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A Study on the Application of an Estimated Ammonia Emission Factor Reflecting the Operating Characteristics of Open Laying Hen Houses in Korea

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Abstract: In Korea, winch curtains are used when operating open-type barns. The winch curtain method is a method of opening the curtain by taking into account the temperature, which has the characteristics of an open-type barn when used but can have the discharge characteristics of a closed-type barn when operated in an enclosed manner. In this study, the related methodologies were reviewed and measured to examine and reflect the characteristics of curtain opening in open sheds. The results of NH_3 concentration measurements showed that the average daily concentration was 5.60 ppm when operating in an enclosed state, 0.20 ppm when operating in an open state, and 0.70 ppm when operating intermittently. It was found that the operating concentration in a closed state is relatively higher than that in an open and intermittent state. Therefore, it was examined whether the characteristics of open barns differ depending on the type of operation and whether this should be taken into account when developing emission factors. The NH_3 emission factor developed in consideration of these characteristics was 0.33 kg NH_3/year/animal housing area (AP), which was similar to the emission factor developed overseas.

Keywords: open laying hen houses; ammonia; tracer gas method; emission factor

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1. Introduction

In 2013, the World Health Organization (WHO) classified particulate matter (PM) as a Group 1 carcinogen. The PM2.5 concentration in Republic of Korea increased by approximately 5% in 2023 compared to that in 2022 [1]. Ultrafine particle concentration in Republic of Korea was >5 μg/m^3 in 2022, which exceeded the WHO standard for annual concentration of ultrafine particles. Moreover, only five cities in Republic of Korea exhibited an annual average concentration of 19.7 μg/m^3 or less, which is the regulation standard for ultrafine particle concentration in Republic of Korea. This indicates that ultrafine particles still require increased management [2,3].

PM 2.5 can be divided into direct and indirect emissions based on their origin from emission sources and secondary sources through chemical reactions, respectively. Indirect emissions account for approximately 72% of total ultrafine particle emissions, thus highlighting the need for their increased management [4]. The secondary products of ultrafine particles include nitrogen oxides (NOx), sulfur oxides (SOx), volatile organic compounds, and NH_3. Among these, NOx and SOx have been studied extensively and consequently effectively managed; however, similar research on NH_3 and its management is relatively lackluster [5–7].

In 2022, NH_3 emissions in Republic of Korea were 315,975 tons, of which the agricultural sector accounted for 84%. Moreover, 92% of these NH_3 emissions from the agricultural sector were from the manure management sector [8]. In the case of manure management, NH_3 emission factors developed in Republic of Korea are used to calculate emissions for cattle and pigs, and emission factors from the European Environment Agency and US Environmental Protection Agency are used for the rest of the items [9–11]. Therefore, developing an emission factor that reflects the overall NH_3 emission characteristics of Republic of Korea is necessary. NH_3 emitted from manure management mainly comes from livestock houses. As of 2020, the number of open livestock houses in Republic of Korea was approximately seven times more than that of closed livestock houses [12], thus indicating the need to consider the characteristics of NH_3 emissions from open livestock housing while calculating the NH_3 emission factor of the corresponding manure management sector.

In Republic of Korea, NH_3 emissions from open livestock housing have been mainly measured using the chamber method [13]. Moreover, the NH_3 emission factor for cattle and pigs was developed using this method. However, in the case of this method, it is difficult to consider the actual ventilation amount in the open house, and it has disadvantages in that it is not possible to monitor ammonia emissions in real time. In addition, there is difficulty in measuring the actual livestock while they are in the barn, taking into account the breeding environment and measuring them inside [14].

In addition to the method of using a classical chamber, which is mainly used in Republic of Korea, there is the method of using a tracer gas to calculate the flow rate and then calculate the emission based on this. The tracer gas method is widely used for various purposes, but it is also used to calculate emissions from livestock activity and manure management or to develop the related coefficients. A lot of research has been conducted on what tracer gas should be used and the impact of this [15–18]. In particular, the Verification of Environmental Technologies for Agricultural Production (VERA), a multinational cooperation organization created to test and verify environmental technologies in the agricultural sector, also introduced the tracer gas method as a methodology for measuring ammonia in open-air barns and presented a protocol for relevant measurement conditions.

