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Estimation of CO_2 Emissions in Incinerator by Actual Measurement and IPCC Guideline†

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This research analyzed the emission factors of emission characteristics of incineration facilities of municipal solid waste and compared the results by different estimation methods, in order to suggest the emission amount estimation methods that occur in municipal solid waste. It can be understood that the total actually measured CO_2 emission was shown low by comparison with emission amount by the IPCC guideline. For estimating the CO_2 emission for biomass, the average amount of actually measured CO_2 was also shown wide difference with the average emission amount by the estimation method suggested in the IPCC guideline. One of the reasons in these results is that it shows wide difference compared with estimation result by IPCC guideline because actual CO_2 measurement in incinerator could be done only twice a year. Also, it is considered that the CO_2 emission amount is rapidly increased owing to incineration of the food wastewater in the incinerator.

Key Words: CO_2 Emission, IPCC, Tier, Municipal solid waste.

INTRODUCTION

In order to actively cope with the international environment for reducing the greenhouse gases, the proper amount of emission of national greenhouse gas is required and in case of Korea, when estimating the amount of greenhouse gas, the basic value of the Tier 1 method (simple method) is applied by the 1996 IPCC Guideline and the Tier 2 method is applied in some fields. However, in recently published IPCC Good Practice Guidance (IPCC 2001) and 2006 IPCC Guideline, it is recommended to apply the country-specific emission factor before the basic value in such case when country-specific values are available and the researches are in progress in a way to secure these unique values in advanced countries[1-6].

In such case when the data related to emission factor that are suggested in 2006 IPCC guideline is in shortage, the greenhouse gas emission amount is estimated by using the database of the advanced nation. Meanwhile, for some of the parts that are obtainable with some data, the Tier 2 method is applied and as for the emission-statistic data that are presented, the Tier 2 method results are basically adopted and the Tier 1 method results are only adopted for the unobtainable parts. However, it should be noted that the country-specific emission factor is not constructed for the most of the nations, but is estimated by using the basic methods and emission factors among estimation instructions of international organizations and advanced nations and also there is shortage of researches on the uncertainty of degree of management and values of emission factors for emission factors and main variables that largely influence on the estimation of greenhouse gases.

As for the researches on the estimation of greenhouse gas in Korea, since the country-specific emission characteristic values such as the emission density and emission factors are not constructed, it is not possible to precisely estimate the greenhouse gas emission amount by using the basic methods among the emission estimation methods of international organization and advanced nations and this can limit the establishment of national strategies. Accordingly, in order to precisely estimate the amount of emission, it is necessary to obtain precise information about facilities and emission state by technology, operation method by process and development of reduction technology. Accordingly, this research analyzed the emission factors of emission characteristics of incineration facilities of municipal solid waste and compared the results of the estimation by the estimation methods, in order to suggest the emission amount estimation methods that occur in municipal solid waste.

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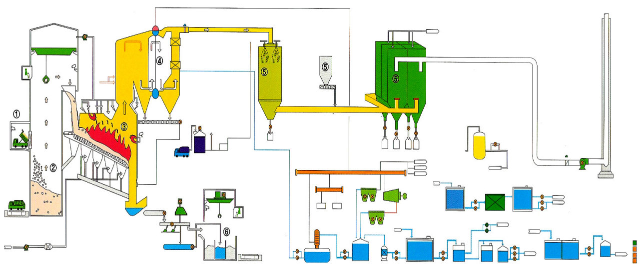
EXPERIMENTAL

Research target incineration facility: The target facilities of this research is the continuous stoker type incineration facility that disposes of 200 ton per day and as it annually incinerates 65,000 tons of wastes, it produces 620,000 GJ of heat annually. The overview of incineration facility is presented in Fig. 1. As for the incinerator facility characteristics, the household wastes are inserted onto the grate and stirred to be transported for incineration and the incineration process of the wastes is composed of drying, pre-combustion, post-combustion and cooling and since the speed of each of the steps of grate is controllable, it is possible to change the combustion zone according to the waste characteristics. As for the structure of the incinerator, the transportation of the waste and the flow of combustion gas are the same direction and it is an effective way of combustion by passing pyrolyzed toxic gas through the upper part of main combustion zone in dry zone.



