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The Study on Biomass Fraction Estimation for Waste Incinerated in Korea: A Case Study

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Academic Editor: Bhavik Bakshi
Received: 13 February 2017; Accepted: 25 March 2017; Published: 28 March 2017

Abstract: In this study, to determine the biomass fraction to apply to the estimation of greenhouse gas (GHG) emissions from the waste incineration sector, municipal solid waste, industrial waste, and sewage sludge incineration facilities were selected and analyzed, and the biomass fractions found in these facilities were compared. The biomass fractions of Municipal solid waste, industrial waste, and sewage sludge in incineration facilities were shown to be 57%, 41%, and 78%, on average, respectively. In the case of municipal solid waste and industrial waste incineration facilities, the values were similar to those of previous studies. However, the biomass fraction of wastes and sewage sludge except for municipal solid waste was found to be significantly different from the IPCC default. Accordingly, we believe that the biomass fractions used to estimate the GHG emissions of different incineration facilities should reflect the characteristics of each waste type. At present, the basic value given by the IPCC for biomass fraction is used in Korea to estimate the GHG emissions of each waste incineration facility. Some studies have found a difference between the value obtained using the basic value given by the IPCC and the value obtained using values that reflect the characteristics of Korea. In common with previous studies, in this study the biomass fraction of waste incineration facilities and sewage sludge incineration facilities except for municipal solid wastes showed a large difference, which is also expected to affect the estimation of GHG emissions. If further studies collect additional data on the biomass fraction of each waste type, this study along with the additional data collected will assist in the development of a state level greenhouse gas emission factor and contribute to the improvement of the reliability of the national GHG inventory.

Keywords: climate change; greenhouse gas; biomass fraction; waste incinerator

1. Introduction

Incineration is a widely used waste treatment method. It is popular because it uses less space than waste reclamation, it is hygienic, and the incineration heat can be used as an energy source [1]. While waste reclamation has been the most common waste treatment method in Korea since 2007, its use has been gradually decreasing while the use of incineration has been gradually increasing [2]. Greenhouse gas emissions from the incineration sector are gradually increasing and now account for the largest share of the waste sector's greenhouse gas emissions, reaching 7.4 million tCO_2eq in 2013

[3]. Efforts must therefore be made to improve the reliability of the greenhouse gas inventory for the incineration sector in relation to the fulfillment inspection discussed in the Paris Agreement.

Though national emission factors are being developed for some of the parameters used to estimate greenhouse gas in Korea's waste sector, many emission factors have not yet been developed and the basic values given by the IPCC are used instead. In particular, CO_2 emissions from biomass are to be reported separately from overall CO_2 emissions from the incineration sector [4].

The basic value given by the IPCC for the biomass fraction of incinerated waste is the one currently used, but it may not reflect the national characteristics of Korea. Some studies have reported the difference between the IPCC value used in Korea and the actual biomass fraction [5,6]. To improve the reliability of the inventory, it is therefore necessary to conduct many studies and collect a large amount of data on the related parameters that reflect the national characteristics.

Waste incinerated in Korea is basically divided into municipal solid waste, industrial waste, and sewage sludge, and greenhouse gas emissions are estimated for each type of waste. Accordingly, this study aimed to estimate and compare the biomass fractions of each type of waste incinerated in Korea.

2. Methods

This study looked into the biomass fraction used to estimate the greenhouse gas emissions from the waste incineration sector and estimated and compared the biomass fractions of each type of waste incinerated in Korea. The biomass fractions in the municipal solid waste, industrial waste, and sewage sludge collected from each incineration plant were analyzed and compared.

2.1. Selecting the Appropriate Facilities

Korea has four seasons: spring, summer, autumn, and winter. The lifestyles of its residents in relation to clothes, food, and other factors change seasonally, and the properties of their waste may also change. In order to measure the seasonal factors together, samples of waste incineration gas were collected during the summer–autumn period from July–September, the winter period from January–February, and the spring period in March. The object facility was selected from the Gyeonggi-do region, which showed the highest waste generation in 2014. Three sites were selected: one each for municipal solid waste incineration facilities, industrial waste incineration facilities, and sewage sludge incineration facilities, which are classified in Korea's waste incineration sector greenhouse gas inventory. Also, the selected facility is incinerating at least 100 ton of waste per day on average, and the status of the facility is shown in Table 1.

