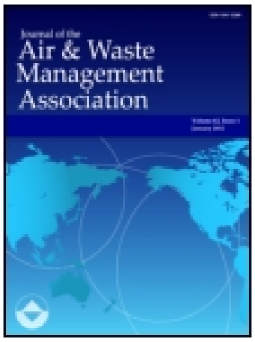

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TECHNICAL PAPER

The comparison of fossil carbon fraction and greenhouse gas emissions through an analysis of exhaust gases from urban solid waste incineration facilities

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ABSTRACT

In this study, in order to understand accurate calculation of greenhouse gas emissions of urban solid waste incineration facilities, which are major waste incineration facilities, and problems likely to occur at this time, emissions were calculated by classifying calculation methods into 3 types. For the comparison of calculation methods, the waste characteristics ratio, dry substance content by waste characteristics, carbon content in dry substance, and ^{12}C content were analyzed; and in particular, CO_2 concentration in incineration gases and ^{12}C content were analyzed together. In this study, 3 types of calculation methods were made through the assay value, and by using each calculation method, emissions of urban solid waste incineration facilities were calculated then compared. As a result of comparison, with Calculation Method A, which used the default value as presented in the IPCC guidelines, greenhouse gas emissions were calculated for the urban solid waste incineration facilities A and B at 244.43 ton CO_2/day and 322.09 ton CO_2/day, respectively. Hence, it showed a lot of difference from Calculation Methods B and C, which used the assay value of this study. It is determined that this was because the default value as presented in IPCC, as the world average value, could not reflect the characteristics of urban solid waste incineration facilities. Calculation Method B indicated 163.31 ton CO_2/day and 230.34 ton CO_2/day respectively for the urban solid waste incineration facilities A and B; also, Calculation Method C indicated 151.79 ton CO_2/day and 218.99 ton CO_2/day, respectively.

Implications: This study intends to compare greenhouse gas emissions calculated using ^{12}C content default value provided by the IPCC (Intergovernmental Panel on Climate Change) with greenhouse gas emissions calculated using ^{12}C content and waste assay value that can reflect the characteristics of the target urban solid waste incineration facilities. Also, the concentration and ^{12}C content were calculated by directly collecting incineration gases of the target urban solid waste incineration facilities, and greenhouse gas emissions of the target urban solid waste incineration facilities through this survey were compared with greenhouse gas emissions, which used the previously calculated assay value of solid waste.

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Introduction

Republic of Korea is making efforts in international climate change activities, such as announcing at an international conference a 30% reduction from the greenhouse gas emission prospects until 2020; accordingly, efforts to reduce greenhouse gases are in active progress in all areas, involving the establishment of greenhouse gas inventories (Jeon et al., 2010; Lee et al., 2012). The waste sector in such greenhouse gas inventories takes up about 2.1% of the national total emissions, with 43.9% increase of greenhouse gas emissions as of 2010 compared with 1990 at 14.2 million tons carbon dioxide equivalent (CO_2eq). The incineration method among the disposal methods of such waste takes up a high percentage in Republic of Korea compared with other countries; also, Republic of Korea is emitting 5666.7 Gg CO_2eq, which takes up 33.9% of greenhouse gas emissions from the waste sector in 2010 (Greenhouse Gas Inventory and Research Center of Korea [GIR], 2012). Thus, managing emissions and securing the reliability of greenhouse gas emissions of the incineration sector among the waste sectors are very important.

The yearly disposal amount of incineration facilities of the whole country is 3,963,740 tons per year, the number of days worked 290 days per year, and the number of hours worked 20 hours per day. Of this disposal amount, household waste takes up the most at 97.3%; other than this, there are sewage sludge, wood waste, food waste, impurities, etc. For the physical composition of waste brought into incineration facilities of the whole country,

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combustibles take up 86.6%, whereas incombustibles and other take up 13.4%. Also, 27.5% of these combustibles were surveyed to be made of paper, and 25.7% of vinyl plastics (Ministry of Environment [MOE], 2013). In the Intergovernmental Panel on Climate Change (IPCC) guidelines, it is advised that when greenhouse gas emissions of the waste sector are calculated, only CO_2 that is derived from fossil fuels is to be calculated as emissions, and CO_2 that is derived from biomass is not to be included in emissions (IPCC, 1996, 2006; Palstra and Meijer, 2010; Avfall Sverige AB, 2012).