Since open-type livestock houses breed livestock in an open environment, it is difficult to calculate the flow rate, unlike in a closed-type barn with ventilation holes or an industrial facility with an outlet, so it is difficult to calculate the level of emissions. In the case of the tracer gas method, it can be used to calculate the emission of air pollutants in an open barn because the ventilation rate can be calculated using the difference in concentration between the inside and outside the hen house by theoretically calculating or injecting the tracer gas [19]. In addition, it is important to cooperate with farmers to conduct measurements. The tracer gas method allows measurements to be taken without entering the barn, so we chose this method because it can more easily facilitate cooperation with farmers.

In Republic of Korea, when raising livestock in an open barn, winch curtains are used together to control the breeding environment. In particular, when a winch curtain is used, the environment inside the barn may have a closed type of characteristic, so it is necessary to consider this when developing a representative NH_3 emission factor.

Therefore, in this study, the NH_3 emission factor is calculated for open laying hen houses, using the tracer gas method of the VERA test protocol, and based on these data, we will consider a method that can reflect the characteristics of the winch curtain opening and closing.

2. Methods

2.1. Selection of a Laying Hen House

The target facilities were selected to be sufficiently compliant with the protocol criteria, taking into account the measurement criteria proposed by the VERA test protocol, which are used to calculate the NH_3 emission factor of an open-range laying hen house using the tracer gas method [19].

The breeding environment of the laying hen house is described in Table 1. A target facility that raised 4000 laying hens, each weighing 1.8 kg or more and used for more than two months, was selected. These conditions fulfilled the criteria of the VERA test protocol of a minimum of 750 animals and a livestock housing use period of two months before actual measurement.

Table 1. Agronomic requirements for laying hens.

	Laying Hens (This Study)	**Laying Hens (VERA Test Protocol)**
Permitted weight range (kg)	1.8	-
Minimal period of use of the housing system	More than 2 months	2 months
Feed requirements' crude protein (CP)	16–18% CP	DK: 16–18% CP DE: 15–20% CP
Minimum number of animals	4000	750

2.2. Measurement of NH_3 and CO_2 Concentrations

The concentration of NH_3 and CO_2 was measured three times on site in Republic of Korea. The measurement period was from 2020 to 2021, with measurements taken in October 2020 and June and July 2021. Data were collected for three days during each measurement. The concentration measurement results were then used to calculate the NH_3 emission factor.

The VERA test protocol proposes the use of CO_2 or SF_6, which are relatively stable gases unaffected by ambient conditions, as tracer gases in open-range barn facilities.

The method of calculating the flow rate using CO_2 is calculated by considering the theoretical emissions generated from the animal's metabolism, such as heat and respiration, without direct gas injection.

In the case of SF_6, the flow rate is calculated by injecting this gas directly and using it as a tracer gas of this concentration. The actual gas must be injected into the barn, so the relevant settings must be carried out by actually entering the barn, which is difficult to obtain consent form the relevant farm owners. This is because farm owners are very concerned about the stress levels of the livestock. So, CO_2 was selected as the tracer gas because it has relatively few restrictions.

Furthermore, internal and external CO_2 concentrations were measured by installing a Non-Dispersive Infrared Instrument (NDIR, TSI-7525, TSI Inc., Shoreview, MN, USA), whereas internal and external NH_3 concentrations were measured using Cavity Ring-Down Spectroscopy (CRDS, G2103, Picarro Inc., Santa Clara, CA, USA). The internal NH_3 concentration was measured at five points at 2 m intervals using a multi-sampler while considering the main wind direction; meanwhile, the external concentration was measured at a point farther than 5 m, as per the recommendations by the VERA test protocol to reduce internal influence.