Table 1. Characteristics of the investigated waste incinerator**.**

Classification	Waste Type	Capacity (Ton/Day)
A incinerator	MSW (Municipal Solid Waste)	300
B incinerator	Industrial waste	100
C incinerator	Sewage sludge	200

2.2. Sampling of Waste Incineration Gas

The characteristics of the gas emitted from municipal solid waste and industrial waste incineration facilities may vary according to the amount and properties of the waste input [7–9]. In countries such as Australia, the USA, and Japan, a continuous measurement method is recommended to monitor the characteristics of incineration gas when measuring greenhouse gas emissions.

The guidelines for the climate change policy enforced in Korea specify an emission estimation method related to continuous measurement. Additionally, the Mandatory Reporting Rule (MRR) currently in effect in the USA states that an incineration gas sample for the estimation of greenhouse gas emissions from a waste incineration facility should be collected continuously for 24 h or until a sample sufficient to satisfy ASTM D6866-08 is secured [10]. Also, some studies have shown that collecting incineration gas emitted from an incineration facility is simpler and yields more reliable results than estimating the biomass fraction of solid waste [5,6]. Accordingly, in this study an incineration gas sample was collected continuously for 24 h, referring to the method outlined in ASTM D6866-08. The sampling of the incineration gas was measured seven times for each facility considering the seasonal factors according to the schedule of the facility.

Korea monitors air pollutant in real time by installing TMS for each combustion facility in order to monitor air pollutant. The back end of the tele-monitoring system installed to monitor air pollutants in Korea was set as the spot from which the sample was to be collected. The incineration gas sample was collected using the incineration gas collecting device created for this study. The system diagram of this incineration gas collecting device is shown in Figure 1. The device was comprised a water remover, a pump to absorb the incineration gas, and an electronic mass flow for maintaining flue gas at a constant flow rate.

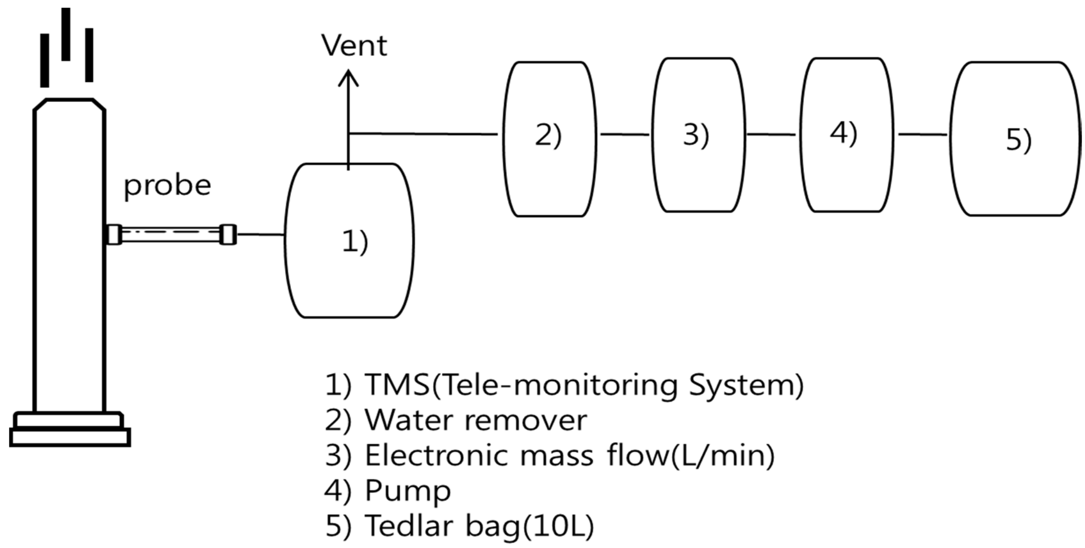

Figure 1. Schematic of the field setup for flue gas sampling of the incinerator**.**

2.2. Estimation of Biomass Fraction

There are various methods for estimating the biomass fraction and they are used in many studies [11–16]. The related standard test methods are DS/CEN/TS 15440, CEN/TR 15591, and ASTM D6866 [10,17,18]. In such standard test methods, the ^{14}C method, selective dissolution method, and the balance method are presented as the methods of estimating biomass fraction. In the EU, the ^{14}C method and the selective dissolution method are the ones recommended for estimating biomass fraction in relation to greenhouse gas emissions trading (EU-ETS MRR). In this study, the ^{14}C method was used to estimate biomass fraction.