For the content of such fossil fuel–derived carbon, ^{12}C, there are differences according to the type of waste; accordingly, it can affect the calculation of greenhouse gas emissions occurring during waste incineration (Fuglsang et al., 2014). In foreign countries, studies on such ^{12}C content are being actively conducted (Renewable Energy Association [REA], 2007; Reinhardt et al., 2008; Stabe et al., 2008; Fuglsang et al., 2011; Larsen et al., 2013; Schnöller et al., 2014); yet in Republic of Korea, ^{12}C content default value as presented in the IPCC guidelines is being used (Kim et al., 2010, 2012; Kan et al., 2008; Jang et al., 2008). However, since ^{12}C content default value of the IPCC guidelines, which is the world mean value, has a limit that prohibits taking into consideration the climatic conditions in Republic of Korea and the components of waste brought into incineration facilities, calculating ^{12}C content of Republic of Korea is an urgent matter. Also, using this information, it is necessary to accurately calculate greenhouse gas emissions by developing a calculation method.

Recently, in Republic of Korea, studies have been conducted to calculate ^{12}C contents unique to Republic of Korea (Lee at al., 2015). However, those studies include only solid waste analysis such as studies of detailed classification systems for ^{12}C-based wastes to be incinerated, and studies that calculate ^{12}C contents in incinerator exhaust gases such as with the present study are lacking.

Thus, by focusing on the urban solid waste incineration facilities in Republic of Korea, this study intends to compare greenhouse gas emissions calculated using ^{12}C content default value provided by the IPCC with greenhouse gas emissions calculated using ^{12}C content and waste assay value that can reflect the characteristics of the target urban solid waste incineration facilities. Also, the concentration and ^{12}C content were calculated by directly collecting incineration gases of the target urban solid waste incineration facilities, and greenhouse gas emissions of the target urban solid waste incineration facilities through this survey were compared with greenhouse gas emissions, which used the previously calculated assay value of solid waste. Likewise, greenhouse gas emissions of the waste incineration sector were calculated by using various methods in this study. Also, this study intends to propose the most appropriate calculation method for calculating greenhouse gas emissions of Korean urban solid waste incineration facilities by comparing these methods.

This study intends to find the differences between emissions calculated using the assay value of solid waste and the emissions through actual measurement by comparing these three calculation methods. Also, in the case of using the assay value of solid waste, this study intends to compare the differences in emissions between when the default value presented in the IPCC guidelines was used and when the value calculated by directly analyzing waste in this study was used. Through comparing these methods, this study intends to propose the most appropriate calculation method for calculatieenhouse gas emissions of urban solid waste incineration facilities.

Methods

Selection of target facilities

In this study, studies were conducted targeting urban solid waste incineration facility A with the capacity of 420 t/day and urban solid waste incineration facility B with the capacity of 500 t/day, both of which are the major urban solid waste incineration facilities in Republic of Korea. Both A and B use the stoker system for their incineration method, their combustion gas processing facilities include selective noncatalytic reduction (SNCR), semidry cleaning equipment, suction filter, etc. SNCR is an equipment for removing nitrogen oxides (NO_x), which is included in the exhaust gases of urban solid waste incineration facilities, and semidry cleaning equipment is an equipment for removing acidic gases such as hydrogen chloride (HCl), sulfur oxides (SO_x), etc. Suction filters were installed to efficiently remove harmful pollutants such as heavy metals and dioxin. Also, the targeted urban solid waste incineration facilities are using waste heat recovery equipment in order to recycle waste heat produced during waste incineration into energy.

Classification method for solid waste characteristics

Carbon included in solid waste can be classified into ^{12}C, which is fossil fuel derived, and ^{14}C, which is biomass derived; the content of such fossil fuel–derived carbon, ^{12}C, is called fossil carbon fraction (FCF). Such ^{12}C content differs according to the type of waste; accordingly, it can affect the calculation of greenhouse gas emissions occurring during waste incineration. ^{14}C is used as an indicator of biomass, and the half-life of ^{14}C is 5730 years. Therefore, ^{14}C is not emitted when fossil fuels are burnt because only ^{12}C exists in fossil fuels. Accordingly, ^{12}C is emitted when fossil fuels are burnt. Therefore, if ^{12}C is excluded from the entire C emissions, only ^{14}C emitted from biomass burning will be left.

If biomass-derived CO_2 emissions are not excluded when calculating greenhouse gas emissions of urban solid waste incineration facilities, the emissions could be overcalculated. In order to prevent such overcalculation and accurately calculate greenhouse gas emissions, carbon content in dry substance according to waste characteristics and ^{12}C content that exclude the biomass-derived ^{14}C among other carbon contents are important. However, in the existing studies on greenhouse gas emission calculation for many urban solid waste incineration facilities in Republic of Korea, carbon content in dry substance and ^{12}C content default value as presented in the IPCC guidelines are used; hence, studies on carbon content in dry substance and ^{12}C content are still insufficient. Carbon content in dry substance and ^{12}C content default value of the IPCC guidelines, which have been used previously in many studies, as the world average value, have limits that prohibit taking into consideration the climatic conditions of Republic of Korea and the characteristics of waste brought into the targeted urban solid waste incineration facilities. Thus, in this study, the characteristics were classified after directly collecting waste samples by using the conical quartering method by visiting the target urban solid waste incineration facilities.

