보건학석사 학위논문

Assessment of Hydrogen Sulfide and Ammonia Concentrations in Swine, Poultry, Cattle Farms

돼지, 닭, 소 농장에서의 황화수소와 암모니아 노출 평가

2016 년 2 월

서울대학교 보건대학원

환경보건학과 산업보건전공

석 지 원

Assessment of Hydrogen Sulfide and Ammonia Concentrations In Swine, Poultry, Cattle Farms

돼지, 닭, 소 농장에서의 황화수소와 암모니아 노출 평가

지도교수 윤 충 식

이 논문을 보건학석사 학위논문으로 제출함

2015 년 11 월

서울대학교 보건대학원

환경보건학과 산업보건전공

석 지 원

석 지 원의 보건학석사 학위논문을 인준함

2015 년 12 월

위 원 장 조 경 덕 (인)

부 위 원 장 고 광 표 (인)

위 원 윤 충 식 (인)

Abstract

Assessment of Hydrogen Sulfide and Ammonia Concentration in Swine, Poultry, Cattle Farms

Jiwon Seok
Department of Environmental Health Sciences
Graduate School of Public Health
Seoul National University, Korea

Advisor Chungsik Yoon, Ph.D., CIH

Objective Livestock facilities have changed rapidly throughout history in order to pursue more favorable conditions for producing more animal products. An increased number of livestock have consequently resulted in an increased generation of animal feces. Both ammonia (NH_3) and hydrogen sulfide (H_2S) are major pollutant gases released from animal facilities and can cause chronic respiratory ocular irritation and even death at high concentrations, within a few minutes.

The purposes of this study were to assess hydrogen sulfide and ammonia concentrations in swine, poultry and cattle farms and to determine the influential factors.

Methods This study was conducted in July and August 2012, as well as throughout June, July, August, September and October 2015. Samples were collected from four swine farms. Both NH_3 and H_2S gases were present at five poultry farms and five cattle farms. Sampling was measured using direct-reading instruments at animal housing and manure facilities. This study operated agitation to perform manure treatment processing in manure facilities. Samples were measured for between 20 minutes to over 60 minutes, at 5 seconds intervals.

Results Concentrations of hydrogen sulfide and ammonia were highest at the slurry storage, while hydrogen sulfide was either not detected at all or in very low concentrations at other facilities. In animal housing, ammonia was the highest at the swine farm and the poultry farm was the second highest. Concentrations of ammonia at dairy farms and in beef cattle showed similar results. Hydrogen sulfide and ammonia numbers at most of the facilities at farms were influenced by environmental factors. Swine and poultry housing showed a correlation with type of building and dairy cattle and beef cattle farms showed a correlation with the size of animal housing. All manure facilities showed a correlation with the area.

Conclusions The concentrations of hydrogen sulfide and ammonia varied greatly depending on farm condition and their changes were affected by environmental and other factors. Therefore, hydrogen sulfide and ammonia concentrations should be controlled periodically and potential health problems should be considered in relation to individuals working on farms.

Keyword: Hydrogen sulfide, Ammonia,
Swine, Poultry, Dairy Cow, Beef cattle, Livestock, Farm

Student number: 2011-23836

Contents

List of Tables

List of Figures

1 Introduction

Due to the development and growth of the national economy, livestock feeding operations have changed from small scale family-owned operations to large scale operations in the last few decades. The feeding environment of livestock facilities has improved because they are directly related to livestock production and quality. The concentrated animal feeding operation (CAFO) system has been introduced because it is suitably able to control the feeding environment factors, such as indoor temperature and humidity (Donham et al., 1986). As the number of animals being raised in confined spaces increases, the indoor air quality could be aggravated by pollutants such as animal feces.

The feces excreted by swine, cattle and chickens have different composition and bio-degradation characteristics which have great influences on composting operations, including aeration rate, composting period, bulking agent option, odor control and product quality. (Yañez et al., 2009).

Ammonia (NH_3), carbon dioxide (CO_2), hydrogen sulfide (H_2S), and sulfur dioxide (SO_2) are among the major pollutant gases released from animal facilities. Excessive quantities of NH_3 emitted from livestock and poultry farms could have a negative impact on the environment and ecosystems. Ammonia has also been reported to relate to livestock odor annoyance and health outcomes in residential outdoor environments (Vidal et al., 2014), although it is not the main component of odorants. Hydrogen sulfide is a prominent gaseous constituent in animal buildings and manure storage (Hooser et al., 2000).

Hydrogen sulfide is considered the most dangerous gas from livestock production systems and was responsible for the deaths of many animals and farm workers at animal facilities (Beaver et al., 2007; Oester helweg et al., 2008). When manure in deep-pit is agitated by mixing during pit emptying, paramount increases in Hydrogen sulfide releases can occur (Hoff et al., 2006; Blanes-Vidal et al., 2012).

