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Development of Ammonia Emission Factor for Industrial Waste Incineration Facilities Considering Incinerator Type

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Abstract: In this study, the emission factor and concentration of ammonia from industrial waste incineration facilities were analyzed through actual measurements. The ammonia emission factor was calculated and the difference in ammonia emission factor for each type of incineration was confirmed through the Mann–Whitney U test. As a result of analyzing 279 samples, the NH₃ emission factor of the SNCR facility of stoker types was 0.012 kgNH₃/ton, and the NH₃ emission factor of the SNCR facility of the rotary kiln methods was 0.014 kgNH₃/ton. Additionally, the NH₃ emission factor of this study was higher than the NH₃ emission factor (0.003 kgNH₃/ton) suggested by Kang’s study (0.009 kgNH₃/ton) and EMEP/EEA (2006). There is a need to develop an NH₃ emission factor that takes into account the characteristics of Korea, since it is largely different from the NH₃ emission factor of EMEP/EEA. As a result of statistical analysis of the stoker type and the rotary kiln method, the null hypothesis that there is no difference between each type was adopted (p-value > 0.05), indicating that there was no statistical difference in the ammonia emission factors of the stoker type and the rotary kiln type.

Keywords: PM₂.₅ secondary sources; industrial waste incinerator; NH₃ emission factor

1. Introduction

According to the 2019 World Air Quality Report published by IQAir in 2019, 61 cities in South Korea with high concentrations of fine dust (PM₂.₅) were included in the top 100 cities affiliated to OECD member countries. Compared to 2018, 17 cities were added to the list, indicating that air pollution has not been alleviated [1].

Fine dust (PM₂.₅) can be divided into direct emissions from emission sources and indirect emissions (secondary production) from chemical reactions involving NH₃, sulfur oxides, nitrogen oxides, and volatile organic compounds. Indirect emissions account for approximately 72% of the total fine-dust emissions, and the largest emissions result from NH₃ reacting with sulfur and nitrogen oxides [2–4].

Recently, many management policies have been implemented due to the increase in PM₂.₅ concentration, and in the case of Korea, various efforts are being made, such as preparing many measures to reduce PM₂.₅ and establishing related laws.

In relation to the above, although sulfur and nitrogen oxides are relatively well-managed, NH₃ is controlled as a substance generating odor and air pollution, implying that the allowable emission concentrations are high and there is insufficient related emission control and research. Therefore, it is necessary to conduct research on NH₃ emission calculation and the development of emission factors [5–7].

Waste disposal methods include incineration, landfill, and recycling. Selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) techniques are used to re-
move nitrogen oxides, which are air pollutants emitted during incineration processes. If an excess amount of NH$_3$ is used during the process, it is emitted into the atmosphere [8–11].

However, NH$_3$ emissions are not considered when calculating the total amount of air pollutants emitted through industrial waste incineration in Korea [12]. Furthermore, as SCR and SNCR equipment are used in industrial waste incineration facilities, the development of related emission factors and emission calculations is necessary. Although studies on ammonia emission factors of MSW or sludge incineration facilities have been conducted, it has been found that no studies have been conducted on ammonia emission factors of industrial waste incineration facilities [13,14].

Therefore, this study attempted to analyze the emission concentration and develop the NH$_3$ emission factors in industrial waste incineration facilities, and to use statistical methods to calculate NH$_3$ emission factors and determine the difference in NH$_3$ emission factor for each type of incinerator.

2. Method

2.1. Selection of Objective Facilities

NH$_3$ emission factors by incinerator type in industrial waste incineration facilities were calculated by acquiring process data such as concentration, TMS (Tele-Monitoring System) data, and fuel usage. The incinerator types were classified as presented in Table 1. We selected the stoker and rotary kiln incinerators. A total of 179 samples were analyzed, of which 136 and 43 samples were obtained from the stoker and rotary kiln incinerators, respectively. Ammonia concentration measurement data are for 3 years (2017~2019).

| Waste Type     | Incinerator Type | De-Nox Facilities | Sampling |
|----------------|------------------|-------------------|----------|
| Industrial Waste | Stoker           | SNCR              | 136      |
|                | Rotary Kiln      | SNCR              | 43       |
|                | Total            |                   | 179      |

2.2. NH$_3$ Analysis in Industrial Waste Incinerators

In this study, the indophenol method, which is official method in Korea, was used to analyze the concentration of NH$_3$ [15,16]. The amount of NH$_3$ was calculated by adding sodium hypochlorite and phenol-sodium nitroprusside solutions to the sample solution, and by measuring the absorbance of the indophenols produced by the reaction with NH$_3$ ions. The NH$_3$ samples were collected by placing NH$_3$ absorption liquids (a standard boric acid solution of 50 mL that can absorb) into two volumetric flasks and using a mini pump (SIBATA MP-ΣNII, Saitama, Japan) to suck 50 L of exhaust gas for 20 min at a rate of 2.5 L/min.

