A Study on Applying Biomass Fraction for GHG Emission Estimation of Sewage Sludge Incinerator in Korea: A Case Study

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Abstract: According to the IPCC guidelines, CO₂ emissions from biomass should be excluded from the entire amount of CO₂ emissions when calculating CO₂ emissions and should be separately reported due to the “carbon neutrality.” Sewage sludge is one of the representative biomass fuels. And it is mixed with fossil fuels in terms of greenhouse gas reduction or is used as fuel to replace fossil fuels by itself. According to the results of this study, biomass contents of both the sewage sludge and the sewage sludge incineration exhaust gases did not amount to 100%. At present, in many countries (South Korea, Japan, and Germany), when calculating greenhouse gas emissions from sewage sludge incinerator, all CO₂ emissions from sewage sludge are judged to be biomass and only those greenhouse gas emissions that correspond to Non-CO₂ gases are calculated as greenhouse gas emissions. However, since, according to our results, the content of sewage sludge is not 100% biomass, if CO₂ emissions are excluded according to the existing greenhouse gas emission calculation method, the amount of emissions may be underestimated. Therefore, to accurately calculate greenhouse gas emissions from sewage sludge incinerator, CO₂ emissions should be calculated in consideration of the fossil carbon contents of sewage sludge.

Keywords: sewage sludge; biomass fraction; sewage sludge incinerator; GHG emission

1. Introduction

While previously 70% of sewage sludge in South Korea had been disposed of using the method sea dumping, sea dumping of sewage sludge has been completely prohibited since 2011 pursuant to the London Dumping Convention amended in 1996 [20]. Consequently, incineration, with its advantages of large sewage sludge weight reduction effects, excellent stability, and transformation of sewage sludge into solid fuel, has come to the fore as an alternative for sewage sludge disposal. Due to these advantages, incineration has become the main method of sewage sludge disposal in many countries, including Germany and Japan [5, 16, 22].

According to the IPCC guidelines, CO₂ emissions from biomass should be excluded from the entire amount of CO₂ emissions when calculating CO₂ emissions and should be separately reported due to the “carbon neutrality.” Sewage sludge is one of the representative biomass fuels. And it is mixed with fossil fuels in terms of greenhouse gas reduction or is used as fuel to replace fossil fuels by itself [3, 6, 21].

Municipal waste and industrial waste incineration facilities are excluded biomass fraction when calculating greenhouse gas emissions. In particular, in sewage sludge incineration facilities, CO₂ emissions from the calculation of greenhouse gas emissions are considered as CO₂ emissions from biomass excluding CO₂ emissions. Therefore, GHG emissions from sewage sludge incineration facilities are calculated only for Non-CO₂ emissions [8, 11, 12].
However, some studies reported that the biomass content of sewage sludge might not be 100% [4, 13, 23]. If, as reported in some studies, the biomass content of sewage sludge is not 100%, CO₂ emissions should be considered when greenhouse gas emissions are calculated. Therefore, it is necessary to accurately estimate and reflect the biomass content of sewage sludge in order to improve the reliability of greenhouse gas emissions from sewage sludge incineration facilities.

The present study aims to figure out how biomass contents should be applied when greenhouse gas emissions in sewage sludge incineration facilities are calculated.

2. Methods

The present study seeks to figure out how biomass contents should be applied in the calculation of greenhouse gas emissions in sewage sludge incineration facilities. To this end, we planned to analyze the biomass content of sewage sludge inputted into subject incineration facilities and the biomass content of gases collected from final incineration and to compare the resultant values to finally figure out the biomass content of sewage sludge incineration facilities.

2.1. Selection of objective facilities

The subject facility, located in Gyeong gi-do, was selected for the reason that at least 150 ton of sewage sludge are on average generated on it per day. The selected sewage sludge incineration facility uses the fluidized bed incineration (that is predominantly used in sewage sludge incineration facilities in South Korea); the prevention facilities installed in the subject incineration facility are a Selective Non-Catalytic Reduction (SNCR) facility, a nitrogen oxide removing facility; a Bag Filter, a dust removing facility; a semi-dry reaction tower; and a wet wash tower. Sewage sludge samples and sewage sludge incineration exhaust gas samples were collected in January-March 2015. The current conditions of the subject facility are shown in Table 1.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Facility name</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incineration facility</td>
<td>Incinerator</td>
<td>150 ton/day</td>
</tr>
<tr>
<td></td>
<td>SNCR</td>
<td>673 Nm⁻³/min</td>
</tr>
<tr>
<td>Air pollution prevention facility</td>
<td>bag filter dust collector</td>
<td>427 Nm⁻³/min</td>
</tr>
<tr>
<td></td>
<td>SDR</td>
<td>427 Nm⁻³/min</td>
</tr>
<tr>
<td></td>
<td>Wet Scrubber</td>
<td>427 Nm⁻³/min</td>
</tr>
</tbody>
</table>

2.1. Sampling of waste incinerator facility

In many EU countries, as well as in the USA, Japan, and Australia, continuous measurement methods are presented and recommended for greenhouse gas measurement in waste incineration facilities in order to enhance reliability [7, 9, 10].