Materials contained in the waste were classified into paper, wood/straw, plastics/vinyl, food waste, textiles/leather, incombustibles, and other. Of these, for paper, wood/straw, plastics/vinyl, textiles/leather, carbon content in dry substance and ^{12}C content were calculated by producing standard samples. For food waste, since it is the origin of biomass, 0% was applied for ^{12}C content as it is in IPCC. Also, in order to reflect the characteristics of waste brought into target urban solid waste incineration facilities, carbon content in dry substance was calculated by producing standard samples. Since incombustibles and others were nonflammable substance or substance with indistinguishable shapes, and it was judged that standard sample production and analysis would be difficult, the IPCC default value was applied for carbon content in dry substance and ^{12}C content.

Also, in the 2006 IPCC guidelines, it is specified that coated paper, synthetic leather, etc., can be included in the fossil fuel–derived ^{12}C content; hence, paper was classified into regular paper, coated paper, and printed paper; and textiles/leather were classified into cotton textiles, synthetic textiles, natural leather, and synthetic leather.

Analysis method for solid waste

In this study, in order to analyze carbon content in dry substance for each waste characteristic, an automatic elemental analyzer, Thermo Finnigan-Flash EA 1112 (Thermo Fisher Scientific, USA), was used. An automatic elemental analyzer is mostly used as an equipment for analyzing the content of carbon, hydrogen, nitrogen, and sulfur in samples. In this study, carbon content in dry substance was calculated by analyzing after drying the standard samples for each waste characteristic. For the analysis method, the dynamic flash combustion method was used, in which carbon within the standard sample was oxidized, separated using a column, and then quantified using a thermal conductivity detector (TCD). The column used was ParaQ-X, which is 2 m in length; also, for the analysis conditions, in the case of temperature, the oven temperature of TCD was adjusted to 65 °C, and the furnace temperature was adjusted to 950 °C. For the gas flow rate used during analysis, in the case of carrier gas (He 99.999%; MS Gas Corporation), it was set at 140 mL/min; in the case of oxygen (O_2 99.99%; DongMin Specialty Gases), it was set at 240 mL/min; and in the case of reference gas, it was set at 100 mL/min.

Also, in order to raise reliability of the assay value of carbon content in dry substance by waste characteristics, quality assurance/quality control (QA/QC) of an automatic elemental analyzer, Thermo Finnigan-Flash EA 1112 was implemented before analyzing the standard samples. QA/QC was conducted by using BBOT samples (2,5-bis(5-tert-butylbenzoxazolyl)thiophene: C = 72.59%, H = 6.06%, N = 6.54%, S = 7.43%, O = 7.42%).

Among the methods to analyze the fossil fuel–derived ^{12}C content among carbon content in dry substance, there are accelerator mass spectrometry (AMS), liquid scintillation counter (LSC), and isotope ratio mass spectrometry (IRMS). Currently in foreign countries, many studies are being conducted using accelerator mass spectrometry, which has low measurement uncertainty and requires a small amount of necessary standard samples (Hamalainen et al., 2007; Palstra and Meijer, 2010). The analysis method for ^{12}C content of accelerator mass spectrometry is analyzing the density of each substance after converting ions into high kinetic energy by accelerating them. Through this analysis method, it is possible to separate and analyze ^{12}C. In this study, ^{12}C content was calculated by using accelerator mass spectrometry. Also, in order to compare greenhouse gas emissions calculated by using the assay value of solid waste and greenhouse gas emissions calculated by using the assay value of incineration gases, incineration gases collected at the targeted urban solid waste incineration facilities were analyzed simultaneously with ^{12}C content during the analysis of CO_2 concentration in the laboratory.

The incineration gas collection method

In order to collect incineration gases emitted at target urban solid waste incineration facilities, the ASTM (American Society for Testing and Materials) D 6866 sample collection method was applied (ASTM International, 2007). For urban solid waste incineration facilities, the characteristics of waste inputted during incineration can change continuously, and this characteristic can alter the amount of greenhouse gas. Thus, in this study, the method for collecting incineration gases for 24 hr straight was used without using the intermittent incineration gas collection method. As shown in Figure 1, the incineration gas collection method was composed of mass flow controller (Alicat Scientific, USA) for collecting incineration gases at a constant flow rate; a pump (KNJ, Korea); a moisture eliminator (Alpha, Korea) that can remove moisture by cooling incineration gases of high temperatures at a low temperature (3 °C) in order to protect the pump and the mass flow controller, which are greatly affected by moisture; drainage pump (Alpha) for removing this moisture, timer (Herabell, Korea), which can control the incineration gas collection time; and automatic on/off valve (Syntrk, Korea), which can take into account the inspection and purge times that could occur during the collection of incineration gases.

