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국내 돈사 악취 방출량 측정 결과 분석

Analysis of Field Measured Odor Emission Rate in Pig Houses

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ABSTRACT

Odors emitted from pig houses have been a constant root of legal issues in pig farming. These gases are among the main causes of health and mental stresses to nearby communities, so policymakers and researchers continuously study to reduce the concentration of odorous gases from pig facilities. A continuous field experiment proved that the concentration of odor emissions inside the pig houses is highly dependent on ventilation rate, breeding details, and animal activities. However, the standard odor emission rate worldwide widely varies due to differences in pig house designs and ventilation requirements. Thus, this study aimed to measure the odor emission rates, considering the actual condition of selected Korean pig houses, through field measurement. The odor measurements were performed at three different pig production facilities without odor abatement technologies. The target experimental pig houses were buildings for weaning, growing, and fattening pigs. Results showed that the actual ventilation rate in target pig houses falls below the standard ventilation requirement of pigs, resulting in high odor concentrations inside the pig houses.

Keywords: Ammonia; complex odor; livestock emission; pig house; ventilation rate

Ⅰ. Introduction

To be able to sustain the demand for meat, livestock production is continuously enhanced and enlarged. This production intensification has led to an uncontrollable upsurge in the generated manure both domestically and globally (OECD, 2003). Data obtained from the Statistics Korea (2020), the size of breeding decreased from 8.09 million heads in 2010 to 6.49 million head in 2020. According to the Ministry of Environment (2019), here in South Korea, an estimate of 33.65 million m^3 of manure was produced in one year. Where about 53.0% of this manure generated accounted for the manure produced from the pig facilities. Specifically, those who are residing at the downwind side of the pig farms may experience health effects, discomfort and depreciation of property values due to the transport of unwanted gases that are emitted from the exhaust of pig houses (Brancher et al., 2017; AArnink et al., 2007).

Odor, which is a combination of around 150 gas components in different concentrations, is one of the main issues identified in the expansion of pig production. Traditionally, this odor is caused by the continuous microbial degradation of organic substances such as animal faeces, urine and feeds that were

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usually wasted during the feeding process. As previously mentioned, the increased breeding intensity brings increased attention to unwanted smell as these will lead to serious and offensive environmental issues. Especially, inappropriate dumping of livestock waste contributed to the increased occurrences of odor concentration from the pig farms. Therefore, an accurate estimation of odor emitted from the pig houses plays a vital role in the formulation of regulations and policies related to livestock production. According to Lim et al (2001), a correct assessment and evaluation of odor emission and other gas emissions from the pig house will provide precise data on emission rate which is an important input data for odor and gas dispersion models. This will help policymakers to suggest allowable separation distance between the farm and the nearest community to protect the residents from excessive odor exposure (Conti et al., 2020).

Presently, the estimation of the actual odor emission rate of pig house reflects other critical factors such as animal activities and ventilation rate. Depending on the region, pig growth stages and season, the odor emission rates from various countries have been standardized. For instance, European countries such as Netherlands, Germany and Denmark have published odor emission factors for different animal categories and housing systems (Vera, 2011; Denmark 2005; and VDI, 2011). Typically, the EU standard utilized the OU_E s^{-1} unit to describe the odor concentration. Unlike the European countries, the Unites States' standard defines odor emission rates in terms of dilutions to threshold ratio (D/T). Moreover, the United State odor emission rate is not unified since the legislation for odor emission will be highly dependent on each state (Bokawa, 2010). In the case of other Asian countries such as in Japan and China, specific odor emission rate for different pig stages is still not yet established but odor emission standard for various pollutants such as ammonia is already available. In addition, manuals on how to assess odorous pollutants are widely utilized. For instance, in Japan, the standard odor emission rate was evaluated by the so-called "triangular odor bag method" which utilized three sets of air samples where 1 out of 3 has an odorous compound (Japan Ministry of Environment, 1996). In China, odor emission standard for odour pollutants GB 14554-93 (CEPA, 1993) was developed and continuously improve to assess the odor pollutants. Specifically, the odor emission related to livestock sources was also published in 2001 under GB 1856-2001 (CEPA, 2001).