A bottle filled with silica gel was installed in front of the collected NH$_3$ sample to remove moisture from the samples [17]. A schematic diagram on acquiring NH$_3$ samples is illustrated in Figure 1. The NH$_3$ concentration was determined by measuring the absorption in the absorption liquid using a spectrophotometer (Shimadzu 17A, Kyoto, Japan) with a wavelength of 640 nm.

2.3. Development of NH$_3$ Emission Factor

Mathematical formulae used in studies related to the development of NH$_3$ emission factors were referred to, and Equation (1) was used to calculate the NH$_3$ emission factors [18,19]. The NH$_3$ concentration, flow rate, and amount of waste incinerated are required to calculate the NH$_3$ emission factors of industrial waste incineration facilities.
Testing the normality of the ammonia emission concentration data, an average comparison analysis method was used that fits the normality result. The data on the amount of industrial waste were obtained through the target business site.

\[
EF_{NH_3} = \left[ C_{NH_3} \times \frac{M_w}{V_m} \times Q_{day} \times 10^{-6} \right] \bigg/ FC_{day}
\]  

where \( EF \) is emission factor (kg NH\(_3\)/ton); \( C_{NH_3} \) is NH\(_3\) concentration in flue 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 a daily amount of industrial waste (ton/day).

2.4. Statistical Analysis Method for Incinerator Type

The average distributions of the NH\(_3\) emission factor for each type of incinerator were compared to investigate whether the incinerator type of the industrial waste incineration facilities affects the NH\(_3\) emission factor. SPSS 21 was used to compare the average distributions, and the statistical procedures for comparing the average distribution of the NH\(_3\) emission factor by incinerator type are shown in Figure 2 [14]. In this study, after testing the normality of the ammonia emission concentration data, an average comparison analysis method was used that fits the normality result.

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

Figure 2. Schematic of statistics analysis.
3. Results and Discussion

3.1. NH$_3$ Emission Factors of Industrial Waste Incineration Facilities

In this study, the NH$_3$ emission factors were calculated using the NH$_3$ concentration and the data obtained from industrial waste incineration facilities, and the results are presented in Table 2. NH$_3$ emission factors of the industrial waste incineration facilities were 0.012 and 0.014 kgNH$_3$/ton for the stoker and rotary kiln incinerators, respectively.

### Table 2. NH$_3$ emission factor by type of incineration at industrial waste incinerator.

| Incinerator Type | NH$_3$ Emission Factor | N (Unit: kgNH$_3$/ton) |
|------------------|------------------------|------------------------|
| Stoker           | 0.012                  | 136                    |
| Rotary Kiln      | 0.014                  | 43                     |

Currently, there are no comparable data because the NH$_3$ emission factor for industrial waste incinerators is not calculated in Korea. Therefore, the NH$_3$ emission factor of the incineration of municipal solid waste calculated in a related study was used for comparison with the NH$_3$ emission factor listed in the EMEP/EEA (2006) of Europe [21]. As presented in Table 3, the NH$_3$ emission factors obtained in this study were observed to be higher than the values obtained by Kang et al., and the value listed in the EMEP/EEA (2006) [18,19,21].

### Table 3. Comparison of NH$_3$ emission factors at waste incinerator.

| Classification       | Waste Type | Incinerator Type | NH$_3$ Emission Factor (Unit: kgNH$_3$/ton) |
|----------------------|------------|------------------|---------------------------------------------|
| This study           | Industrial Waste | Stoker          | 0.012                                      |
|                      |             | Rotary Kiln      | 0.014                                      |
| Kang et al. (2020)   | MSW         | Stoker           | 0.009                                      |
| EMEP/EEA (2006)      | MSW         | -                | 0.003                                      |

3.2. Normality Test for NH$_3$ Emission Factors of Industrial Waste Incineration Facilities

The normality of the data must be tested for statistical analysis of the calculated NH$_3$ emission factors. The K-S test is typically used if there are more than 2000 datapoints, whereas the Shapiro–Wilk test is used if there are less than 2000 [22,23].