(1) waste input (2) waste bunker (3) incinerator (4) waste heat boiler (5) exhaust gas facility (6) ash bunker

Fig. 1. Schematic diagram of stoker incinerator

The primary incineration temperature is operated in 1,200 to 1,300 ºC temperature range and the harmful contaminants are completely eliminated by maintaining the 2nd incineration temperature at 870 to 980 ºC. The acidic gases (SO_x, HCl) that occurs during the incineration process supplies slaked lime onto semi-dry reaction tower (SDR) as slurry to be processed as neutralization reaction and the generating dust, heavy metals, dioxins and unreacted hazardous gas, are eliminated by collecting them in filter dust collector. SNCR is eliminated by reducing the nitrogen oxide (NO_x) with the usage of ammonia. Also, by installing the automatic gas analyzer in the chimney which is the final outlet for emitted gas, the monitoring system is constructed so that harmful ingredients are not emitted to outside and 2 and 3 layers of pollution protection facilities are constructed.

CO_2 emission estimation: The emission was calculated based on the estimated value of the amount of waste incinerated considering the waste activity data according to the municipal solid wastes (MSW) composition, dry matter content, total carbon content, the fraction of fossil carbon and the oxidation coefficient. The emission calculation method by the incineration is estimating the value (oxidized fossil carbon amount) that was found by multiplying the oxidation coefficient based on the fossil carbon content value among the incinerated wastes as the CO_2 emission. In this research, the CO_2 emission by the method of Tier 2a that applies emission factors as suggested in 2006 IPCC Guideline[7] and the CO_2 emission that was obtained by using Tier 3 that uses unique emission factors were compared for analysis. In order to precisely estimate the emission amount, we have applied the CO_2 emission calculation formula based on MSW composition, rather than the CO_2 emission calculation based on the total amount of waste based on the incinerated waste as suggested in the guideline.

$$CO_2 \text{ emission (Gg/yr)} = MSW \cdot \Sigma (WF_j \cdot dm_j \cdot CF_j \cdot FCF_j \cdot OF_j) \cdot 44/12$$

where MSW: Total amount of municipal solid waste based on incinerated wet moisture (Gg/yr); WF_j : Waste type/fraction of substance of composition element j within municipal solid waste, ($\Sigma WF_j = 1$); dm_j: Dry substance content among the composition elements of incinerated municipal state waste, (%); CF_j: The fraction of carbon within dry substance of composition element j, (%); FCF_j : The fraction of fossil carbon from total amount of carbon of composition element j, (%); OF_j : Oxidization fraction, (%); 44/12 : CO_2 conversation factor for carbon; j = paper/cardboard, textiles, food waste, tree, rubber/leather, plastic, glass and other inert waste.

Also, we have estimated the amount of CO_2 emission by biomass based on the CO_2 emission estimation method in the part of waste incineration as suggested by IPCC Guideline. The theoretical emission amount of target incineration facility through CO_2 emission by biomass was estimated and it was compared with total CO_2 emission measured by incinerator for analysis. The CO_2 emission by biomass was estimated through the component by property in household waste incineration amount and the dry substance content of each appearance. The CO_2 emission by biomass is calculated as follows.

$$CO_2 \text{ emission (Gg/yr)} = MSW \cdot \Sigma (WF_i \cdot dm_i \cdot CF_i \cdot (1\text{-}FCF_i) \cdot OF_j) \cdot 44/12$$

where, CO_2 emission : CO_2 emission by biomass; MSW: The total amount of municipal state waste based on incinerated moisture content (Gg/yr); WF_j: The fraction of waste type/substance of composition element j within municipal state waste; dm_j : Dry content fraction among composition element j of incinerated municipal state waste, (%); CF_j : Carbon fraction within dry substance of composition element j (%); FCF_j: Fossil gas carbon fraction from total amount of carbon of composition element j (%); OF_j: Oxidization fraction (%); 44/12 : CO_2 conversion coefficient for carbon; j : Paper/cardboard, textiles, food waste, wood, rubber/leather, plastic, glass and other inert waste.

CO_2 emission factor estimation: In order to compare the Tier 2a method and Tier 3 method, we have used the activity values of corresponding incinerator facilities with MSW and waste fraction (WF_j). As for the dry content fraction from waste and the carbon fraction from dry substance, we have used IPCC specific value in Tier 2a method and used the self-analyzed value in Tier 3 method. As for the fossil carbon fraction (FCF_j) among the total carbon, we have used the IPCC guideline specific values for all and as for the oxidization fraction (OF_j), since the well-designed incineration facilities show nearly 100 % of oxidization rate, we have applied 100 % of oxidization rate.