However, in the case of South Korea, despite having passed the legislation to reduce odor emission, recent standards published about gas emissions from pig facilities only include ammonia, hydrogen sulphide and VOCs. And since Korean standard odor emission factors were not currently available, it become more and more difficult to predict the odor emission factors from standard Korean pig houses. The unavailability of the Korean standard odor emission factors also resorted in the utilization of other international standard as an input value for numeral analysis of the odor dispersion model leading to some discrepancies between the simulated and actual odor dispersion values. This may be due to the difference between the pig house designs, feeding management, and so on. Thus, the overall aim of this paper is to present the derived estimated odor emission rate from different pig growth stages. The information obtained from this paper will be used as validation input data for the development of a multi-source odor dispersion model.

II. Material and Methods

1. Selection of the Target Experimental Farm

The selection of the pig farm where a long-term field experiment can be conducted was determined by considering various factors. Firstly, the pig farm should not have mechanical odor reduction system during the first stage of the field experiment. This is to ensure that the obtained odor concentration reflects the actual odor emission emitted by the pigs grown inside the pig facilities. Second, the pig houses where the experiment was conducted must have a mechanical ventilation. This criterion was solely based on the allowability of ventilation airflow measurement in mechanical exhaust fans. Shown in Fig. 1, is the external and internal condition of the selected pig farm considered in the study. The pig farm was located in an almost flat topography at Chungcheongbuk-do, Eumseong-gun, Samseong-myeon, Cheonpyeong-ri, South Korea (36° 58' 51 "N 127° 29' 49 "E, Elevation: 99 m). A total of 15 pig buildings were present inside the farm utilizing either sidewall or roof-chimney exhaust fans. Fig. 1a illustrates the satellite view of the experimental pig farm and the corresponding pig stage that was grown in each pig house. For the conduct of the field experiment, Buildings #1, #2 and #10