The normality of the data can be determined by assuming the null hypothesis that states the population is normally distributed. If significance is >0.05, a normal distribution is assumed; however, if significance is <0.05, the null hypothesis is rejected, and the population distribution is considered non-normal.

A statistical program (SPSS 21) was used in this study, and the Shapiro–Wilk method was used to determine the normality because the number of samples for each type of waste incinerator was less than 2000 [22,23]. Normality test results showed that the values obtained for both the stoker and rotary kiln incinerators used in the incineration of industrial waste had a significance of less than 0.05, indicating that they do not follow a normal distribution, and the results are presented in Table 4.

### Table 4. The result of normality test on NH$_3$ emission factor data by incinerator type at industrial waste incinerators.

| Normality Test Result | Shapiro–Wilk |
|-----------------------|--------------|
|                       | Statistic    | Degrees of Freedom, Df | Sig.     |
| Stoker                | 0.948        | 136                     | 0.000    |
| Rotary Kiln           | 0.808        | 43                      | 0.000    |
3.3. Mann–Whitney U Test of NH₃ Emission Factor by Incinerator Type

The normality test results of the NH₃ emission factors by incinerator type showed that all distributions were non-normal. Therefore, the difference between the two groups was determined using the Mann–Whitney U test, typically used when normality is not met, and the results are presented in Table 5.

Table 5. The result of Mann–Whitney U test by NH₃ emission factor by industrial waste incinerator type.

| Incinerator Type | Mean ± SD | Z    | p-Value |
|------------------|-----------|------|---------|
| Stoker SNCR      | 0.012 ± 0.006 | -1.374 | 0.169   |
| Rotary Kiln SNCR | 0.014 ± 0.016 |       |         |

The analysis results showed that significance was >0.05, indicating that the null hypothesis that states “there is no difference in NH₃ emission factors between the two incinerator types” was accepted. Thus, there is no difference in NH₃ emission factors between the stoker and rotary kiln types.

4. Conclusions

In this study, NH₃ emission factors were calculated for two types of incinerator used in industrial waste incineration facilities in Korea, as NH₃ emission factors are currently not applied, and the statistical difference between the two emission factors obtained was analyzed.

Based on the classification of industrial waste incinerators, the NH₃ emission factors were calculated for the stoker and rotary kiln incinerators, and all facilities were investigated using SNCR equipment. A total of 179 samples were acquired, of which 136 and 43 samples were from the stoker and rotary kiln incinerators, respectively:

1. The results showed that the NH₃ emission factor of SNCR equipment in stoker incinerators was 0.012 kgNH₃/ton, whereas that for the rotary kiln incinerators was 0.014 kgNH₃/ton. Because the NH₃ emission factor of the incineration of industrial waste is not currently applied in Korea, the NH₃ emission factor of municipal solid waste incineration reported in another study was used for comparison with the NH₃ emission factor listed in the EMEP/EEA (2006) of Europe.

2. Comparison of the results showed that the NH₃ emission factors of this study were higher than those reported by Kang et al., (0.009 kgNH₃/ton) and the value stated in the EMEP/EEA (0.003 kgNH₃/ton) (2006). In particular, the NH₃ emission factor obtained in this study was vastly different from the value listed in the EMEP/EEA, which was measured abroad, indicating that the development of NH₃ emission factors needs to be conducted considering the characteristics of Korea.

3. The difference in NH₃ emission factors between the stoker and rotary kiln incinerators was analyzed statistically. The Mann–Whitney U test was used for analysis, as values for both incinerator types showed a non-normal distribution. The results showed that the null hypothesis, stating there is no difference between the two types, was accepted (p-value > 0.05), indicating that there was no statistical difference between the NH₃ emission factors of the stoker and rotary kiln incinerators.

Some of the industrial waste incineration facilities in Korea were found to use fluidized bed incinerators, but no data related to the fluidized bed incinerators were obtained in this study. Therefore, NH₃ emission of fluidized bed incinerators should be addressed in future studies, followed by statistical analysis of the differences between NH₃ emission factors among incinerator types and a determination of whether emission factors need to be developed for each type of incinerator. Furthermore, research on the calculation of NH₃ emission factors in solid waste and sewage sludge incineration facilities is expected to enhance the reliability of the NH₃ inventory in the field of waste management.
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