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

Seongmin Kang [1], Seungjin Kim [2], Jeongwoo Lee [3], Youngjae Jeon [1], Ki-Hyun Kim [4] and Eui-chan Jeon [1,*]

[1] Department of Environment & Energy, Sejong University, Seoul 209, Korea; smkang9804@gmail.com (S.K.); joiboy@naver.com (Y.J.)
[2] Cooperate Course for Climate Change, Sejong University, Seoul 209, Korea; kimseungjin8611@gmail.com
[3] Department of Earth and Environmental Sciences, Sejong University, Seoul 209, Korea; leejwsky@gmail.com
[4] Department of Civil & Environmental Engineering at Hanyang University 222, Seoul; kkim61@hanyang.ac.kr
* Correspondence: ecjeon@sejong.ac.kr; Tel.: +82-2-3408-4353

Abstract: According to the IPCC guidelines, CO_2 emissions from biomass should be excluded from the entire amount of CO_2 emissions when calculating CO_2 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 CO_2 emissions from sewage sludge are judged to be biomass and only those greenhouse gas emissions that correspond to Non-CO_2 gases are calculated as greenhouse gas emissions. However, since, according our results, the content of sewage sludge is not 100% biomass, if CO_2 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, CO_2 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, CO_2 emissions from biomass should be excluded from the entire amount of CO_2 emissions when calculating CO_2 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, CO_2 emissions from the calculation of greenhouse gas emissions are considered as CO_2 emissions from biomass excluding CO_2 emissions. Therefore, GHG emissions from sewage sludge incineration facilities are calculated only for Non-CO_2 emissions [8, 11, 12].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 February 2017 doi:10.20944/preprints201702.0035.v1

Peer-reviewed version available at Sustainability 2017, 9, 557; doi:10.3390/su9040557

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%, CO_2 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 1. Characteristics of the sewage sludge incinerators included in study

Classification	Facility name	Capacity
Incineration facility	Incinerator	150 ton/day
Air pollution prevention facility	SNCR	673 Nm^3/min
	bag filter dust collector	427 Nm^3/min
	SDR	427 Nm^3/min
	Wet Scrubber	427 Nm^3/min

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

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 February 2017 doi:10.20944/preprints201702.0035.v1
Peer-reviewed version available at Sustainability 2017, 9, 557; doi:10.3390/su9040557

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℃ 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.

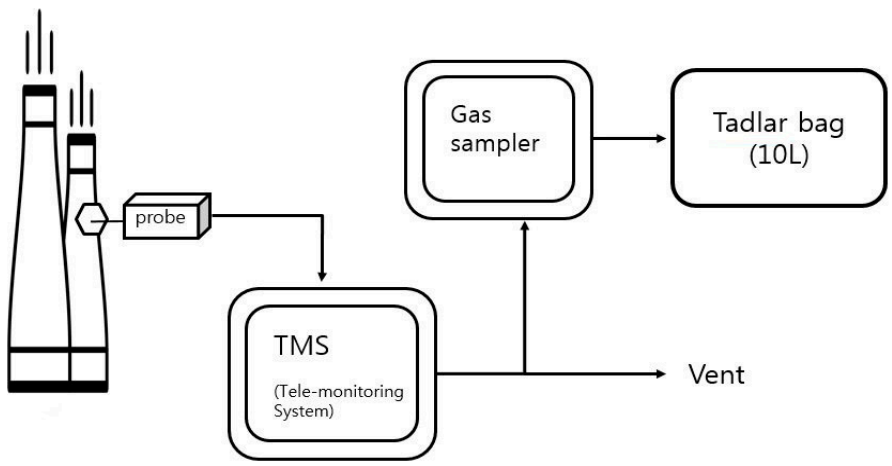

Figure 1. Schematic of the field setup for flue gas sampling of the incinerator

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 ^{14}C 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 ^{14}C method was used to calculate the biomass contents of sewage sludge and sewage sludge incineration exhaust gases. According to the official test methods, ^{14}C 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 (^{14}C) 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

Peer-reviewed version available at Sustainability 2017, 9, 557; doi:10.3390/su9040557

geologists. 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.

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

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

$$\%\text{Bio C} = 100\% - \%\text{Fos C} = \left(\frac{f_{M,sample}}{f_{M,bio}}\right) \times 100\% \tag{2}$$

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.