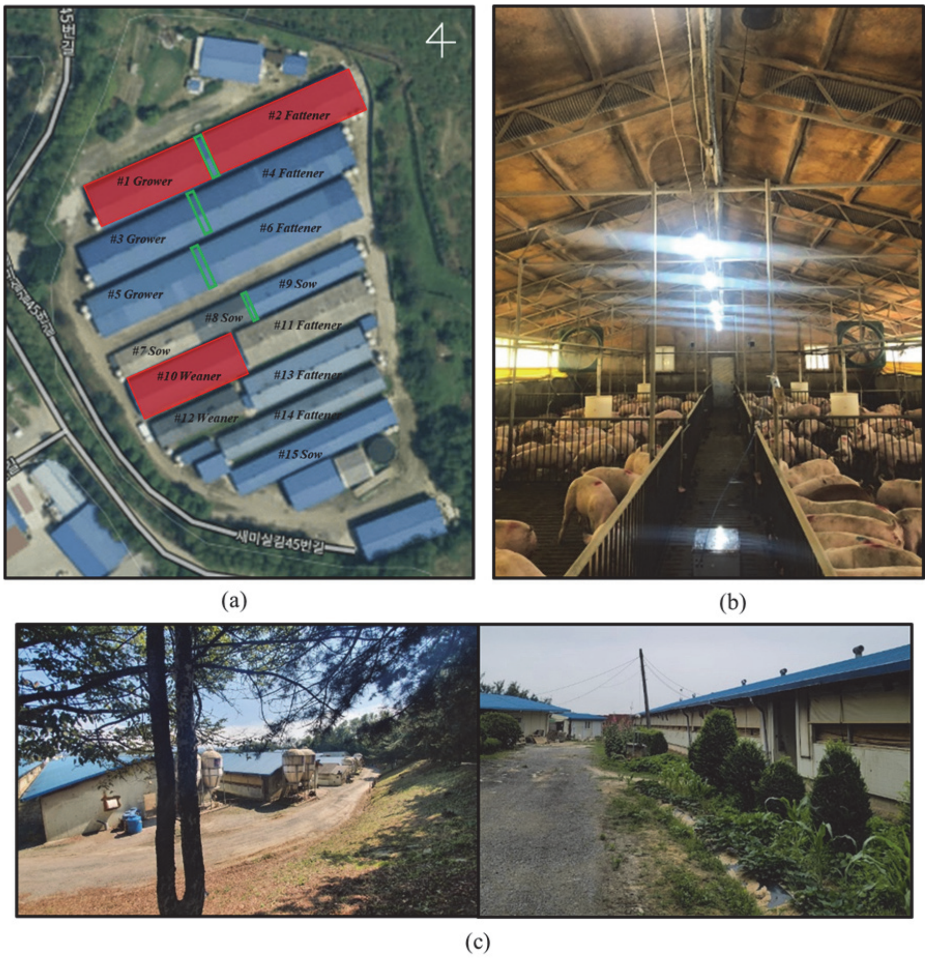

Fig. 1 a) Satellite Image of the experimental farm, b) Internal environment of Building #2, c) External environment of the target pig farm

were selected as representative experimental pig house for the derivation of odor emission factors for growing pig, fattening pigs and weaners.

Table 1 on the other hand, summarizes the specifications of the selected experimental pig houses. Building #1 houses grower pigs, Building #2 breeds fattener pigs while Building #10 houses weaners. Both Building #1 and Building #2 have an All-in-All-out breeding type. This means that pigs of a certain age were housed in that specific pig house and were moved all at once after each rearing period. Whereas for Building #10, weaners were transferred to the grower and fattening house after reaching the desired breeding weights. When compared with the Korean standard breeding density of 0.30 m^2, 0.6 m^2 and 0.90 m^2 for weaners, growers and finishers, respectively (Cho and Kim, 2011), the space allowances for growing pigs inside the target pig houses were within the allowable breeding densities. In terms of the ventilation system, all target pig houses have 300 mm diameter exhaust fans that are either installed at the roof or the sidewall. The total number of exhaust fans were summarized also in Table 1.

2. Measurements devices and procedures

The field experiment was conducted from June to December 2021 at the target experimental farm. Specifically, the collection of air samples inside the target building was done when other environmental factors (e.g. outside temperature, atmospheric stability, breeding head, building cleaning conditions, etc) that may affect the odor concentration inside and outside the experimental pig farm were almost identical. In total, about 9 set of field visits were conducted throughout the experimental period which lasted about 1 day per experimental visits. For

Table 1 Detailed specification of the target experimental pig houses

Specification	Building #1	Building#2	Building #10
Type of pig	Grower	Fatteners	Weaners
Building Specification			
Dimension (L x W)	31 m × 13 m	58 m ×13 m	29 m × 8 m
Ridge Height	4.73 m		4.40 m
Eave Height	2.86 m		2.78 m
Ventilation Specification			
Ventilation Type	Roof-chimney	Roof-chimney	Sidewall
Number of Fans	4 (300 mm Ø)	5 (300 mm Ø)	3 (300 mm Ø)

instance, prior to the conduct of the field experiment, weather conditions such as temperature and wind environment were first checked to ensure an identical environment during each measurement period. Also, wind speed and wind directions were monitored in real-time to verify the current outside wind environment.

A. Weather and other internal conditions

Several experimental devices were used to collect the needed data inside the pig farm. During the field experiment, a weather station was installed on the roof of the experimental pig farm to measure the weather environment (Fig. 2a). The weather station is a 2900ET model of Spectrum Technologies (Spectrum Technologies, Inc.,Aurora, IL, USA) is a multifunction device that can measure wind speed, wind direction, solar radiation, ambient temperature, relative humidity, and precipitation simultaneously. This device was used to monitor the above-mentioned meteorological properties during the planning of the field visit. Also, three Hobo data loggers (UX100-003, Onset computer corporation, USA) were strategically placed at the center aisle inside the target pig house to measure the real-time internal temperature and humidity of all the selected pig houses.