In confined spaces, such as manure storage tanks, the concentration of hydrogen sulfide may be high, even life-threatening. Previous studies have shown that a total of 77 fatalities from 56 incidents occurred in the U.S. between 1975 and 2004 (Beaver et al., 2008). In Korea, a total of 23 fatalities from 14 incidents occurred between 1998 and 2012 (KOSHA 2012; National emergency management agency 2012).

Many previous studies have been carried out to measure airborne endotoxins, dust or H_2S emissions from manure facilities such as waste treatment lagoons, manure compost spots, and slurry pits (Blunden et al., 2008; O' Shaughnessy et al., 2012; Fetra J. et al., 2015), and have investigated the comparison of airborne dust from animal housing between swine and poultry farms (Yang et al., 2014). However, the study of assessment of hydrogen sulfide and ammonia concentrations in swine, poultry and cattle has not been fully investigated.

The purposes of this study were to assess hydrogen sulfide and ammonia concentrations of animal house and manure facilities in swine, poultry, cattle farms and to determine influential factors such as temperature, RH, velocity, animal species, building structure, the number of animals, and the number of fans.

2 Methods and materials

2.1 Sampling Sites

Most animal farms have two main facilities, animal housing and manure storage facilities. There are many animals and waste products of animals, as well as automatic feeding machines. The animal housing at cattle farms was open, whilst most animal housing of swine, poultry farms was confined. Manure storage facilities are mainly composed of slurry storage and manure compost spots. Slurry storage was operated only in swine farms to keep the manure in a slurry state (a mixture of feces and urine) while manure compost storage, usually consisting of three walls, operated at all animal farms.

This study was conducted during Summer from June, through July until August in 2012, and from Jun, July, August, September and October in 2015. Samples were collected in four swine farms, five poultry farms and five cattle farms. The swine farms were composed of animal housing, slurry storage, and manure compost storage whilst poultry and cattle farms were composed of animal housing and manure compost storage. The complete sampling outline is shown in Figure 1.

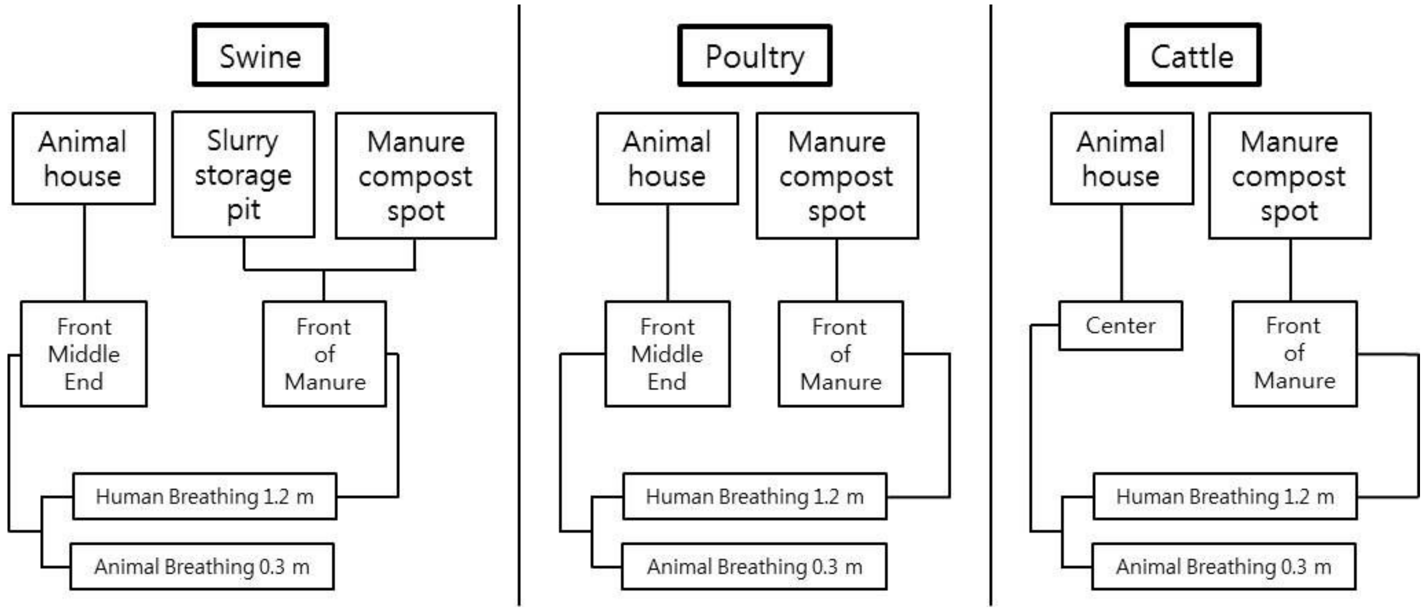

Figure 1. A Schematic diagram of gas monitoring in this study.

2.1.1 Swine farm

A swine house is a confinement structure of a pit type where fences are on both sides. Swine feed and water are supplied automatically through the fence. The floor of the swine housing was a fully slatted floor which waste falls through (Figure 2). When the pit is full, waste is moved to the slurry storage through a pipe or a pump.