RESULTS AND DISCUSSION

CO_2 emission concentration and emission amount by measurement: As for the measurement of CO_2 concentration, the concentration rate and the flow rate were consecutively measured for 4 h per day with 1-min interval twice a year in

TABLE-1
ACTUAL MEASURED CO_2 CONCENTRATION AND FLOW RATE FROM STACK

Item	Year					
	2007	2008	2009	2010	2011	Average
CO_2 concentration (%)	6.9	9.5	10.5	10.7	12.1	**9.94**
Flow (m^3/h)	48,554	51,549	55,381	58,082	60,964	**54,906**
Waste incinerated (ton/yr)	56,678	61,042	61,819	62,227	65,788	**61,511**
CO_2 total emission (tCO_2 eq/yr)	80,800	123,000	148,000	151,000	181,000	**136,760**
CO_2 emission factor (tCO_2/twaste)	1.43	2.01	2.40	2.43	2.75	**2.20**

TABLE-2
MSW COMPOSITION DATA BY PERCENT IN THIS STUDY INCINERATOR AND IPCC GUIDELINE (2006) DEFAULTS (UNIT:%)

Waste composition	This study						IPCC guideline
	2007	2008	2009	2010	2011	Average	Eastern Asia
Paper	27.1	26.9	32.0	34.4	31.7	30.0	18.8
Textiles	9.0	8.7	6.3	7.3	6.0	7.4	3.5
Food waste	22.7	21.6	15.3	15.4	15.3	17.8	26.2
Wood	8.9	9.1	8.8	8.1	10.6	8.9	3.5
Plastic	28.7	29.6	32.8	29.7	29.7	29.7	14.3
Other	20.2	5.5	6.4	6.5	6.4	5.9	33.7

TABLE-3
CONTENTS OF DRY MATTERS, TOTAL CARBON AND FOSSIL CARBON OF DIFFERENT MSW COMPONENTS

Waste composition	This study		IPCC guideline	
	Dry matter content (%) in wet weight	Total carbon content (%) in dry weight	Dry matter content (%) in wet weight	Total carbon content (%) in dry weight
Paper	79	39	90	46
Textiles	72	48	80	50
Food waste	33	44	40	38
Wood	85	48	85	50
Plastic	98	69	100	75
Other	87	2	90	3

the chimney of target facilities from 2007 to 2011. The CO_2 concentration emitted from the chimney of incinerator facility and the CO_2 emission that was calculated by using the yearly CO_2 emission concentration (%) by actual measurement and the emission flow amount (m^3/h), is summarized in Table-1. As for the CO_2 emission concentration measurement by household waste incinerator facility, it was shown to have steadily increased from 6.9 % in 2007, 9.5 % in 2008, 10.5 % in 2009, 10.7 % in 2010 and 12.1 % in 2011. As for the incinerated amount of waste, it has been 56,678 ton in 2007, 61,042 ton in 2008, 61,819 ton in 2009, 62,227 ton in 2010, 65,788 ton in 2011 and the actual total emission amount of CO_2 was between 80,800-181,000 ton/yr. The total average emission amount of CO_2 is 136,760 ton/yr and the CO_2 average emission factor that divided total CO_2 emission amount by waste processing amount was found to be 2.20 t CO_2/t waste.

In order to precisely estimate the trustworthy national greenhouse gas emission amount, it is necessary to construct the emission factors and activity data that reflect the features of unit incinerator. By applying the detailed and concrete emission factors by incinerator, it is possible to estimate the precise amount of emission of the Tier 3 method level that is recommended by IPCC guideline. Accordingly, the focus was made on the composition needed for estimation of CO_2 emission in the waste incinerator, dry substance content and the carbon ratio.

The waste composition ratio that is processed in the household waste incinerator targeted in this research and the values of household waste composition ratio in the East Asian region of IPCC Guideline in 2006 are summarized and compared in Table-2. This data is based on the weight of the wet waste that includes foods and other wet garbages. As for the composition ratio of the household waste that is processed in the incinerator targeted in this research, it can be understood that the paper has the highest ratio, followed by the plastic.