The ventilation rate inside the target pig houses was also carefully assessed. The measurement of the ventilation rate of each experimental pig house is a crucial factor that affects the internal environment of pig houses. This means that the ventilation condition of the specified pig house can either improve or worsen the odor emitted through the exhaust fans. A properly ventilated pig house will provide an appropriate

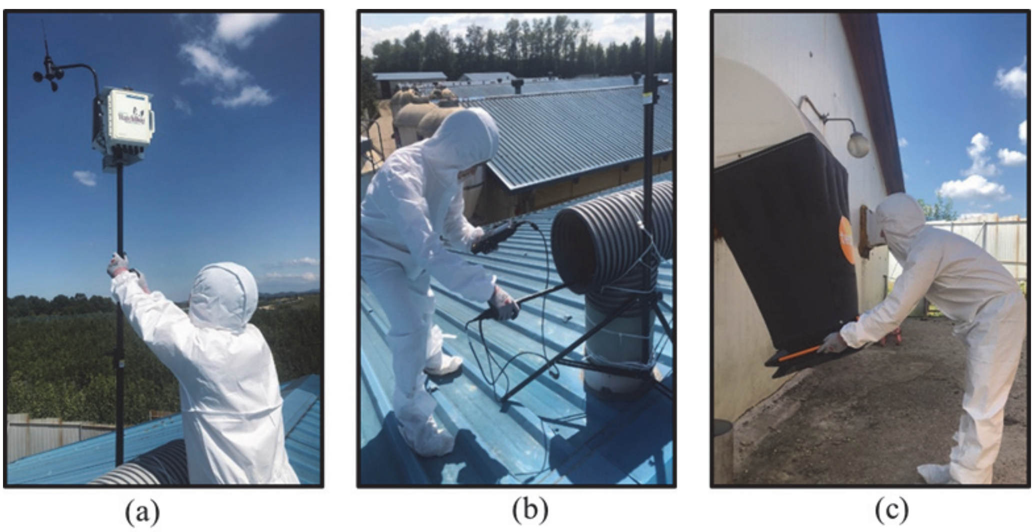

Fig. 2 Some of the devices used to measure the external and internal environment of the target pig houses a) portable weather station, b) hot-wire anemometer, c) hood-type anemometer

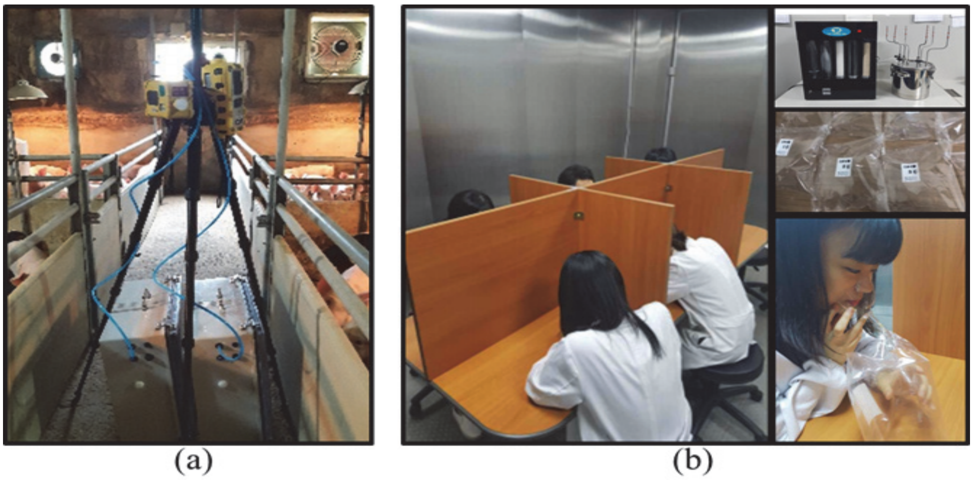

Fig. 3 a) collection of air samples inside the target pig house b) evaluation of odor concentration using olfactometry method

growing environment for the pigs and a good working environment for farm workers. In this study, TESTO manufactured sensors were used to measure the ventilation rate of the exhaust fan of each pig house. In the case of exhaust fans installed on the roof of the pig house, the high airflow (hot-wire) Testo anemometer was used while a low airflow (hood type) Testo anemometer was used to measure the airflow rate of sidewall exhaust fans as Shown in Fig. 2.

