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Ammonia Emission Characteristics and Emission Factor of Municipal Solid Waste Incineration Plant

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Abstract: This study aims to analyze whether ammonia emission occurs when municipal solid waste (MSW) is incinerated. In cases where ammonia is emitted, we aim to develop an emission factor, calculate annual emission amounts by utilizing activity data (waste incineration amount) applied in air pollutant emission calculations for the waste combustion in Korea, and investigate whether there is a need for emission calculation. As a result of the study, the ammonia emission factor of the MSW incineration facility to be studied was 0.0091 kgNH_3/ton, which was 3 times higher than the emission factor in Europe. In the case of emissions, a randomly developed emission factor was applied to confirm the necessity of development of the emission factor, and as a result of the application, it was found to be 22 NH_3 ton/year, which is the same number as the annual NH_3 emission of the entire waste treatment sector in 2016. Therefore, we believe that MSW incinerator facilities should be recognized as one of the major NH_3 omitted emission sources. Moreover, it is evident that there is a need for an NH_3 emission factor and emission calculations that reflect the characteristics of Korea.

Keywords: PM2.5 secondary sources; municipal solid waste; missing sources; ammonia emission factor

1. Introduction

The 2018 annual average ultrafine dust (PM2.5) concentration in Korea was 24 μg/m^3, representing the second-worst air quality of the member countries of the Organization for Economic Cooperation and Development after Chile (24.9 μg/m^3) [1].

One of the main causes of the increase in ultrafine dust is the increase in the emission of substances that contribute to the secondary formation of ultrafine dust, including Volatile Organic Compounds (VOCs), Ammonia (NH_3), Nitrogen Oxide (NOx), and Sulfur Oxides (SOx), among others [2]. The amounts of NOx and SOx in Korea are measured in real-time by air-pollution-monitoring stations at major stationary combustion sites [3–5]. Of the substances that contribute to the secondary formation of particulate matter, only NH_3 undergoes odor management; thus, there is a lack of emission management and related studies to tackle this issue. Therefore, there is a need for ammonia emission estimates, the development of an emission factor, and further research. In particular, for the calculation of the volume of ammonia emissions, Korea mainly applies emission factors from the US Environmental Protection Agency (US EPA) or the European CO-oRdinated Information (CORINAIR). Furthermore, there are numerous omitted emission sources that remain unknown [6–8]. Therefore, the importance of research pertaining to the emission of NH_3 omitted emission sources, and the development of emission factors that reflect the characteristics of Korea is increasing.

NH_3 emission sources are varied, and combustion sites are one of the dominant NH_3 emission sources [9]. Out of these combustion sites, NH_3 emission volumes are calculated for plants for power

generation and petroleum product production. The amount of NH_3 emitted through slip is estimated due to the operation of selective catalytic reductions (SCRs) and selective non-catalytic reductions (SNCRs) that utilize NH_3 to reduce NOx [10,11]. Moreover, SCRs and SNCRs are installed and operated in municipal waste combustion sites, but the resulting NH_3 emission amounts are currently not calculated in Korea. Currently, there is only one case of developing an ammonia emission factor for related waste incineration facilities in Europe CORINAIR, and in Korea, the application of air pollution emission factor for waste incineration facilities is based on the US EPA data. However, EPA data is missing the emission factor for NH_3. Therefore, the emission is not calculated by applying the NH_3 emission factor itself. Therefore, this study aimed to measure and analyze whether ammonia emission occurs when municipal solid waste (MSW) is incinerated. If ammonia is emitted, the emission coefficient will be developed to review the annual ammonia emissions by utilizing the activity data (waste incineration) applied to the calculation of air pollutant emissions in Korea's waste incineration sector, and to confirm the need to develop ammonia emission coefficients. Since the calculation of ammonia emissions in this study is to determine the necessity of developing emission factors by reviewing approximate annual emissions, representativeness was not considered.

2. Methods

2.1. Selection of Target Facilities

Ammonia samples were collected to determine the ammonia concentration from gas ports in MSW incinerator facilities. The operating conditions in the target facilities and the number of samples collected are presented in Table 1. Sample collection was carried out more than twice in the target facilities, and six samples were collected. Since the purpose of this study was to confirm ammonia emission, samples were collected according to the schedule of the target facility as much as possible.

Table 1. Characteristics of the investigated municipal solid waste (MSW) incinerator.