For this incineration gas collection device, QA/QC was conducted in the laboratory in order to reduce uncertainty that can occur during collection before collecting incineration gases at target urban solid waste incineration facilities. Also, for QA/QC, 20.01% of CO_2 standard gas was inputted in the front, and then the concentration of each was analyzed and compared by collecting CO_2 standard gas out of the rear. The analysis results of CO_2 concentration indicated that the average concentration of standard gas at the front was 20.03%, and the average concentration analyzed by collecting the standard gas at the rear was 20.07%, showing the difference of 0.04% from the concentration of the standard gas of the front. The standard deviation of the standard gas of the rear was calculated at 0.06%, and the relative standard deviation was calculated at 0.28%.

The analysis method for the incineration gas concentration

The concentration of CO_2 among incineration gases of target urban solid waste incineration facilities was analyzed using gas chromatography with flame ionization detector (GC-FID). Also, for the FID, since detection sensitivity for

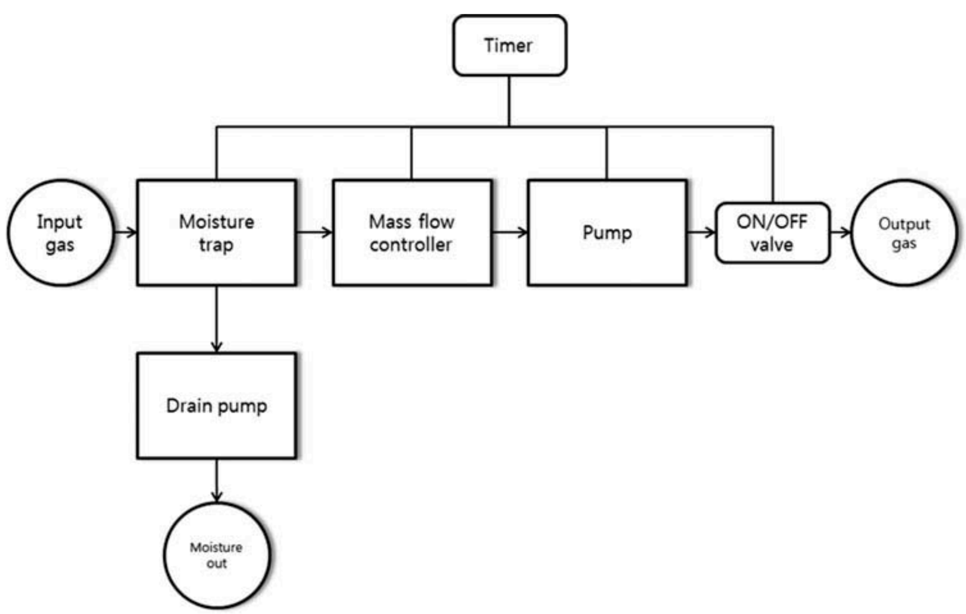

Figure 1. Schematic for incineration gas sampling.

CO_2 does not exist, a methanizer was installed to analyze CO_2 by converting it into methane (CH_4). For a column used to separate CO_2 from other gas components at this time, Porapak Q 80/100 was used; also, for operating conditions, in the case of temperature, the temperature of the sample injection was set at 100 °C, the temperature of the detector was set at 250 °C, the temperature of the methanizer was set at 350 °C, and the temperature of the oven was set at 80 °C; and in the case of the flow rate, carrier gas (99.999%) was set at 30 mL/min, hydrogen (99.999%) was set at 30 mL/min, and air (zero grade) was set at 300 mL/min.

Prior to analyzing the CO_2 concentration of incineration gases emitted at the targeted urban solid waste incineration facilities, a calibration curve for quantitative analysis of the CO_2 concentration was prepared by using CO_2 standard gas (Rigas, Korea). The CO_2 standard gas concentration for preparing a calibration curve was analyzed by producing four different concentrations in the range of 1~10%. As a result, R^2 value of the calibration curve was 0.9999, showing excellent linearity.

Also, 10.1% of the CO_2 concentration standard gas (Rigas) was analyzed five times to verify the repeatability of GC-FID, and as a result, the relative standard deviation of the CO_2 concentration indicated 0.13%, showing excellent repeatability.