B. Odor concentration

Odor concentrations were evaluated using the standard olfactometric method. The odorous air samples were collected using a commercially available gas collector that was strategically placed inside the target pig house as illustrated in Fig. 3a. The air sample collectors were installed with 10L polyester aluminium bags (Top-Trading Corp, South Korea) where the air samples were stored and properly secured. Each of the collected air samples was carefully transported and evaluated within 24 hours after the collection. When evaluating the odor samples, the odor panel must have proper olfaction. Thus, an olfaction test kit was used to evaluate if the panel has the minimum requirements. A minimum of five panels were selected to evaluate the collected samples from the farm. The total odor concentration of the collected air samples was evaluated using EN 13725 2003 standard for air dilution olfactometry method. The scope of the EN 13725:2003 states that "This European Standard specifies a method for the objective determination of the odor concentration of a gaseous sample using dynamic olfactometry with human assessors and the emission factors of odors emanating from point sources, area sources with outward flow and area sources without outward flow. The primary application is to provide a common basis for evaluation of odour emissions in the member states of the European Union." Presently, the EN 13725 2003 guideline is the widely preferred way in most countries to evaluate the impacts caused by the different odour-emitting activities on the surrounding communities. However, this specific method can only be used in the discontinuous measurement at a specific sampling time and cannot provide information about odour quality and cannot distinguish the presence of different odors.

C. Calculation of odor emission

Since it is not sufficient to consider only the gathered odor concentration inside the target pig house, mandatory inclusion of ventilation rate which accounts for the amount of airflow inside the pig house is needed to obtain the odor emission rate (OER). As cited by Shauberger et al. (2013), the emission rate is closely related to the live mass of the pig, floor area and the number of animals grown inside each pig house. The OER which is expressed in the European odour unit per second ($OU_E\ s^{-1}$) at the target pig house is determined by multiplying the odor concentration and the total airflow rate as shown in Eq. 1 and Eq. 2. As mentioned, the ventilation rate must be evaluated in a normal olfactometry condition which includes an average outside temperature of 20 ^{o}C and pressure of 101.325 Pa based on the guidelines stated in EN 13725, 2003.

$$V_{ij} = \frac{V_{exhaust}}{n} \quad (1)$$

where V_{ij} is the ventilation rate (OU s^{-1} animal $place^{-1}$), $V_{exhaust}$ the mean ventilation rate measured in the outlet taken in test compartment (i) at day (j) (m^3 s^{-1} animal $place^{-1}$) and n is the number of pigs grown inside the pig house.

$$E_{ij} = V_{ij} \times C_{ij} \quad (2)$$

where E_{ij} is the odour emission(OU_E s^{-1} animal $place^{-1}$), V_{ij} is the ventilation rate (m^3 s^{-1} animal $place^{-1}$) and C_{ij} is the mean odour concentration in the outlet taken in test compartment (i) at day (j) (OU m^{-3})

Ⅲ. Results and Discussion

1. Details of the field experiment

Summarized in Fig. 4 are the breeding details during the conduct of the field experiment. The 1st to 9th experimental schedule written at the horizontal axis represents the date where the field experiments were conducted. As can be seen from the graphs, there are about 2 breeding periods during the conduct of the field experiments. This means that the pigs, especially those housed in Building #2 have reached the marketable weight and were disposed of. Afterwhich, a new batch of pigs was housed in the aforementioned pig house.

According to Yeo et al (2020), appropriate control of the internal environment is very crucial as the pigs exposed to unfavourable environmental conditions may increase the possibility of metabolic imbalances that may lead to reduced productivity. These appropriate internal environment control can be managed by controlling the ventilation rates inside the pig house. Based on the experiment results, the ventilation rate from the exhaust farm of each pig house was measured and summarized in Table 2. As observed, the varying amount of ventilation rate of the exhaust fans is highly dependent both on the farmer's intuition. Analysis of the measured ventilation rate showed that the actual ventilation rates inside the selected pig houses were below the MWPS-32 recommended ventilation per animal which is 3.39～25.48 CHM and 11.89～59.46 CHM during the colder season and 42.47～59.46 CHM and 127.42～203.88 CHM during hot season for weaners and fatteners, respectively. This may be caused by not providing enough number of exhaust fans as some of the fans during the conduct of the field experiments were not operational. Similarly, the external temperature gradually decreased from highest temperature of 29.1 °C on August 11 in summer to -0.4 °C temperature at the end of the experimental period. The change in ventilation rates with the change in external temperature were done by not operating only a selected number of exhaust fans during the colder season. Thus, in the hot summer season, the ventilation rate was operated at an average of 15.764 CHM and gradually decreased with the change in season (e.g. autumn to winter) reaching an average of 6,457 CHM for all the considered pig houses. For instance, the field experiment conducted from October 20 to December 2 showed that the ventilation rate at Building#1 and Building #2 decreased despite having an almost constant number of pig heads and an increased growing stage. In the case of the September 2 field experiment, Building #2 was found to have a very low ventilation rate of 7,551 CHM which is 70.0% lower compared to the