The poultry house measures 45 m × 6 m × 3.5 m (length × width × height) and operates with a natural ventilation system. It is equipped with winch curtains that the farm

owner adjusts based on extensive experience to maintain appropriate temperatures. Due to seasonal factors, the curtains remain fully open during summer months, completely closed during winter, and are opened and closed intermittently during spring and autumn. The laying hens are raised in three-tiered cage systems (Figure 1).

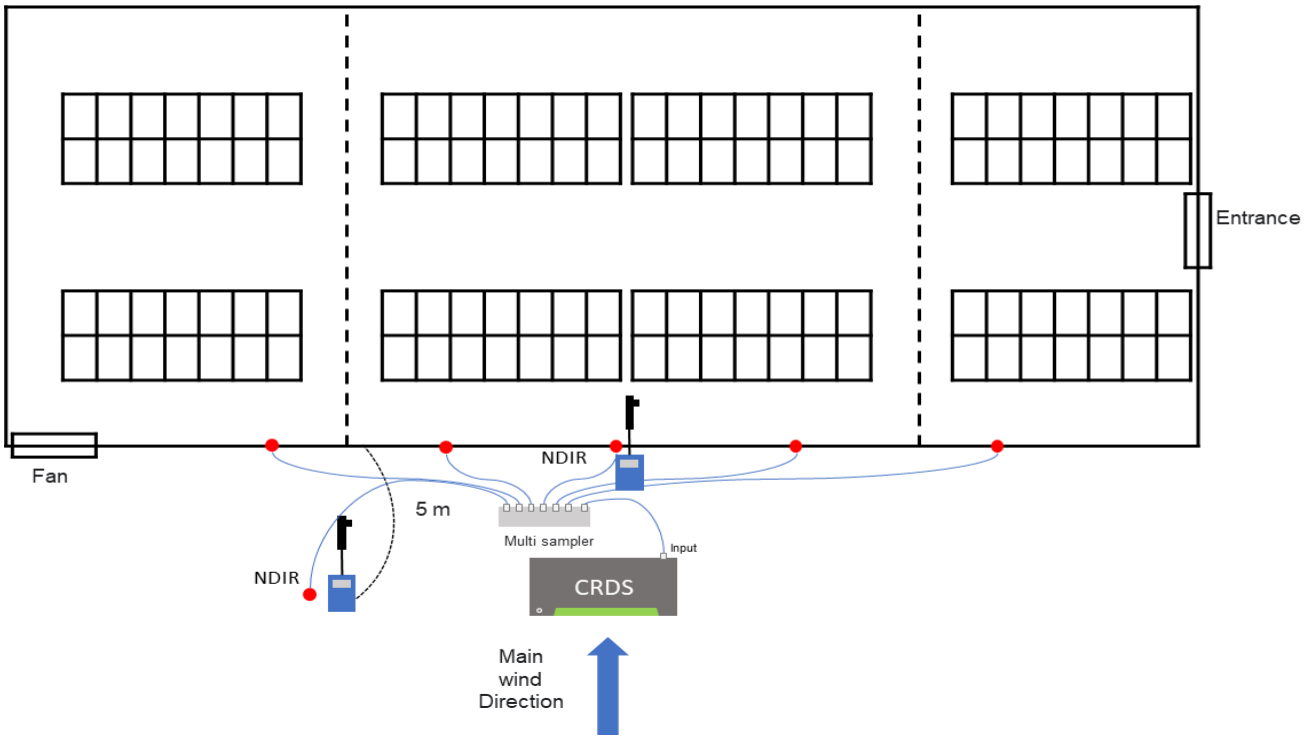


Figure 1. Schematic of NH_3 and CO_2 measurement positions at the open laying hen house.