The calculation method for greenhouse gas emissions of resource recovery facilities

In this study, in order to compare calculation methods for greenhouse gas emissions of urban solid waste incineration facilities, greenhouse gas emissions were calculated by classifying the calculation method into three types. Calculation method A is a method suggested by the IPCC (IPCC, 2006); it calculates greenhouse gas emissions by using the assay value of solid wastes, as seen in eq 1. In the case of calculation method A, for dry substance content, carbon content in dry substance, and ^{12}C content, the default value as proposed in the IPCC guidelines was used. Also, in the case of waste characteristics ratio of target urban solid waste incineration facilities, the characteristics ratio calculated in this study was applied in the calculation owing to the absence of the value proposed by IPCC.

$$E_{A,CO_2} = MSW \times \sum_i \left(WF_i \times dm_{A,i} \times CF_{A,i} \times FCF_{A,i} \times OF_i\right) \times \frac{44}{12} \tag{1}$$

where E_{A,CO_2} is CO_2 emissions of calculation method A (t CO_2/day); MSW is the amount incinerated for household waste of the targeted resource recovery facilities (t/day); WF_i is the characteristics ratio of i within MSW; $dm_{A,i}$ is the IPCC dry substance content of i within MSW; $CF_{A,i}$ is the carbon content in dry substance of the IPCC guidelines of i within MSW; $FCF_{A,i}$ is ^{12}C content of the IPCC guidelines of i within MSW; OF_i is the oxidation factor (1 applied); and 44/12 is a conversion factor.

As shown in eq 2, calculation method B is similar to calculation method A as a method of using the assay value of solid waste. But unlike calculation method A in which the characteristics ratio calculated in this study was applied only for the waste characteristics ratio of the targeted urban solid waste incineration facilities, for calculation method B, the values analyzed in this study were used for the waste characteristics ratio, dry substance content, carbon content in dry substance, and ^{12}C content.

It is determined that this will reflect the characteristics of the targeted urban solid waste incineration facilities, by comparison with calculation method A, which used the world average value.

$$E_{B,CO_2} = MSW \times \sum_i \left(WF_i \times dm_{B,i} \times CF_{B,i} \times FCF_{B,i} \times OF_i\right) \times \frac{44}{12} \tag{2}$$

where E_{B,CO_2} is CO_2 emissions of calculation method B (t CO_2/day); MSW is the amount incinerated for household waste of the targeted resource recovery facilities (t/day); WF_i is the characteristics ratio of i within MSW; $dm_{B,i}$ is the dry substance content of i within MSW calculated in this study; $CF_{B,i}$ is the carbon content in dry substance of i within MSW calculated in this study; $FCF_{B,i}$ is the ^{12}C content of i within MSW calculated in this study; OF_i is the oxidation factor (1 applied); and 44/12 is a conversion factor.

As shown in eq 3, calculation method C, as a method of calculating greenhouse gas emissions through real measurement, calculates greenhouse gas emissions by analyzing CO_2 concentration in incineration gases and ^{12}C content. As this is a method that does not use the assay value of solid waste considered to have relatively complex procedures, and high uncertainty, it is determined that it will be possible to simplify the procedures and lower the uncertainty.

$$E_{C,CO_2} = \left(C_{CO_2} \times Q \times \frac{44}{22}.4 \times 10^{-5}\right) \times FCF_{C,i} \tag{3}$$

where $E_{C,CO2}$ is CO_2 emissions of calculation method C (t CO_2/day); C_{CO2} is CO_2 concentration (%); Q is dry flow rate (m^3/day; at 0 °C and 1 atmosphere); and $FCF_{C,i}$ is the ^{12}C content in incineration gases.

Results

Carbon content in dry substance by waste characteristics

In this study, in order to obtain the waste characteristics ratio of the urban solid waste incineration facilities A and B, sample collection was conducted three times each, and the greenhouse gas emissions were calculated by using the average value. As shown in Table 1, for the waste characteristics ratio, for both urban solid waste incineration facilities A and B, paper had the highest percentages at 35.19% and 36.03%, respectively; for dry substance content, it was analyzed to be 57.23% and 60.23%, respectively. In the case of wood/straw, among the wastes of the targeted urban solid waste incineration facilities, the percentage was lowest at 1.81% and 4.10%, respectively, and for dry substance content, it was analyzed to be 59.07% and 71.72%, respectively. Plastics/vinyl, which have the second highest percentage after paper, took up 21.62% and 24.69%, respectively, and the dry substance content was analyzed to be 73.71% and 75.18%, respectively. In the case of food waste, the percentages were 8.83% and 9.21%; the dry substance content was analyzed to be 35.21% and 39.11%, respectively, the lowest among the wastes of the targeted urban solid waste incineration facilities. For textiles/leather, it was 8.04% and 6.43%, respectively, in which textiles took up the most, and a small amount existed for leather. The dry substance content of textiles/leather was analyzed to be 65.37% and 69.12%. In the case of incombustibles, the percentages were 4.53% and 6.97%; and the dry substance content was analyzed to be highest at 95.39% and 90.52%. In addition, for other, the percentages were 19.98% and 12.57%, and the dry substance content was analyzed to be 57.01% and 59.81%. Also, for the average value by waste characteristics, in the case of paper, it was indicated to be 42.81% and 41.13%, respectively, for the urban solid waste incineration facilities A and B; and for wood/straw, it was analyzed to be 38.12% and 39.09%, respectively. For textiles/leather, it indicated 56.84% and 51.45%, respectively; and for incombustibles, carbon content in dry substance was not calculated. Finally, for other, it was calculated at 1.97% and 9.19%, respectively.