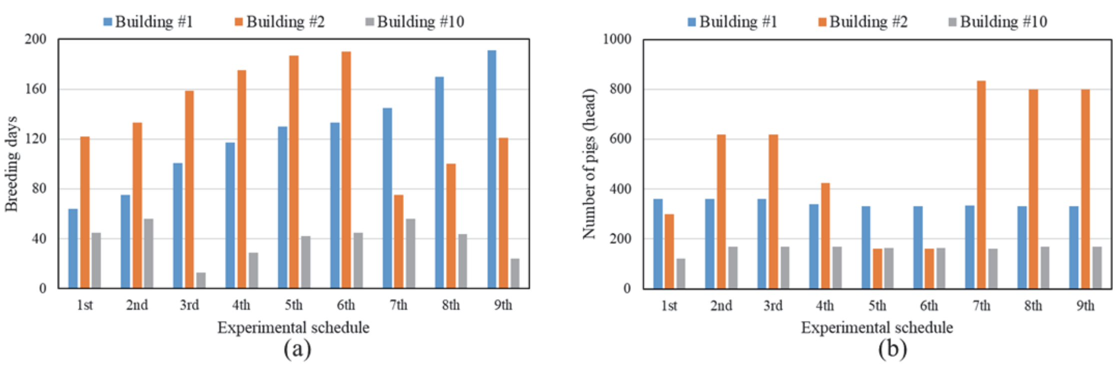

Fig. 4 Graph showing the detail of pigs such as a) number of pigs; b) growing days

Table 2 Average measured ventilation rate

Date		External temperature (℃)	Ventilation rate (m^3hr^{-1})		
			Building #1	Building #2	Building #10
30-Jun	1st	25.9	18,708	21,986	2,939
11-Aug	2nd	29.1	24,586	32,216	5,822
6-Sep	3rd	23.5	26,160	7,551	1,908
22-Sep	4th	22.6	4,779	9,954	1,287
5-Oct	5th	26.2	16,562	12,272	2,503
8-Oct	6th	18.8	8,085	6,413	1,503
20-Oct	7th	10.0	9,345	15,711	1,500
12-Nov	8th	5.9	7,200	8,788	880
2-Dec	9th	-0.4	3,349	5,822	267

*Building#1: Fatteners/ Grower; *Building#2: Fatteners/ Grower; *Building#10: Weaners

recommended ventilation rate by MWPS-32 for 424 fattening pigs.