The ^{14}C method uses behavior of the carbon isotopes that exist in nature, specifically the principle of ^{14}C, where the abundance of ^{14}C changes over time after interaction ceases between the stable isotopes, ^{12}C and ^{13}C, and the atmosphere. This method dates a sample by precisely measuring its ^{14}C content and estimates biomass fraction by measuring the percentage of CO_2 in the gas generated by fossil fuel [19].

The ^{14}C analysis method includes the Liquid Scintillation Counter (LSC), Accelerator Mass Spectrometer (AMS), and Isotope Ratio Mass Spectrometer (IRMS) methods, and the AMS method was used in this study. AMS is a method which determines the dating value and the percentage of CO_2 in the gas generated by fossil fuel by precisely measuring the amounts of the stable carbon isotopes ^{12}C and ^{13}C and the radioactive isotope ^{14}C through quantitative analysis of ^{14}C in the nucleus of the final atom, by accelerating, through ionization, the sample atoms to analyze their energy, momentum, and the charge state. AMS has the advantages that an analysis can be performed with a sample of only 1 g and that its results are about 105 times more precise than those of a general mass spectrometer [20].

The AMS analysis is apt for the carbon dating of small samples. The application of ASTM-D6866 to derive "biogenic carbon content" is based on the same concepts as radiocarbon dating, but without the 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 National Institute of Standards and Technology (NIST) standard with a known radiocarbon content equivalent approximately to the year 1950, chosen because it represented a time prior to thermo-nuclear weapons testing that 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 geologists. Therefore, 1950 is used as the reference year in accordance with "fractions of modern carbon (FM)" as below and biomass fraction are calculated by comparing the ratios of radioactive carbon isotopes $^{14}C/^{12}C$ existing in the standard sample and the analysis sample.

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

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

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

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.

3. Result and Discussion

3.1. Biomass Fraction of Municipal Solid Waste (MSW) Incineration Gas

The biomass fraction of municipal solid waste incineration facilities ranged from 55% to 58%. The average biomass fraction of municipal solid waste incineration facilities was 57% and the standard deviation was 1.46%. The results of the study, the average of each season, and previous studies and the biomass fraction suggested by IPCC were shown in Table 2. In the case of municipal solid waste, 57% in spring, 57% in summer, 56% in autumn, and 58% in winter, indicating that there was no significant seasonal difference in overall biomass fraction.

Table 2. The result of biomass fraction analysis of flue gas from MSW incinerator.

Classification	This Study				Mohn, J. et al. [13]	S.W.L. Palstra et al. [16]	IPCC GPG 2000 [21]
	Season	Sampling	Biomass Fraction	Season Mean			
A incinerator	Spring	1st	57	57	51–53	49–52	60
	Summer	1st	58	57			
		2nd	55				
	Fall	1st	55	56			
		2nd	56				
	Winter	1st	58	58			
		2nd	58				
Mean			57	-			
SD(Standard deviation)			1.46	-			

When compared with previous studies, the results of Mohn, J. et al., Palstra, S.W.L. et al. [13,16] were higher than those of 49–52% and lower than the default 60% of IPCC GPG 2000. Overall, the biomass fraction of municipal solid waste incinerator in this study did not show any significant difference from previous studies.

3.2. Biomass Fraction of Industrial Waste Incineration Gas

The biomass fraction of the industrial waste in incineration facilities was shown to range from 36 to 49. The biomass fraction of industrial waste incineration facilities ranged from 36% to 49%. The average biomass fraction of industrial waste incineration facilities was 41% and the standard deviation was 4.16%. The results of the study, the average of each season, the results of previous studies, and the biomass fraction suggested by IPCC2006 G/L are shown in Table 3. The biomass fraction of industrial waste incineration facilities was 36% in spring, 43% in summer, 40% in autumn, and 45% in winter.