In Republic of Korea, recyclable waste wastes are separated, emitted, and collected according to emission method per type. Food waste is put in food waste bag, emitted to containers, and collected, so food waste takes up a small part among wastes. Paper and plastics/vinyl, including coated fliers, plastics/vinyl with labels attached, polluted paper, and polluted plastics/vinyl, are not recyclable, so they take up a huge part of wastes.

^{12}C content

Among solid wastes of the targeted urban solid waste incineration facilities, in the case of paper and textiles/leather, since there are types possessing ^{12}C content as coated paper, synthetic leather were included, in addition to the origin of biomass as regular paper and natural leather, and the standard samples by detailed classification were produced and analyzed in order to analyze the relevant ^{12}C content. In this study, in the case of items classified in detail by waste characteristics, ^{12}C content was analyzed for each; also, by applying, to ^{12}C content classified in detail then calculated, the detailed classification percentage by waste characteristics as indicated in Table 2, the final ^{12}C contents for paper and textiles/leather were calculated.

For the assay value of ^{12}C content included in carbon content in dry substance, as shown in Table 3, in the case of paper, ^{12}C content of regular paper was 0%,

Table 1. MSW analysis by MSW incineration facility.

	Incinerator A			Incinerator B		
MSW Component	Waste Composition (%)	Dry Matter Content in % of Wet Weight	Total Carbon Content in % of Dry Weight	Waste Composition (%)	Dry Matter Content in % of Wet Weight	Total Carbon Content in % of Dry Weight
Paper	35.19 ± 2.40	57.23 ± 4.47	42.81 ± 4.39	36.03 ± 0.88	60.23 ± 4.02	41.13 ± 2.80
Wood/Straw	1.81 ± 0.31	59.07 ± 2.52	43.32 ± 3.46	4.1 ± 1.43	71.72 ± 9.10	42.12 ± 4.32
Plastics/ Vinyl	21.62 ± 1.91	73.71 ± 4.69	65.11 ± 6.79	24.69 ± 2.62	75.18 ± 1.73	69.15 ± 5.90
Food waste	8.83 ± 0.39	35.21 ± 8.50	38.12 ± 0.59	9.21 ± 1.03	39.11 ± 9.06	39.09 ± 2.48
Textiles/ Leather	8.04 ± 1.59	65.37 ± 11.92	56.84 ± 3.63	6.43 ± 1.58	69.12 ±10.77	51.45 ± 4.10
Inactive waste	4.53 ± 0.40	95.39 ± 0.80	0	6.97 ± 0.69	90.52 ± 5.85	0
Others	19.98 ± 0.38	57.01 ± 18.33	1.97 ± 0.05	12.57 ± 5.44	59.81 ± 9.46	9.19 ± 1.71

Table 2. The detailed classification ratios (%) of paper and textiles/leather.

Waste Composition	Detailed Classification	Ratio
Paper	Paper	60.4 ± 5.1
	Printed paper/Coated paper	39.6 ± 5.1
Textiles/Leather	Textiles	60.2 ± 17.2
	Synthetic textiles	36.9 ± 14.6
	Natural leather	0
	Synthetic leather	2.9 ± 3.1

Table 3. ^{12}C fractions (%) by MSW incinerator.

	^{12}C Fraction		^{12}C Fraction	
Waste Composition	This Study	Waste Composition	This Study	IPCC
Paper	0	Paper	4.5	1
Printed paper/Coated paper	11.3			
Wood/straw	0.8	Wood/straw	0.8	0
Plastics/Vinyl	99.8	Plastics/Vinyl	99.8	100
Textiles	1.5	Textiles/ Leather	25.1	20
Synthetic textiles	59.3			
Natural leather	25.2			
Synthetic leather	79.4			

and that for coated and printed paper was calculated at 11.3%. In the case of regular paper, since it was composed of 100% biomass, ^{12}C content was not calculated; however, since ink and coated paper used for printing contain carbon, which is the basis of fossil fuel, ^{12}C contents of coated and printed paper were calculated. For wood/straw, ^{12}C content was calculated at 0.8%; hence, it was revealed that it was mostly composed of biomass. For plastics/vinyl, ^{12}C content was calculated at 99.8%; hence, it was revealed that it was mostly composed of carbon, which is the origin of fossil fuel. In the case of textiles/leather, the calculations indicated 1.5% for cotton textiles, 59.3% for synthetic textiles, 25.2% for natural leather, and 79.4% for synthetic leather. By applying the detailed classification percentage calculated in this study to each ^{12}C content calculated, the final ^{12}C content by waste characteristics was calculated. As a result, it was indicated that paper was 4.5%, wood/straw was 0.8%, plastics/vinyl was 99.8%, and textiles/leather was 25.1%. In this study, the calculated ^{12}C contents were compared with ^{12}C contents of the IPCC guidelines.