2. Measured odor concentration

Shown in Table 3 are the evaluation results on odor concentration conducted at the target experimental farm. As mentioned previously, the odor concentration evaluation inside each pig house followed standard procedures which were done within 24 hours after the samples has been collected. In general, the measured odor concentration inside each pig house varies depending on external temperature, ventilation rate, growing period and number of heads grown in the facility. However, a general trend can be observed from the field measured data where the odor concentration inside each pig house tends to increase with the decrease in ventilation rate. For example, by comparing the odor concentration measured on August 11 and September 6, when the ventilation rate changed from 5,822 CHM to 1,908 CHM (67.2% ventilation reduction), the odor concentration for Building#10 was increased 10 times. This findings was in agreement with the result published by Shauberger et al. (2012) which states that the odor emission increases with the increase of ventilation rate. In addition, those pig houses with a higher number of pig head showed a higher odor concentration value. The average odor concentration inside the pig house was evaluated to have 298.0 OU m^{-3}, 620.7OU m^{-3} and 953.4 OU m^{-3} for pigs in Building #1, Building #2 and Building #10, respectively. Using the measured odor concentration and the measured ventilation rates, it was found that the computed odor emission factor was 26.8～66.3% lower compared to the standard odor emission factors from the European countries which ranged from 3.3 to 52.6 OUE s^{-1} animal $place^{-1}$ depending on pig stages and season. This may account to the difference in the operating condition of selected experimental farm and the commercial farm in European regions which were highly dependent on the actual environmental condition. In addition, the difference between the emission factor between the Building #1 and Building #2 has an average value of 332.7 OU m^{-3} (34.8% lower). This difference may account for the difference in the growth stage and number of housed pigs inside the facility. Using the equation described in Eq.1, the computed odor emission factor has an average of 3.00 OU s^{-1} animal $place^{-1}$ and 1.98 OU s^{-1} animal $place^{-1}$ for weaners for the hot and mild seasons, respectively. Whereas, in the case of fatteners, an average of 9.88 OU s^{-1} animal $place^{-1}$ and 7.08 OU s^{-1} animal $place^{-1}$ for the hot and mild seasons were computed.

In summary, the amount of odor concentration emitted from each experimental pig house varies through the experiment period which may account for the following reasons:

a. **Ventilation.** The ventilation rate is varying depending on the outside temperature. A reduced ventilation rate of exhaust fans will result to an increased inside odor concentration.
b. **Growing Density**. The growing density of pigs inside each pig house influenced the total odor concentration accumulated within the pig house.

Table 3 Measured odor concentration inside the selected pig houses

Date		External temperature (℃)	Odor concentration (OU m^{-3})		
			Building #1	Building #2	Building #10
30-Jun	1st	25.9	173.2	448.1	448.1
11-Aug	2nd	29.1	81.8	448.1	144.2
6-Sep	3rd	23.5	3107.0	1442.0	1442
22-Sep	4th	22.6	310.7	208.0	7.1
5-Oct	5th	26.2	2080.0	669.0	66.9
8-Oct	6th	18.8	2080.0	310.7	144.2
20-Oct	7th	10.0	208.0	427.2	208.0
12-Nov	8th	5.9	91.9	191.0	77.5
2-Dec	9th	-0.4	448.0	1,442.0	144.0

Building#1: Fatteners/ Grower; *Building#2: Fatteners/ Grower; *Building#10: Weaners

c. **Age of pig.** There is a positive correlation between the age of the pig and the amount of odor emission generation. This means that with the increase in the age of the pig, the odor emission also increased.

Considering all of this, a direct comparison between the result of the field experiment evaluating the odor emission in pig houses is quite difficult as various parameters present within the experimental pig house are different in every experimental procedure. Nevertheless, the field-measured odor concentration obtained in this study can be used as an input value to test the accuracy of the developed dispersion models.

Ⅳ. Conclusion

The result of the field experiment on the selected pig houses showed ventilation rates lower than the suggested ventilation rate regardless of the pig growth stage. As the result, both the measured odor emission and the ammonia gas inside the pig houses were higher. Specifically, an average of 298.0 OU m^{-3} was found for weaners and 787.0 OU m^{-3} for growers/fatteners. These values were 26.8～66.3% lower compared to the European Standard for odor emission for pig. As a result, the use of actual measured odor concentration on the dispersion model for a multi-source odor emission may not be suitable. However, the field-measured values can be used as validation values to check the accuracy of the developed dispersion model. Therefore, adjusting the computed odor emission factors based on the international standard for odor emission factors and ventilation rates are recommended to be used to derive the total odor emission from other pig farms where field experiments are not possible. The result of the analysis revealed that the odor emission factor has an average of 3.00 OU s^{-1} animal $place^{-1}$ and 1.98 OU s^{-1} animal $place^{-1}$ for weaners for the hot and mild seasons, respectively. Whereas, in the case of fatteners, an average of 9.88 OU s^{-1} animal $place^{-1}$ and 7.08 OU s^{-1} animal $place^{-1.}$

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