less uncertainty compared to estimating the biomass fraction of the solid waste (Kang et al., 2016; Kim et al., 2016). This study collected incineration each gas samples for the estimation of the biomass fraction for 24 consecutive hours in reference to the method ASTM D 6866-08. Incineration gas sampling was carried out following the schedule of the study facilities.

Korea legally mandates the installation of CEMS at large-scale incineration facilities for air pollution monitoring in real time. The sampling point was set at the posterior part of the CEMS. Incineration gas samples were collected using an independently developed incineration gas collector (Fig. 1). The incineration gas collector consists of a water remover to remove the water content of the gas (Alpha AGC-71003, Korea), a pump to vacuum the incineration gas (KNJ 5 L/min, Korea), and an electronic mass flow meter (MCS--16LPM, USA)to maintain incineration gas at a certain regular flow.

Table 1
Characteristics of the investigated MSW incinerator.

Incinerator	Capacity (ton/day)	Incineration method
A	150	Stoker
B	150	Stoker
C	300	Stoker

2.3. Analysis of biomass fraction

DS/CEN/TS 15440, CEN/TR 15591, and ASTM D6866 are the standard testing methods for the estimation of biomass fraction and include ^{14}C methods, the Selective Dissolution Method, and the Balance Method. The EU recommends the ^{14}C method or the Selective Dissolution Method for the estimation of the biomass fraction for the greenhouse gas emission trading (EU ETS MRR). Moreover, many researchers are conducting active research at incinerator facilities regarding these methods to estimate the from biomass fraction to the total amount of CO_2 (Mohn et al., 2012; Muir et al., 2015). This study applied the ^{14}C method as well.

The ^{14}C method uses carbon isotopes and estimates the biomass fraction with precision by measuring the amount of ^{14}C with varied abundance, dating the sample, and measuring the proportion of CO_2 in the air generated from fossil fuels.

LSC (Liquid Scintillation Counting), AMS (Accelerator Mass Spectrometry), and IRMS (Isotope-ratio mass spectrometry) are the common methods used in the ^{14}C analysis and AMS was selected to be applied in this study. AMS accelerates the ionization of the sample atoms and analyzes the energy, momentum, and the status of the electrical charge. AMS quantitatively analyzes the isotope of the final atomic nucleus ^{14}C. The amount of the naturally occurring carbon isotope ^{12}C and the stable isotopes of ^{13}C and ^{14}C were measured with precision to estimate the carbon age and the proportion of CO_2 generated by fossil fuels (NIER, 2012). AMS is able to analyze samples as small as 1 g. It features an excellent precision rate that is about 105 times higher than other mass spectrometers (Matthias, 2008).

The AMS analysis method is a spectroscopic technique to accurately measure the number of isotopes in atomic nuclei such as ^{14}C by ionizing and accelerating atoms in samples and analyzing the energy, momentum, and the state of charge. When the biomass contents of samples should be calculated using the ^{14}C Method like the AMS analysis method, 1950 is used as the reference year in terms of "fractions of modern carbon(FM)" as shown below and biomass contents are calculated by comparing the ratios of radioactive carbon isotopes $^{14}C/^{12}C$ existing in the standard sample and the analysis sample.

$$f_{M,Sample} = \frac{\left(\frac{^{14}C}{^{12}C}\right)_{sample}}{\left(\frac{^{14}C}{^{12}C}\right)_{AD1950}} \quad (1)$$

whereas fM, Sample is the promptly measured parameter, the fraction of biogenic or fossil carbon (%Bio C, %Fos C) has more substantive relevance.

$$\%\ \mathrm{BioC} = 100\% - \%\mathrm{FosC} = \left(\frac{f_{M,sample}}{f_{M,bio}}\right) \times 100\% \quad (2)$$

Since ^{14}C in fossil matter is completely decayed, the content of biogenic carbon (%Bio C) is directly proportional to the ^{14}C fraction in the emitted CO_2.

2.4. Statistics analysis method for optimal sampling cycle estimate

The average values of the monthly, quarterly, semi-annual, and annual data were compared to estimate the optimum sampling cycle for the biomass fraction estimation at the three MSW incineration facilities. SPSS 21 was used for the statistical data analysis. The distribution of the biomass fraction data was examined. In general, parametric statistical analysis methods assume that the distribution of the population is known; thus, the parametric methods are more efficient than the non-parametric methods that are used when the distribution is unknown. In particular, the statistical analysis method is more reliable when the population has