2.3. Estimation of the NH_3 Emission Factor

The tracer gas method is used for calculating ventilation rates based on the difference between the internal and external concentrations of the target gas and the tracer gas, and it is the basis for calculating the amount of air pollutants emitted from livestock buildings. The VERA Test Protocol presents a formula for calculating ventilation rates (flow rate) by taking into account the CO_2 concentration inside the chamber when using CO_2 as a tracer gas. In the case of CO_2 concentration, both theoretical and actual values are considered. Among them, the CO_2 theoretically generated is calculated by considering the respiration and heat generation of animals, and the value and actual measurement are calculated by considering the CO_2 concentration inside and outside the hen house. In particular, reference books related to the calculation of heat generation units (HPUs) that take into account animal respiration and heat generation are also presented.

First, the ventilation rate of the livestock house was calculated using the theoretical CO_2 concentration based on the heat emissions and respiration of animals. Accordingly, the laying hens' HPU was determined, because it considers the CO_2 emissions from the metabolic processes of animals and represents the amount of heat production; thus, it can be used to calculate CO_2 emissions generated per heat production process. The HPU and ventilation rate were calculated using the formula suggested by the International Commission of Agricultural Engineering, as given in Equations (1) and (2), respectively [20].

The HPU (unit: W) is the total daily heat production per kg of laying hens in the laying hen house. The HPU of the laying hens was calculated using Equation (1) as follows:

$$HPU = N \times 6.28 \times m^{0.75} + 25 \times Y^2 \quad (1)$$

N is total number of chickens in the laying hen house, $m^{0.75}$ is weight of laying hens (kg), and Y^2 is egg production per day (kg/day).

Subsequently, the ventilation rate considering the HPU was calculated using Equation (2).

$$VR = \frac{0.185 \times HPU}{(CO_{2(inside)} - CO_{2(outside)}) \times 10^{-6}} \quad (2)$$

where VR is the Ventilation Rate (m^3/h); $CO_{2(inside)}$ is the CO_2 concentration inside the hen house (ppm); $CO_{2(outside)}$ is CO_2 concentration outside the hen house (ppm); and 0.185 is the convert coefficient (m^3/h HPU)

According to the CIGR, the CO_2 volume generated using Equation (2) is 0.185 m^3/h per HPU, which is based on the results of several experiments. The HPU and ventilation rate were calculated after sufficient theoretical verification for each livestock species. Notably, the related constants were presented only as coefficients.

Finally, the NH_3 emission factor was calculated on a yearly basis according to the standards of previous studies using Equation (3). Since VR is expressed in units of flow per hour, the emission factor was calculated by considering 24 h and 365 days in order to create an emission factor in units of years.

$$NH_{3EF} = VR \times \frac{NH_{3(inside)} - NH_{3(outside)} \times M_w}{A \times V_m} \times 24 \times 365 \times 10^{-6} \quad (3)$$

where A is the breeding head or allowable number of heads per area (AP); V_m is the Volume (integer) in the standard state of 1 mole of ideal gas = 24.45 (10^{-3} m^3/mol); $NH_{3(inside)}$ is NH_3 concentration inside in the hen house (ppm); $NH_{3(outside)}$ is NH_3 concentration outside the hen house (ppm); and M_W is the molecular weight of NH_3 (17.031 g/mol). This study used an appropriate livestock breeding criterion of 0.075 m^2/head per unit area of livestock breeding facilities for laying hens, as stipulated in the Enforcement Decree of the Livestock Industry Act of Republic of Korea.

3. Results

3.1. NH_3 Concentration in the Open Laying Hen House

Table 2 shows the measured NH_3 concentrations. The first measurement was taken in October, when the weather was cool and the winch curtains were closed. The average indoor concentration at this time was 5.6 ppm, with a maximum of 9.59 ppm and a minimum of 3.22 ppm, indicating a relatively high concentration. The second measurement period was in June, when the weather was hot, so the system was operated with the winch curtains open. The average indoor concentration during this period was 0.20 ppm, with a maximum of 0.33 ppm and a minimum of 0.10 ppm. Finally, the third measurement period was during the hot summer period, though there were also periods of rain, resulting in relatively lower temperatures. During this period, the winch curtains were closed when it rained and opened when it did not rain. During the measurement period, the facility was operated with the winch curtains were open for approximately 16 h. At this time, the average internal concentration was 0.70 ppm, with a maximum of 1.72 ppm and a minimum of 0.27 ppm. The overall average NH_3 concentration inside during the measurement period was 2.36 ppm, with a maximum of 9.59 ppm and a minimum of 0.10 ppm.