Foods, woods and paper among the incinerated household wastes include most of the (degradable organic carbon: DOC) and textile, plastic and rubber wastes are non-biological and include the carbon by the fossil gas among the household wastes. In order to estimate the CO_2 emission by the incineration, it is necessary to distinguish the fossil gas of incinerated wastes as well as the non-biological carbon content and the biological carbon content. For estimation of waste incinerator greenhouse gas emission amount in this research, the values of the dry matter content ratio (%) that was analyzed in the research lab, along with the total carbon ratio (%) among dry wastes and the household wastes composition ratio in the East Asian region of 2006 IPCC Guideline, were presented in Table-3.

In this research, as for the dry content ratio: paper was 79 %, fiber 72 %, trees 85 %, plastic 98 % and the food was the lowest at 33 %. Although these results showed similar figures to the dry matter content ratio in 2006 IPCC guideline, the paper dry content matter of the guideline was 90 % which is considered to have shown relatively high value. Also, the total carbon content of the dry waste was 39-69 % and it showed relatively constant range value compared to 38-75 % in 2006 IPCC guideline.

CO_2 emission estimation: The CO_2 emission (Tier 2a method) was estimated by measuring the CO_2 emission of the municipal solid waste incinerator and applying the emission factor provided by the IPCC guideline, as well as the emission that was estimated by applying the emission factor measured in the target facility (Tier 3 method) were compared for analysis. The results are presented in Fig. 2.

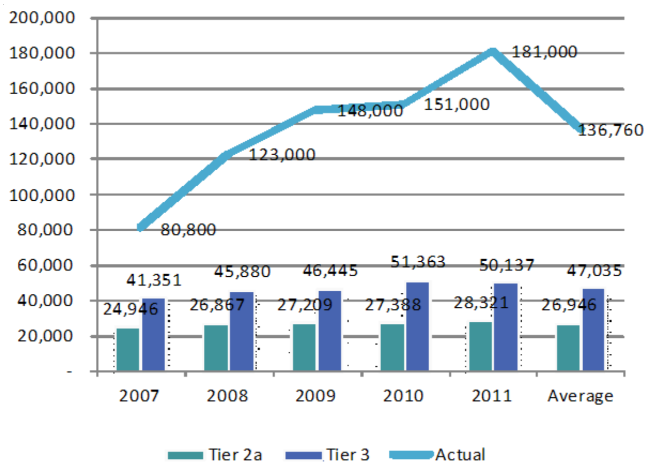


Fig. 2. Comparison of CO_2 emissions by 2006 IPCC guideline Tier 2a, Tier 3 and actual measurement

From the results, it can be understood that the fossil CO_2 emission by Tier 2a method of municipal solid waste incinerator was 24,946~28,320 ton/yr and it shows lower distribution value compared to the fossil CO_2 emission by the Tier 3 method that showed 41,351~51,362 ton/yr of range. Also, it can be understood that the total CO_2 emission that was actually measured and the emission amount by the IPCC guideline show big difference from the year of 2008. Comparing with the total average CO_2 emission amount of 136,760 ton/yr, the values estimated by Tier 2a method and Tier 3 method are each 26,946 ton/yr and 47,035 ton/yr respectively and they were undervalued compared to the values estimated by actual measurement. These differences are due to the the composition rate of wastes and the differences of dry matter content and carbon content and the differences become large in the CO_2 emission of fiber and plastic.

By estimating the CO_2 emission for biomass, the result of theoretical total emission amount of CO_2 and the compared results of total actually-measured CO_2 emission amount are presented in Fig. 3. As for this result, the actually-measured average amount of CO_2 was 136,760 ton/yr and shows big difference with the average emission amount of 86,462 ton/yr that was estimated by the estimation method suggested in the IPCC guideline and the difference appears from the year of 2008. The reason is because in case of the incinerator that was set as the target in this research, it incinerates the food wastes by injecting into the incinerator from 2008. Although the proportion of the solid waste among the food wastes is comparatively low at 10~15 %, since the concentration of suspended solids (SS) is high at around 70,000 ppm, the CO_2 emission amount is regarded to have rapidly increased even though the total incineration amount of the waste did not increase too much. Accordingly, these reasons are believed to have caused the difference in the CO_2 emission amount by the IPCC guideline and the CO_2 emission amount that was actually measured.