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

(Unit:%)

Sampling	Biomass fraction
1	77.38
2	76.25
3	77.12
Mean	76.92
SD	0.59

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 February 2017 doi:10.20944/preprints201702.0035.v1

Peer-reviewed version available at Sustainability 2017, 9, 557; doi:10.3390/su9040557

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

(Unit:%)

Sampling	Biomass fraction
1	74.45
2	77.02
3	78.20
Mean	76.56
SD	1.92

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.

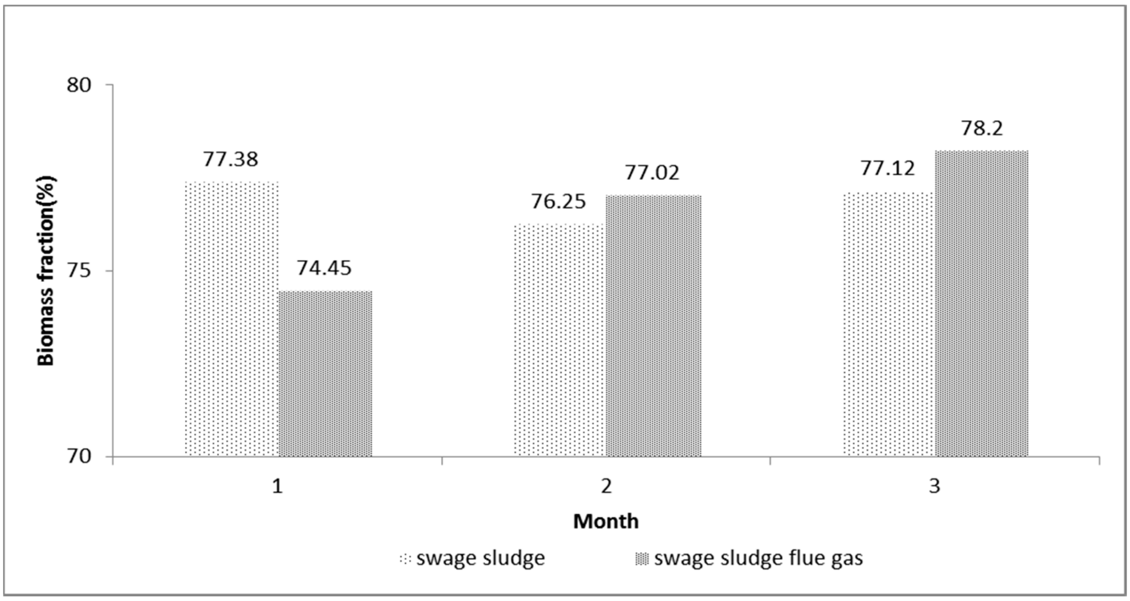

Figure 2. Comparison between sewage sludge and sewage sludge flue gas of the biomass fraction

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 CO_2 emissions from sewage sludge are judged to be biomass and only those greenhouse gas emissions that correspond to Non-CO_2 gases are calculated as greenhouse gas emissions. However, since, according our results, the content of sewage sludge is not 100% biomass, if CO_2 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, CO_2 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 CO_2 emission calculation methods using such biomass contents will improve the reliability of greenhouse gas inventories of sewage sludge incineration facilities.

Acknowledgements: “This work is financially supported by Korea Ministry of Environment(MOE) as 「Graduate School specialized in Climate Change」.”