Table 2. Ammonia concentration at the open laying hen house.

Classification		NH_3 (ppm)		*n*	Operation
		In	Out		
1st	Mean	5.60	0.46	41	Closed operation of the winch curtain
	Max	9.59	0.49		
	Min	3.22	0.24		
2nd	Mean	0.20	0.17	32	Open operation of the winch curtain
	Max	0.33	0.30		
	Min	0.10	0.08		
3rd	Mean	0.70	0.31	43	Intermittent operation of the winch curtain
	Max	1.72	0.62		
	Min	0.27	0.17		
Mean		2.36	0.38		
Max		9.59	0.62		
Min		0.10	0.08		

External concentrations also showed variations depending on the operational conditions, with an overall average of 0.38 ppm, a maximum of 0.62 ppm, and a minimum of 0.08 ppm.

3.2. CO_2 Concentration in the Open Laying Hen House

The CO_2 and NH_3 concentrations were measured simultaneously to calculate the NH_3 emission factor of the open laying hen house using the tracer gas method. The corresponding measurement results are summarized in Table 3. During the first period, when the winch curtain was closed, the internal concentration averaged 746.09 ppm, with a maximum of 967.47 ppm and a minimum of 534.60 ppm. During the second measurement period, when the curtain was open, the average concentration was 487.50 ppm, with a maximum of 577. 13 ppm and a minimum of 434 ppm. During the third period of intermittent operation, the average concentration was 494.08 ppm, with a maximum of 634.50 ppm and a minimum of 494.08 ppm. The average CO_2 concentration inside the barn during the measurement periods was 709.22 ppm, with a maximum of 967.47 ppm and a minimum of 434.40 ppm. For external concentrations, the overall average was 427.07 ppm, with a maximum of 471.65 ppm and a minimum of 345.33 ppm.

Table 3. CO_2 concentration at the open laying hen house.

Classification		CO_2 (ppm)		*n*	Operation
		In	Out		
1st	Mean	746.09	457.66	41	Closed operation of the winch curtain
	Max	967.47	471.65		
	Min	534.60	438.25		
2nd	Mean	487.50	396.52	32	Open operation of the winch curtain
	Max	577.13	421.00		
	Min	434.00	369.00		
3rd	Mean	494.08	427.04	43	Intermittent operation of the winch curtain
	Max	634.50	478.25		
	Min	494.08	345.33		
Mean		709.22	427.07		-
Max		967.47	471.65		
Min		434.40	369.00		

3.3. NH_3 Emission Factor in the Open Laying Hen House

The NH_3 emission factor was calculated through Equations (1)–(3), and the ventilation rate was finally calculated through Equation (2), using the theoretical CO_2 emission calculated through Equation (1) and the actual measured CO_2 emission for laying hens' weight and egg production. The NH_3 emission factor of each open laying hen house was calculated using the tracer gas method for each measurement period and the corresponding results are summarized in Table 4. The NH_3 emission factor was the lowest (0.01 $kgNH_3$/year/AP) in the hen house when the winch curtain was open, whereas it was the highest (0.44 $kgNH_3$/year/AP) when the winch curtain was closed. Moreover, it was 0.19 $kgNH_3$/year/AP when the hen house was operated under mixed conditions, that is, the curtain was both open and closed. Hence, whether the winch curtain was open or closed influenced NH_3 concentration.

Table 4. NH_3 emission factors in relation to the operation in the open laying hen house.