The Mandatory Reporting Rule (MRR) for greenhouse gases of the USA presents the standards for incineration exhaust gas samples for the analysis of biomass contents of incineration facilities. To meet the standards for samples of the MRR, incineration exhaust gases should be continuously measured for 24 hours or the level of ASTM D 6866-08 can be satisfied. In the present study, pursuant to the U.S. mandatory greenhouse gas reporting rule, greenhouse gas samples were continuously collected for 24 hours. In South Korea, air pollutants are analyzed and monitored in
real-time using automatic remote chimney monitoring systems. Incineration exhaust gases were collected at the rear end of a TMS (Tele-Monitoring System), which is a real-time air pollutant analysis device, using an incineration exhaust gas collecting device made by the present authors. The incineration exhaust gas collecting system is shown in Figure 2. The incineration exhaust gas collecting device consisted of a device to cool down high-temperature gases to 3°C to facilitate incineration exhaust gas collection for 24 hours (ALPHA, KOREA), a drain pump for discharge of cooled moisture (ALPHA, KOREA), an electronic mass flow meter for collection of incineration exhaust gases at a constant flow rate (ALICAT SCIENTIFIC, USA), and a pump (KNJ, KOREA). Samples of sewage sludge for further analysis were sampling in the sewage sludge reservoir.

Figure 1. Schematic of the field setup for flue gas sampling of the incinerator

2.2. Analysis of the biomass fraction

Official test methods related to biomass content analysis include ASTM D 6866, DS/CEN/TS 15440, and CEN/TR 15591. The official test methods include 14C methods, Selective Dissolution Methods, and Balance Methods. In addition, many related studies use other relevant methodologies to analyze biomass contents [1, 14, 15, 17, 20].

In the present study, the 14C method was used to calculate the biomass contents of sewage sludge and sewage sludge incineration exhaust gases. According to the official test methods, 14C methods include LSC (Liquid Scintillation Counter), AMS (Accelerator Mass Spectrometer), and IRMS (Isotope Ratio Mass Spectrometer). In the present study, The application of ASTM-D6866 and AMS analysis method was used. The AMS method enables the analysis with tiny quantities (1g) and has the precision that is 105 times higher as compared to general mass analysis devices[18].

The AMS analysis is suitable for the carbon dating of small samples. As it allows the number of atoms of different isotopes of carbon to be counted directly, instead of their ratio having to be inferred from the (very low) level of radioactivity of the sample.

The application of ASTM-D6866 to derive a "Biogenic carbon content" is built on the same concepts as radiocarbon dating, but without use of the age equations. It is done by deriving a ratio of the amount of radiocarbon (14C) in an unknown sample to that of a modern reference standard. The modern reference standard used in radiocarbon dating is a NIST (National Institute of Standards and Technology) standard with a known radiocarbon content equivalent approximately to the year AD 1950. AD 1950 was chosen since it represented a time prior to thermo-nuclear weapons testing which introduced large amounts of excess radiocarbon into the atmosphere with each explosion (termed "bomb carbon"). This was a logical point in time to use as a reference for archaeologists and
Therefore, 1950 is used as the reference year in accordance with “fractions of modern carbon (FM)” as 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.

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

Whereas $f_{M, \text{Sample}}$ is the promptly measured parameter, the fraction of biogenic or fossil carbon (%Bio C, %Fos C) has more substantive relevance.

$$%\text{Bio C} = 100\% - %\text{Fos C} = \left(\frac{f_{M, \text{Sample}}}{f_{M, \text{bio}}}\right) \times 100\%$$  

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 CO2.

### 3. Result and discussion

#### 3.1. Biomass fraction of sewage sludge

To calculate the biomass contents of sewage sludge and sewage sludge incineration exhaust gases, the sewage sludge and sewage sludge incineration exhaust gas samples were collected three times in total, once per month from January to March; furthermore, the biomass contents were analyzed using the AMS method.

According to the results of the biomass contents of sewage sludge sample analysis, the average biomass content was 76.92% and the range of biomass contents was 76.25 – 77.38% depending on the time of sample collection. The standard deviation of the biomass contents of sewage sludge samples was 0.59, suggesting that the biomass contents were not much different across different time periods.