As a result of comparison with the previous studies, these results are similar to the results of Frida C Jones et al. (40–50%). However, they are very different from the default value of 10% proposed by IPCC 2006 G/L. Due to the features of industrial waste, industrial waste is incinerated by contract with the business producing it. Therefore, the characteristic of the input waste may change depending on the contract period. The difference from the IPCC default value is supposed to be due to this. The reason for this difference seems to be that the IPCC 2006 G/L is targeted at the industrial waste incineration facilities, which mainly burn high petroleum products, solvents, and plastics with high fossil carbon content

Table 3. The result of biomass fraction analysis of flue gas from Industrial waste incinerator**.**

<table>
<tr><th rowspan="2">Classification</th><th colspan="4">This Study</th><th rowspan="2">Frida, C. J. et al. [12]</th><th rowspan="2">IPCC 2006 G/L [5]</th></tr>
<tr><th>Season</th><th>Sampling</th><th>Biomass Fraction</th><th>Season Mean</th></tr>
<tr><td rowspan="7">B incinerator</td><td>Spring</td><td>1st</td><td>36</td><td>57</td><td rowspan="9">40–50</td><td rowspan="9">10</td></tr>
<tr><td>Summer</td><td>1st</td><td>43</td><td>43</td></tr>
<tr><td rowspan="3">Fall</td><td>1st</td><td>43</td><td rowspan="3">40</td></tr>
<tr><td>2nd</td><td>39</td></tr>
<tr><td>3rd</td><td>39</td></tr>
<tr><td rowspan="2">Winter</td><td>1st</td><td>49</td><td rowspan="2">45</td></tr>
<tr><td>2nd</td><td>41</td></tr>
<tr><td colspan="3">Mean</td><td>41</td><td>-</td></tr>
<tr><td colspan="3">SD(Standard deviation)</td><td>4.16</td><td>-</td></tr>
</table>

3.3. Biomass Fraction of Sewage Sludge Incineration Gas

The biomass fraction of the sewage sludge in incineration facilities was shown to range from 74 to 81%. The average biomass fraction of the sewage sludge incinerator was 77% and the standard deviation was 1.98%. In the sewage sludge incinerator, 78% in spring, 79% in summer, 81% in autumn, and 76% in winter. The results of the study, the average of each season, and the biomass fraction suggested by IPCC are shown in Table 4.

In IPCC 2006 G/L, the biomass fraction of sewage sludge incineration facilities is 100%, which was different from the results of this study. According to a study by Beta Analytic, Ginger, W. et al., McEvoy, J. et al. [22–24] it was believed that the biomass fraction may not be 100% because the components of the surfactant are not completely decomposed. Therefore, in this study, it was judged that the biomass fraction was not 100% for this reason.

Table 4. The result of biomass fraction analysis of flue gas from swage waste incinerator.

<table>
<tr><th rowspan="2">Classification</th><th colspan="4">This Study</th><th rowspan="2">IPCC 2006 G/L</th></tr>
<tr><th>Season</th><th>Sampling</th><th>Biomass Fraction</th><th>Season Mean</th></tr>
<tr><td rowspan="7">C incinerator</td><td>Spring</td><td>1st</td><td>78</td><td>78</td><td rowspan="9">100</td></tr>
<tr><td rowspan="2">Summer</td><td>1st</td><td>79</td><td rowspan="2">79</td></tr>
<tr><td>2nd</td><td>78</td></tr>
<tr><td rowspan="2">Fall</td><td>1st</td><td>80</td><td rowspan="2">81</td></tr>
<tr><td>2nd</td><td>81</td></tr>
<tr><td rowspan="2">Winter</td><td>1st</td><td>75</td><td rowspan="2">76</td></tr>
<tr><td>2nd</td><td>77</td></tr>
<tr><td colspan="3">Mean</td><td>78</td><td>-</td></tr>
<tr><td colspan="3">SD(Standard deviation)</td><td>1.98</td><td>-</td></tr>
</table>

3.4. Comparison of Biomass Fraction

In this study, municipal solid waste, industrial waste, and sewage sludge incineration facilities were selected and the biomass fraction of the waste in each facility was estimated to look for a way to apply biomass fraction to the incineration facilities for each material incinerated in Korea. The estimated biomass fractions of municipal solid waste, industrial waste, and sewage sludge in incineration facilities were 57%, 41%, and 78% on average, respectively (see Figure 2). In the case of municipal solid waste and industrial waste incineration facilities, the values were similar to those of the previous studies. However, the biomass fraction of wastes and sewage sludge except for municipal solid waste was found to be significantly different from the IPCC default.

The results indicated differences between the biomass fractions of the waste materials incinerated, and the biomass fractions were highest in sewage sludge and lowest in industrial waste. We believe that the biomass fraction of municipal solid waste is relatively high because much municipal solid waste is the residue of biological material and that the biomass fraction of industrial waste is the lowest because much industrial waste is derived mostly from fossil fuel.