Classification	NH_3 Emission Factor ($kgNH_3$/Year/AP)	Operation
1st	0.44	Closed operation of the winch curtain
2nd	0.01	Open operation of the winch curtain
3rd	0.19	Intermittent operation of the winch curtain
Mean	0.31	-

3.4. NH_3 Emission Factor in Relation to the Management of the Open Laying Hen House

Generally, when calculating emission factors based on measurements, they are developed using average values. In this study, in addition to the method of using the average value of the measurement-based average, which is widely used, we tried to reflect the characteristics according to the degree of utilization of the winch curtain used in the open-type barns mentioned earlier. The use of the winch curtain is due to the optimal breeding conditions. In the case of laying hens, if they are raised at temperatures above or below the optimal temperature, it can affect egg production and the life of the laying hen itself. Therefore, based on their previous experience, farmers raise laying hens by opening or closing the winch curtain according to whether it is cold or hot. We found that the optimal temperature for raising laying hens in the relevant previous studies was from 12 °C to 24 °C [21]. In this study, we considered the median value of the previous value (21 °C) to be the optimal temperature. When the temperature was higher than this, we assumed that the winch curtain would open to reflect these characteristics. The temperature data were applied by patterning the coefficients based on the meteorological data of the relevant region. Based on this assumption, the winch curtain in the breeding facility was open for 88 days and closed for 277 days, mainly from June to August, when the temperature was high. Therefore, the emission factor calculated by considering the operation method of the winch curtain and the emission factor calculated by using the actual measurement data as the average annual data were compared. The NH_3 emission factor of the open laying hen house, considering whether the winch curtain was open or closed, was compared with the NH_3 emission factors in other countries to assess the NH_3 emission factor based on a reference annual average value. We found that the NH_3 emission factor was 0.33 $kgNH_3$/year/AP when the characteristics of the winch curtains were reflected. This value was higher than that acquired when the conventional annual average method was used (0.23 $kgNH_3$/year/AP). The increase in the overall emission factor could be because the number of days when the winch curtain was used at the optimal breeding temperature

was higher. The emission factor calculated in this study that reflected the opening and closing characteristics of the winch curtain was found to be similar to the emission factor values of Denmark and the Netherlands. Furthermore, the emission factor of this study was slightly lower than the emission factor of CORINAIR currently applied in Republic of Korea (Table 5). Therefore, further research related to the emission factor should be conducted in the future, considering the specific characteristics of Republic of Korea by reflecting the operation conditions of closed and open laying hen houses.

Table 5. Compression of theNH_3 emission factor of the laying hen house.

Classification		Laying Hen House (kg NH_3/Year/AP)
This study	Mean annual basis	0.23
	Winch curtain characteristic basis	0.33
CORINAIR (1999) [22]		0.37
Denmark (2018) [19]		0.32
The Netherlands (2018) [19]		0.315

This study also presents some limitations. The study conducted measurements at only three times in one open laying hen house. Thus, applying and verifying the applicability of this method to more sites is necessary. Furthermore, research on other livestock species should be conducted as well. In the case of operating characteristics, further research should be conducted to standardize the opening and closing characteristics of the winch curtain and reflect these in discussing NH_3 emission characteristics, as the winch curtain is intermittently opened and closed several times a day in spring and autumn. Moreover, the characteristics of this method can be identified by surveying the related farms.

4. Discussion

This study investigated the operational characteristics of winch curtains commonly used in Republic of Korea and assessed their impact on NH_3 emission factors for open laying hen houses.