Author Contributions: All authors contributed extensively to the various phases of the work presented in this paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Anna, W. L.; Karsten, F.; Niels, H. P.; Johann, F.; Helmut, R.; Thomas, A. Biogenic carbon in combustible waste: Waste composition, variability and measurement uncertainty. Waste Management & Research. 2013, 31(10), pp. 56-66. doi: 10.1177/0734242X13502387
2. ASTM D 6866. Standard Test Methods for Determining the Bio based Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis. 2007
3. Zabaniotoua, A.; Theofiloub, C. Green energy at cement kiln in Cyprus—Use of sewage sludge as a conventional fuel substitute. Renewable and Sustainable Energy Reviews. 2008, 12(2), pp. 531–541. doi:10.1016/j.rser.2006.07.017.
4. Beta Analytic, USA. Sewage sludge. http://www.betalabservices.com/renewable-carbon/sewage-sludge.html(accesseed April 2, 2016)
5. Fytili, D.; Zabaniotoua, A.;. Utilization of sewage sludge in EU application of old and new methods—A review. Renewable and Sustainable Energy Reviews. 2008, 12(1), pp.116–140. doi:10.1016/j.rser.2006.05.014.
6. David, M. K. Biodiesel Production from Municipal Sewage Sludges. Energy Fuels. 2010, 24, pp. 2791–2794. doi:10.1021/ef1001106.
7. Department of the Environment (DOE). Technical guidelines for the estimation of greenhouse gas emissions by facilities in Australia. 2012.
8. Environment agency Austria Umweltbundesamt. Austria's National Inventory Report 2015. 2015.
9. Environmental Protection Agency (EPA). 2011. 40 CFR Part 98 Mandatory Reporting of Greenhouse Gases, Federal Register. 2011, 76(247)
10. European Commission. Biomass issues in the EU ETS. MRR Guidance document. 2012, 17(3)
11. Federal Environment Agency(UBA). National Inventory Report for the German greenhouse Gas Inventory 1990 – 2013, 2015.
12. Greenhouse Gas Inventory Office of Japan(GIO). National Greenhouse Gas Inventory Report of Japan, 2015.
13. McEvoy, J.; Giger, W. Accumulation of linear alkylbenzenesulphonate surfactants in sewage sludges. Naturwissenschaften. 1985, 72(8), pp. 429-431
14. Mohn ,J.; Szidat , S.; Fellner, J.; Rechberger, H.; Quartier, R.; Buchmann, B., Emmenegger, L. Determination of biogenic and fossil CO_2emitted by waste incineration based on $^{14}CO_2$ and massbalances. Bioresource Technology. 2008, 99(14), pp. 6471-6479.
15. Mohn, J.; Szidat , S.; Zeyer, K.; Emmenegger , L. Fossil and biogenic CO_2 from waste incineration based on a yearlong radio carbon study. Waste Management. 2012, 32(8), pp. 1516-1520. doi:10.1016/j.wasman.2012.04.002
16. Werther, J.; Ogada, T. Sewage sludge combustion. Progress in Energy and Combustion Science. 1999, 25(1), pp. 55–116. doi:10.1016/S0360-1285(98)00020-3.
17. Levin, I.; Kromer, B.; Schmidt, M.; Sartorius, H. A novel approach for independent budgeting of fossil fuel CO_2 over Europe by $^{14}CO_2$ observations. Geophysical Research Letters. 2003, 30(23), pp. 2194. doi:10.1029/2003GL018477.
18. Matthias, R. Radiocarbon Measurement of Micro-Scale Samples-A carbon dioxide inlet system for AMS. 2008. Philosophisch-naturwissenschaftlichen Fakulttp der Universiter Bern
19. Mi-yeong, K.; Jae-kwan, Kim.; Hyun-dong, L.; Sung-chul, K. Combustion Characteristics of Sewage sludge-bituminous coal mixture. Applied Chemistry. 2009, 13(1), pp. 93-96
20. Palstra, S.W.L.; Meijer, H.A.J. Carbon-14 based determination of the biogenic fraction of industrial CO_2 emissions. Application and validation Bioresource Technology. 2010, 101(10), pp. 3702–3710. doi:10.1016/j.biortech.2009.12.004

doi:10.20944/preprints201702.0035.v1

Peer-reviewed version available at *Sustainability* **2017**, *9*, 557; doi:10.3390/su9040557

21. Shireen Meher, K.; Debabrata, D. Biohydrogen as a renewable energy resource—Prospects and potentials. International Journal of Hydrogen Energy. 2008, 33(1):258-263. doi:10.1016/j.ijhydene.2007.07.031.
22. Takahiro, M.; Yoshizo, S.; Hidekazu, N.; Takafumi, Y.; Takami, K.; Hitoshi, H.; Seiichiro, O. Combustion characteristics of sewage sludge in an incineration plant for energy recovery. Fuel Processing Technology. 2009, 90(6), pp. 778–783. doi:10.1016/j.fuproc.2009.03.003.
23. Giger, W.; Brunner, PH.; Schaffner, C. 4-Nonylphenol in sewage sludge: accumulation of toxic metabolites from non-ionic surfactants. Science. 1984, 225(4662), pp. 623–625.