Site	Capacity	Type	Air Pollution Prevention Facility	Sampling
MSW incinerator A	150 ton/day	stoker	SCR	6

2.2. Ammonia Analysis at Iron and Steel Production Facilities

To measure the NH_3 emission concentration in the exhaust gas ports of MSW incinerator facilities, this study used the indophenol reaction from the NH_3 emission concentration measurement methods recommended in the Korean "Official Methods to Test Malodor" and "Official Method to Test Air Pollution" [12,13]. Phenol sodium nitroprusside solution and sodium hypochlorite solution were added to the sample solution in the indophenol reaction, and the amount of ammonia was estimated by measuring the absorbance of the indophenols synthesized through the reaction with ammonium ions. Ammonia samples were collected by placing ammonia absorbents (absorbed through a total of 50 mL of boric acid solution) in two 50-mL flasks. Furthermore, 80 L of exhaust gas was sucked in over 20 min at 4 L/min using a mini pump (SIBATA MP-ΣNII, Japan). To remove the moisture in the gas emitted from the MSW incinerator exhaust gas ports, an absorbent bottle containing silica gel was placed in front of the ammonia sample collection device. The mimetic diagram related to the ammonia sample collection is shown in Figure 1. The absorbents collected to measure the ammonia concentration were analyzed using a spectrophotometer, (Shimadzu 17A, Kyoto, Japan) and absorbance was measured for 640-nm wavelengths.

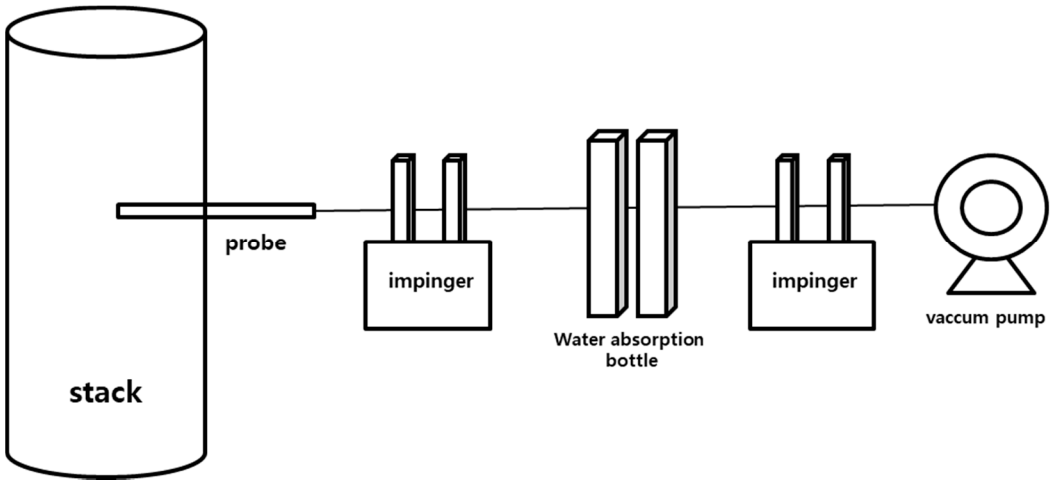

Figure 1. Schematic of the field setup for ammonia sampling at MSW incinerator.

2.3. Development of the NH_3 Emission Factor

The formula for the ammonia emission factor is shown in Equation (1), and the formulas used in research pertaining to the development of ammonia emission factors have been referenced [14,15]. CleanSYS data from the target facility was used as the discharge data required for the development of an NH_3 emission factor for MSW incinerator facilities; the discharge used was the one-day cumulative discharge data. CleanSYS is the air pollution monitoring system managed by the Korean Ministry of Environment; it carries out real-time measurements of air pollutants, such as NOx, SOx, and particulate matter (PM), as well as discharge and exhaust gas temperature, among others [16].

$$EF_{NH_3} = \left[C_{NH_3} \times \frac{M_w}{V_m} \times Q_{day} \times 10^{-6}\right] / FC_{day} \quad (1)$$

where EF is emission factor (kg NH_3/ton); C_{NH_3} is NH_3 concentration in exhaust gas (ppm); M_w is molecular weight of NH_3 (constant) = 17.031 (g/mol); V_m is one mole ideal gas volume in standardized condition (constant) = 22.4 (10^{-3} m^3/mol); Q_{day} is daily accumulated flow rate (Sm^3/day) (based on dry combustion gas); and FC_{day} is daily MSW incineration (ton/day).

3. Result and Discussion

3.1. NH_3 Emission Concentration at an MSW Incinerator

An MSW incinerator facility tentatively called "A" was visited twice for the NH_3 concentration analysis, and a total of six samples were collected. The results of the ammonia concentration analysis are shown in Table 2.

Table 2. NH_3 concentration of the investigated MSW incinerator.