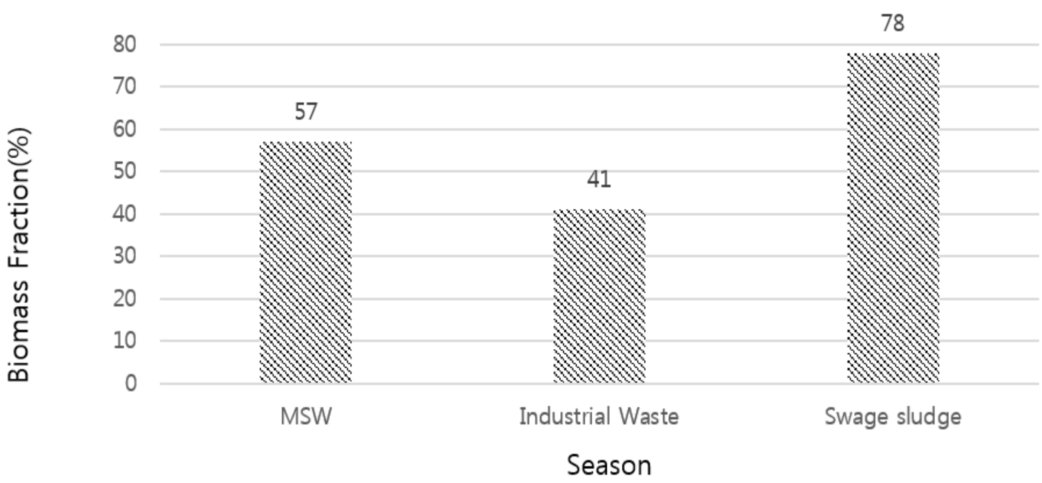

Figure 2. Comparison of estimate method for biomass fraction at target incinerator.

4. Conclusions

In this study, to determine the biomass fraction to apply to the estimation of greenhouse gas emissions from the waste incineration sector, municipal solid waste, industrial waste, and sewage sludge incineration facilities were selected and the biomass fractions found in these facilities were analyzed and compared. To analyze the biomass fraction, a sample of the incineration gas from each waste type was collected continuously for 24 h in a Tedlar bag. A ^{14}C method, the AMS method, was used for this analysis.

The biomass fraction of the municipal solid waste in incineration facilities was shown to range from 55% to 58%, that of the industrial waste in incineration facilities was shown to range from 36% to 49%, and that of the sewage sludge in incineration facilities was shown to range from 74% to 81%. In general, little seasonal variation was found in the biomass fractions of municipal solid waste, industrial waste, and sewage sludge in incineration facilities. The biomass fractions of municipal solid waste, industrial waste, and sewage sludge in incineration facilities were shown to be 57%, 41%, and 78% on average, respectively. The results show that biomass fraction differs between the waste materials incinerated, and the biomass fractions were highest in sewage sludge and lowest in industrial waste. Accordingly, we believe that the biomass fractions used to estimate the greenhouse gas emissions of different incineration facilities should reflect the characteristics of each waste type.

At present, the basic value given by the IPCC for biomass fraction is used in Korea to estimate the greenhouse gas emissions of each waste incineration facility. However, the IPCC recommends that a greenhouse gas emission factor be developed, if possible, to reflect the characteristics of each country, and some studies have found a difference between the value obtained using the basic value given by the IPCC and the value obtained using values that reflect the characteristics of Korea. In common with previous studies, in this study biomass fraction of waste incineration facilities and sewage sludge incineration facilities except for municipal solid wastes shows a large difference, which is also expected to affect the estimation of GHG emissions.

At present, Korea's greenhouse gas reduction policies include energy/greenhouse gas target management and an emissions trading system, and each affected business should estimate and report its greenhouse gas emissions. Accordingly, to improve the reliability of the greenhouse gas inventory for the waste incineration sector, it is necessary to conduct studies on biomass fraction that factor in the characteristics of each waste type. In this study, we analyzed and compared the biomass fractions of each waste type, taking the seasons into account. In this study, the biomass fraction of industrial waste incineration facilities and sewage sludge incineration facilities were significantly different from the default values of IPCC currently applied. If further studies collect additional data on the biomass fraction of each waste type, this study along with the additional data collected will assist in the development of a state level greenhouse gas emission factor and contribute to the improvement of the reliability of the national greenhouse gas inventory.

Acknowledgements: This work was 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.

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