The results of this study were inquired to the Institute for Global Environmental Strategies (IGES) of the IPCC, and as a result, the basic default by IPCC was calculated not by an experiment but by a judgment of experts, so there can be a great deal of difference among countries.

Also, in this study, in order to compare the calculated greenhouse gas emissions of urban solid waste incineration facilities and greenhouse gas emissions calculated through actual measurement, ^{12}C content of incineration gases was analyzed by using the assay value of solid waste. The analysis of ^{12}C content in incineration gases was conducted total three times over 3 months, once a month at each of the urban solid waste incineration facilities. Also, in order to compare with greenhouse gas emissions of urban solid waste incineration facilities calculated by using the assay value of solid waste, sample collection and characteristics classification of waste were conducted on the same day of the implementation. As shown in Table 4, ^{12}C contents in incineration gases of the urban solid waste incineration facilities A and B were calculated at 46.4% and 38.0% on average, respectively.

Incineration gas concentration

In order to find greenhouse gas emissions of urban solid waste incineration facilities through actual measurement, and as a result of analyzing CO_2 concentration of incineration gases collected at the urban solid waste incineration facilities A and B, as shown in Table 5, the urban solid waste incineration facility A showed the concentration range of minimum 6.29% and maximum 7.42%, and the average concentration was 6.83%. The urban solid waste incineration facility B showed the concentration range of minimum 8.67% and maximum 10.91%, and the average concentration was calculated at 9.62%.

Comparison of greenhouse gas emissions by calculation method

In this study, the differences in greenhouse gas emissions for each of the targeted urban solid waste incineration facilities are presented in Figure 2. Calculation method A uses the default value as presented in the IPCC guidelines in calculating greenhouse gas emissions of urban solid waste incineration facilities, and the urban solid waste incineration facilities A and B indicated highest at 244.43 and 322.09 t CO_2/day, respectively. This shows relatively a lot of difference from calculation methods B and C, which show similar emissions. Calculation method B is a method of calcu-

Table 4. ^{12}C fractions (%) by MSW incineration facility.

Sampling	Incinerator A	Incinerator B
1	46.1	37.6
2	46.1	38.0
3	47.0	38.4
Mean	46.4	38.0
SD	0.52	0.40
RSD (%)	1.12	1.05

Table 5. CO_2 concentration (%) analysis by MSW incineration facility.

Sampling	Analysis	Incinerator A	Incinerator B
1	1	7.42	8.82
	2	7.24	8.72
	3	7.13	8.67
	4	7.25	8.91
	5	7.32	8.88
2	1	6.42	10.48
	2	6.58	10.91
	3	6.37	10.54
	4	6.51	10.07
	5	6.29	10.35
3	1	6.78	9.77
	2	6.84	9.65
	3	6.66	9.64
	4	6.72	9.34
	5	6.91	9.59
Mean		6.83	9.62
SD		0.37	0.73
RSD (%)		5.41	7.60

lating greenhouse gas emissions of urban solid waste incineration facilities by using the assay value of solid waste directly calculated in this study, and the urban solid waste incineration facilities A and B indicated 163.31 and 230.34 t CO_2/day, respectively. Calculation method C is a calculation method using the assay value of incineration gases, and it indicated 151.79 and 218.99 t CO_2/day, respectively. Greenhouse gas emissions directly calculated in this study by analyzing solid waste of the targeted urban solid waste incineration facilities and incineration gases such as in calculation methods B and C showed a similar value, and showed a big difference from calculation method A, which used the default value presented in the IPCC guidelines. Calculation methods B and C are values that analyzed solid waste and incineration gases of the targeted urban solid waste incineration facilities; hence, they can reflect the characteristics of waste brought into the targeted urban solid waste incineration facilities; however, it is determined that calculation method A is the world average value and does not reflect the characteristics of the targeted urban solid waste incineration facilities. Urban solid waste incineration facility B with the capacity of 500 t/day had higher greenhouse gas emissions than urban solid waste incineration facility A with the capacity of 420 t/day. The difference of calculation methods B and C was due to the following: since calculation method B collected wastes in grams from several hundred tons of wastes and analyzed them, there can be a difference according to the type and change of collected wastes.

Conclusion

Greenhouse gas emissions of such waste incineration were 5,666,700 t CO_2eq in 2010 and take up 39.9% of total emissions of the waste sector. Thus, for CO_2 emissions of this incineration sector, accurate calculation, securing reliability, and emissions management are very important.