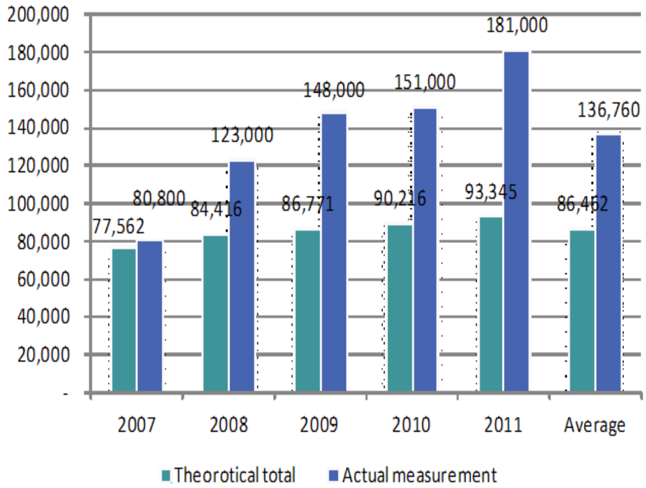


Fig. 3. Comparison of CO_2 actual measured emissions and total theoretical emissions by 2006 IPCC guideline

CO_2 emission factor estimation: In order to compare the results of CO_2 emission factors of Tier 2a and Tier 3 that were estimated by dividing the CO_2 emission amount of the municipal solid waste incinerator by the waste processing amount with the actually measured emission factor (basic unit), was presented in Fig. 4. The average basic unit by the Tier 2a method is 0.42 t CO_2/t waste and the average basic unit by Tier 3 method was 0.73 t CO_2/t waste, that were under-evaluated compared to the basic unit of 1.6 t CO_2/t waste that was actually measured and just as the CO_2 emission amount, it shows big difference from 2008. The reason for this is believed to be because of the change of incinerator condition with its volume of 200 ton/yr in size and also the difference between the value estimated by the Tier 3 method that does not reflect such variable as combustion efficiency and the value that was calculated by actual measurement. Accordingly, it is considered to be necessary to do more researches on various incinerator facilities while considering these variables for estimation of future greenhouse gas and the development of emission factors.

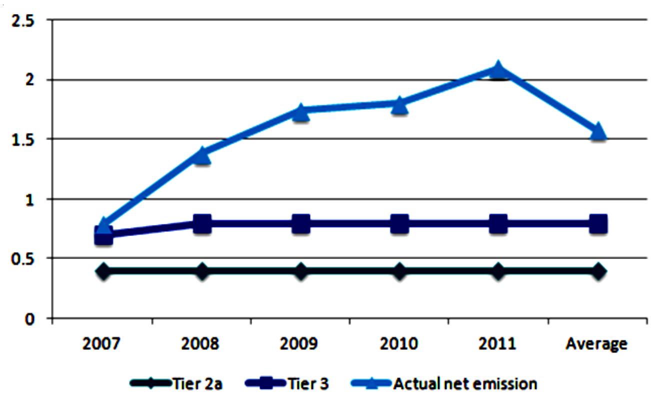


Fig. 4. Comparison of CO_2 emissions factors by 2006 IPCC guideline Tier 2a and Tier 3 and actual

Conclusion

This research analyzed the emission factors of emission characteristics of incineration facilities of municipal solid wasteand compared the results of the estimation by the estimation methods, in order to suggest the emission amount estimation methods that occur in MSW. The main results obtained in this study can be summarized as follows.

(1) The measured CO_2 concentration emitted from the chimney of incinerator facility and the incinerated amount of waste were shown to have steadily increased. The total average emission amount of CO_2 is 136,760 ton/yr and the CO_2 average emission factor that divided total CO_2 emission amount by waste processing amount was found to be 2.20 t CO_2/t waste.

(2) It can be understood that the total actually measured CO_2 emission was shown low by comparison with emission amount by the IPCC guideline. For estimating the CO_2 emission for biomass, the average amount of actually measured CO_2 was also shown wide difference with the average emission amount by the estimation method suggested in the IPCC guideline.

(3) One of the reasons in these results is that it shows wide difference compared with estimation result by IPCC guideline because actual CO_2 measurement in incinerator could be done only twice a year. Also, it is considered that the CO_2 emission amount is rapidly increased owing to incineration of the food wastewater in the incinerator.

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