The results revealed that NH_3 concentrations varied significantly with curtain position; concentrations were highest when curtains were closed (5.60 ppm), lowest when open, and intermediate during intermittent operation. The observed concentration during closed conditions was comparable to those reported in previous studies on closed-type poultry houses in Republic of Korea(3.89–6.65 ppm) [14]. The overall average concentration of 2.35 ppm throughout the measurement period reflected the combined characteristics of open and intermittent operations. This internal concentration aligns with the measurements (0.4–4.2 ppm) reported by Hinz et al. (2010) for cages with weekly belt removal systems [23]. Although our study utilized a scraper system without bedding, the weekly manure handling schedule created conditions similar to those in previous studies, where manure was managed periodically in cages [24–27]. External NH_3 concentrations were moderately elevated compared to the typical urban atmospheric levels (0.001–0.02 ppm) reported in previous studies, likely due to the proximity (5 m) of other livestock housing areas, which was within the distance recommended by the VERA test protocol [28]. It is worth noting that these values exceeded Republic of Korea's Malodor Prevention Act limits, which restrict odor emissions at site boundaries around livestock housing to less than 1 ppm. CO_2 concentrations also exhibited variations depending on the operational conditions of the winch curtains.

The calculated ventilation rate for ammonia emission factor determination averaged 141,636 m^3/h, ranging from 15.60 m^3/h to 2,109,214 m^3/h. Pearson's correlation analysis

revealed a positive correlation (r = 0.6) between ventilation rate and ammonia emission, consistent with findings from previous studies examining this relationship in livestock barns [29–31]. The NH_3 emission factors derived in this study, which incorporated the operational characteristics of winch curtains, were comparable to those reported by VERA for facilities in the Netherlands and Denmark. This similarity may be attributed to the comparable crude protein (CP) content in feed, a factor known to influence NH_3 emissions, across the studied poultry houses. These findings suggest that developing reliable emission factors may not require continuous measurement but rather the establishment of representative standard values for different winch curtain operational periods. This approach is particularly relevant in the Korean context, where farm owners typically prefer to minimize external visitor access to their facilities, making extended monitoring challenging. Therefore, when developing emission factors, it is essential to consider these practical constraints and strategically coordinate measurements during periods when tracer gas methods can be effectively applied and pest infestations are absent, thereby ensuring the representativeness of the collected data.

5. Conclusions

In this study, the NH_3 emission factor was calculated using the tracer gas method for an open-laying hen house, and the emission factor calculation method accounted for whether the winch curtain was operated for the open hen house.

The annual average emission factors developed by considering the operating method of winch curtains used in Republic of Korea was similar to those of Denmark and the Netherlands, which are major livestock producing countries. Therefore, we confirmed that reflecting the opening and closing of winch curtains is an important method that better reflects Korean characteristics.

This study has contributed to the following research fields. We introduced the procedure for calculating NH_3 emissions and emission factors by applying the tracer gas method, which is not the primary chamber measurement method used in Republic of Korea, so that we could review the directions for expanding such research-related measurement methods in Republic of Korea. And since this method does not require entering the actual livestock facilities, we proposed a method that can persuade livestock facilities, which are difficult to cooperate with. In particular, the measurement results did not show a significant difference from the overseas level, confirming the adequacy of the relevant methodology. In addition, the report introduced a method that can reflect the operational characteristics of livestock facilities and confirmed the difference between the previously used overseas NH_3 emission factor and the existing factor in Republic of Korea, thereby discussing the need to develop a new emission factor based on the characteristics of the country and providing basic data to identify the characteristics.

However, in this study, only one open laying hen house was measured three times, so it is necessary to apply and verify this method in more places in the future. In addition, in this study, it was difficult to confirm the environmental characteristics because values of environmental data such as temperature and humidity could not be continuously obtained in a representative manner. Therefore, further research is needed to continuously obtain such data in the future.

While real-time measurement and monitoring would be the best practice, this is practically difficult to implement. Also, in the case of operating characteristics, since the winch curtain is intermittently opened and closed several times a day in spring and autumn, further study is necessary to standardize the opening and closing characteristics of the winch curtain and to reflect that in the ammonia emission characteristics. It is determined that this method can identify these characteristics through surveys of the

relevant farms. In the future, it is necessary to secure a large amount of measurement data, segmented by season, for related measurement cases and operational forms to improve the standardization and reliability of the methodology.

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