In this study, in order to understand accurate calculation of greenhouse gas emissions of urban solid waste incineration facilities, which are major waste incineration facilities, and problems likely to occur at this time, emissions were calculated by classifying calculation methods into three types. For the comparison of calculation methods, the waste characteristics ratio, dry substance content by waste characteristics, carbon content in dry substance, and ^{12}C content were analyzed; and in particular, CO_2 concentration in incineration gases and ^{12}C content were analyzed together.

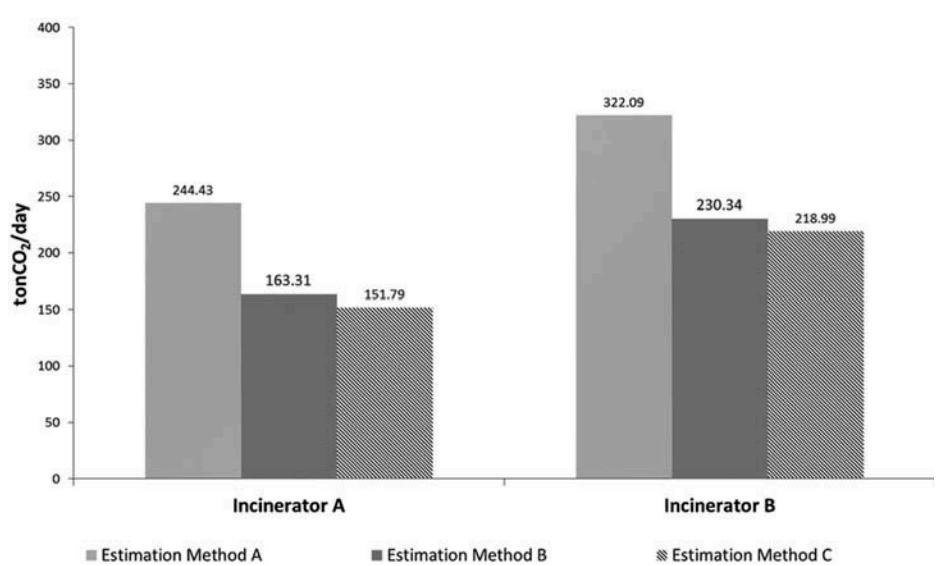

Figure 2. The comparison of estimation methods for GHG emissions in waste incinerators.

In this study, three types of calculation methods were made through the assay value, and by using each calculation method, emissions of urban solid waste incineration facilities were calculated and then compared. As a result of comparison, with calculation method A, which used the default value as presented in the IPCC guidelines, greenhouse gas emissions were calculated for the urban solid waste incineration facilities A and B at 244.43 and 322.09 t CO_2/day, respectively. Hence, it showed a lot of difference from calculation methods B and C, which used the assay value of this study. It is determined that this was because the default value as presented in IPCC, as the world average value, could not reflect the characteristics of urban solid waste incineration facilities. Calculation method B indicated 163.31 and 230.34 t CO_2/day, respectively, for the urban solid waste incineration facilities A and B; also, calculation method C indicated 151.79 and 218.99 t CO_2/day, respectively. Unlike calculation method A, calculation methods B and C showed similar values, and it is determined that this was because, as the values for which solid waste and incineration gases of urban solid waste incineration facilities were analyzed, they reflected the characteristics of the targeted urban solid waste incineration facilities.

In the case of Republic of Korea, separate garbage collection rates are high because firm volume-rate garbage disposal systems are implemented. Therefore, the kinds of wastes sent to incineration plants are different from the global average properties of wastes. Therefore, when calculating greenhouse gas emissions from incineration facilities in Republic of Korea, characteristic values that fit the characteristics of Republic of Korea should be applied rather than the basic values presented by the IPCC that are global average values. If greenhouse gas emissions from urban solid waste incineration are calculated using calculation method A that uses IPCC basic values, the greenhouse gas emissions may be overestimated.

Thus, for urban solid waste incineration facilities, in the case greenhouse gas emissions are calculated with calculation method A, the emissions can be overcalculated. Thus, it is determined that it would be appropriate to calculate greenhouse gas emissions by using calculation methods B and C, rather than calculation method A. Also, in the case of calculation methods B and C, since calculation method B uses the assay value of solid waste, many factors such as characteristics classification of waste, dry substance content, carbon content in dry substance, ^{12}C content, etc., should be considered; thus, compared with calculation method C, it will be time-consuming and the uncertainty will be relatively high. Also, since ^{12}C content must be calculated by waste characteristics, compared with calculation method C, which calculates only ^{12}C content of incineration gases, it will be costly. In the case of calculation method C, unlike calculation method B, since only CO_2 concentration of incineration gases and ^{12}C content are considered, it will relatively take shorter time and have lower uncertainty than calculation method B; also, it is determined that the cost will be less during calculation of ^{12}C content. Also, henceforward, studies that consider the regional and seasonal characteristics for many urban solid waste incineration facilities and incineration facilities will be necessary.

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