Sampling	NH_3 Concentration (ppm)	NOx Concentration (ppm)
1	2.69	29.47
2	2.56	29.24
3	2.77	29.58
4	0.20	46.12
5	0.16	62.20
6	0.20	48.13
Mean	1.43	40.79
SD (Standard Deviation)	1.36	13.62

These results show that the concentration ranged from a maximum of 2.77 ppm to a minimum of 0.16 ppm, with an average concentration measured to be 1.43 ppm. The standard deviation of the NH_3 concentration was 1.36 ppm. The deviation of the NH_3 concentration seemed to be relatively high, which we believe is due to the decrease in NOx concentration. To reduce NOx emissions, combustion sites, such as waste incinerator facilities install and operate SCRs and SNCRs, which reduce the production of NOx using NH_3; more specifically, they use ammonia to reduce the NOx produced. NH_3 is emitted when slip occurs during the usage of substantial amounts of ammonia to reduce NOx emissions during the processes of SCR and the SNCR. It is evident from the results of this study that the emission of NH_3 decreased with increasing concentration of NOx.

3.2. NH_3 Emission Factor at an MSW Incinerator

This study developed an NH_3 emission factor of MSW incinerators by collating the measured NH_3 concentration and data provided by the measurement facility, and the results are shown in Table 3.

Table 3. NH_3 emission factor of the investigated MSW incinerator.

NH_3 Emission Factor ($kgNH_3$/ton)	
This study	EMEP/EEA, 2006 [17]
0.0091	0.0030

The final NH_3 emission factor for MSW was determined to be 0.0091 kgNH3/ton. In the case of Europe, the NH_3 emission factor of MSW is presented in the air pollutant inventory guidebook from the European Monitoring and Evaluation Programme (EMEP)/European Environment Agency (EEA) [17]. A comparison was made between the analysis results of this study and the NH3 emission factor for MSW incinerator facilities set by the EMEP/EEA in Europe. The results of the comparison showed that the measurement-based NH_3 emission factor for MSW in Korea was approximately three times higher than that for the European EMEP/EEA, 0.0030 $kgNH_3$/ton. Therefore, we believe that there is a need for the development of an emission factor for MSW incinerator facilities that reflect the characteristics of Korea, and we believe that ammonia inventory should be included as omitted emissions sources.

3.3. NH_3 Emission Calculation According to Emission Factor Application at an MSW Incinerator

The total amount of ammonia emissions in the waste disposal field in 2016 was found to be 22 NH_3 ton/year [18]. While NH_3 emissions from MSW incinerator facilities are currently not being calculated in Korean national statistics, the emission of air pollutants excludes NH_3. Therefore, if the activity data applied to other air pollutants are utilized, NH_3 emissions can be calculated based on the application of an NH_3 emission factor. In this study, the 2016 annual combustion amount, which is the activity data used to calculate the air pollutant emission amount of MSW incinerator facilities, was used to calculate NH_3 emission amounts by applying the NH_3 emission factor. In addition, changes in the amount of NH_3 emissions in the entire waste disposal field were determined by applying the NH_3 emission amount of the MSW incinerator facilities.

The calculated result of the annual emission amount of MSW incinerator facilities based on the application of the NH_3 emission factor from this study is 22 NH_3 ton/year. This number is the same as the annual NH_3 emission amount for the entire waste disposal field in 2016, and when the NH_3 emission amounts from the MSW incinerator facilities are applied, emissions increase to 44 NH_3 ton/year. According to the results of this research, we believe that MSW incinerator facilities should be recognized as an important omitted emission source and that the development of an NH_3 emission factor and emission amount calculations should be made.

4. Conclusions

This study developed an NH_3 emission factor by measuring the NH_3 content of MSW incinerator facilities, discovered omitted emission sources by calculating emission amounts using the developed emission factor, and analyzed the need for application in inventory.

The study results show that NH_3 was also emitted from MSW incinerator facilities, and that these facilities emitted more than three times the NH_3 emission factor proposed in Europe. In addition, when NH_3 concentrations were higher, more ammonia was used in SCR and SNCR to reduce NOx due to the occurrence of slip; therefore, the concentrations of NH_3 and NOx were inversely proportional.

The emission amount calculation results obtained by applying the NH_3 emission factor based on the actual measurement show that additional NH_3, equivalent to the NH_3 emissions from the entire waste disposal field, was being emitted. Therefore, we believe that MSW incinerator facilities should be recognized as one of the major NH_3 omitted emission sources. Moreover, it is evident that there is a need for an NH_3 emission factor and emission calculations that reflect the characteristics of Korea. Ammonia emissions in this study are to determine the necessity of developing emission factors by reviewing approximate annual emissions, and representativeness was not considered.

As the emission factor was developed based on only one facility to identify the NH_3 emissions, further investigation is required on multiple facilities to improve the reliability of the proposed emission factor. In addition, we believe that the development of the emission factor will be required in the future for incineration facilities, not only for MSW, but also for industrial waste and sewage sludge. If further research on emission characteristics and uncertainty analysis of the emission factor are conducted, we believe that a more reliable basis will be provided.

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