**Table 2.** The result of biomass fraction analyzed of sewage sludge

<table>
<thead>
<tr>
<th>Sampling</th>
<th>Biomass fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>77.38</td>
</tr>
<tr>
<td>2</td>
<td>76.25</td>
</tr>
<tr>
<td>3</td>
<td>77.12</td>
</tr>
<tr>
<td>Mean</td>
<td>76.92</td>
</tr>
<tr>
<td>SD</td>
<td>0.59</td>
</tr>
</tbody>
</table>
3.2. Biomass fraction of sewage sludge flue gas

The average biomass content of incineration exhaust gases from the sewage sludge incineration facility amounted to 76.56%. The biomass contents of the incineration exhaust gases were in the range of 74.45 ~ 78.20% across different times of samples and the standard deviation was 1.92, indicating that the biomass contents were not much different across different periods of time.

Table 3. The result of biomass fraction analyzed of flue gas from sewage sludge

<table>
<thead>
<tr>
<th>Sampling</th>
<th>Biomass fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>74.45</td>
</tr>
<tr>
<td>2</td>
<td>77.02</td>
</tr>
<tr>
<td>3</td>
<td>78.20</td>
</tr>
<tr>
<td>Mean</td>
<td>76.56</td>
</tr>
<tr>
<td>SD</td>
<td>1.92</td>
</tr>
</tbody>
</table>

3.3. Comparison of biomass fraction in objective sewage sludge incinerator

Sewage sludge and sewage sludge incineration exhaust gas samples were simultaneously collected from the sewage sludge incineration facility and the biomass contents were compared. The differences in the biomass contents were smaller than approximately 3%, indicating that the biomass contents of sewage sludge and sewage sludge incineration exhaust gases were not much different. The biomass contents of the samples collected for the first time showed a difference of approximately 3%, while those of the samples collected for the 2nd and 3rd time showed differences below 1%.

The biomass contents of sewage sludge that is the subject of incineration by the sewage sludge incineration facility and those of sewage sludge incineration exhaust gases that are finally emitted after incineration were in the range of 74.45 ~ 78.2%; none of the two results showed a biomass content of 100%. Therefore, when calculating greenhouse gas emissions, sewage sludge incineration facilities should consider fossil carbon contents excluding biomass contents.

According to Giger (1984) and McEvoy (1985), in the analysis of sewage sludge, Linear Alkylbenzene Sulphonate (LAS) and 4-Nonylphenol components contained in surfactants, such as dishwashing detergents, liquids and shampoos, that were not completely treated during sewage treatment remained in sewage sludge. This is the reason why we included fossil fuel-based carbon in sewage sludge in the present study.
4. Conclusions

In the present study, attempts were made to examine how to apply biomass contents to the calculation of greenhouse gas emissions from sewage sludge incineration facilities. To this end, the biomass contents of sewage sludge inputted into the subject incineration facility and those of sewage sludge incineration exhaust gases finally emitted were analyzed using the 14C Method.

Sewage sludge and sewage sludge incineration exhaust gas samples were simultaneously collected three times between January and March 2015.

According to the results of the analysis of biomass contents, the average biomass content of the sewage sludge samples was 76.92% and that of the incineration exhaust gases from the sewage sludge incineration facility was 76.56%, suggesting no big difference on average. The biomass contents of both the sewage sludge and the sewage sludge incineration exhaust gases did not amount to 100%. The reason behind this finding can be the fact that Linear Alkylbenzene Sulphonate (LAS) and 4-Nonylphenol components contained in surfactants, such as dishwashing detergents, liquids, and shampoos, that were not completely treated during sewage treatment remained in sewage sludge (see Giger (1984) and McEvoy (1985)).

At present, in many countries such as South Korea, Japan, and Germany, when calculating greenhouse gas emissions from sewage sludge incineration facilities, all CO2 emissions from sewage sludge are judged to be biomass and only those greenhouse gas emissions that correspond to Non-CO2 gases are calculated as greenhouse gas emissions. However, since, according our results, the content of sewage sludge is not 100% biomass, if CO2 emissions are excluded according to the existing greenhouse gas emission calculation method, the amount of emissions may be underestimated.

Therefore, to accurately calculate greenhouse gas emissions from sewage sludge incineration facilities, CO2 emissions should be calculated in consideration of the fossil carbon contents of sewage sludge.

Further studies aiming to figure out the biomass contents of greenhouse gases emitted from sewage sludge incineration facilities and to compare greenhouse gas emissions according to CO2 emission calculation methods using such biomass contents will improve the reliability of greenhouse gas inventories of sewage sludge incineration facilities.

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References


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