Slurry storage is a type of confinement tank, or a type of open pit, and the size is dictated by the volume of manure. Manure in the slurry storage moves to water treatment process facilities periodically, when tank is filled with slurry.

All the manure compost storage containers are open, and dry manure in the slurry storage is moved to the manure compost storage.

2.1.2 Poultry farm

Poultry housing takes the form of a long rectangle. Most modern farms use confined buildings and are equipped with big fans behind the buildings (Figure 2). The feeding system is equipped with 3 or 4 lines which supply poultry feed and water automatically. The floors are covered with sawdust which is changed on a monthly basis.

Manure from poultry houses is small in quantity, and is distributed over a nearby field or moved to waste treatment facilities. That being so, poultry farms rarely have manure compost storage. For this study, only 2 farms among 5 had manure compost storage.

2.1.3 Cattle farm

There are two main classes of cattle housing, those being dairy cattle and beef cattle. These are the biggest size for the number of animals. The feeding system of cattle housing is a manual system, different from the other two animal farms. Most cattle housing is a hallway with feeding done by workers. However, the watering systems are done automatically in cattle housing. Dairy cattle housing is composed of wide open space. Furthermore, beef cattle housing is classified by the age of the cattle.

Most cattle housing is built on cement floor which is covered with sawdust. Cattle housing usually leads into the manure compost storage. When cattle waste mixed with the sawdust, piles up, it is moved to the manure compost storage by a skid loader. The manure compost storage on cattle farms is usually an open building. Cattle waste also serves well as fertilizer for fields.

Figure 2. Examples of Swine farm (a), Poultry farm (b), Cattle farm (c).

2.2 Sampling methods

Sampling was measured using direct-reading instruments in animal housing and at manure facilities. This study agitated the manure to perform treatment processing in manure facilities.

The study used portable multi-gas monitors (Model PGM6208, RAE System, USA) which could measure ammonia and hydrogen sulfide simultaneously, hydrogen sulfide from 0 to 1,000 ppm, resolution 0.1 ppm and ammonia sensor with a range from 0 to 100 ppm, resolution 1 ppm. Before the sampling operation, the instruments were calibrated using standard gas (25 ppm in NH3, RIGAS, KOREA, 10 ppm in H2S, CALGAZ, USA). Samples were measured for from 20 minutes to more than 60 minutes at 5 seconds intervals.

Temperature and RH were recorded by an Indoor Air Quality Meter (Model 7545, TSI Inc., USA). Air velocity was recorded by an Air Velocity Meter (Model 9555, TSI Inc., USA).

2.2.1 Animal Houses

All samples in animal housing were measured at the heights of the human breathing zone (1.2-1.5 m), and the animal breathing zone (0.2-0.3 m). Swine housing was measured at 1/3 spot, center of the building. Poultry housing was measured at 1/3 spot, center, 2/3 spot of the building. Dairy cattle housing was measured at center of the building and beef cattle housing was measured at the front of the calf fence, and the front of the rearing calf fence.

All fans were operating in the animal housing. Each animal housing has a different number of fans and had installed the fan at different positions.

2.2.2 Manure Facilities

Sampling was measured for 15 minutes to 60 minutes at a distance of 1.2 m-1.5 m from manure. Slurry storage was measured at the entrance using tygon tube. To investigate the highest concentration during manure management processing, agitation was implemented.

2.3 Statistical analysis

The Kolmogorov-Smirnov test was used to determine the data normality. All data was positively skewed, and all of the direct-reading data was adapted to a log-normal distribution. Simple linear regression analyses were conduct to determine the effects of the environmental factors on the hydrogen sulfide and ammonia concentrations and multiple regression coefficients were used to identify the association between concentrations of hydrogen sulfide, ammonia and environmental factors, as well as influential factors such as the number of animal, the number of fans, the size of facilities and the type of buildings in the animal housing.

All statistical analyses were performed by SPSS version 20.0 (IBM Inc., USA)

3 Results

3.1 Characteristics of each livestock farm

Table 1 summarizes the general information about the animal farms in this study. The number of poultry is the highest among the three animals and the animal housing of the poultry and swine farms were confined except for farm G. On the other hand, cattle housing (two from a dairy cattle farm, three from a beef cattle farm) were all open manure compost storage buildings.

Sampling was measured in ten animal housing units (two swine housing units, five poultry housing units, two dairy cattle units and three beef cattle units) , two slurry storage units and eleven manure compost storage units (four swine farms, two poultry farms, two dairy cattle farms and three beef cattle farms).

Table 1. Summary of animal farms facilities characteristics

Type of Animal	Farm	Sampling Area	Type of Building	Area	No. of Animals	Type of Ventilation	No. of Fans	Sampling Spot	
Swine	A	Slurry Storage Tank	Confinement	180 m^3	2,500	Natural	-	Front of Manure	HB[1]
		Compost depot	Open	400 m^3					
	B	Slurry Storage Tank	Confinement	60 m^3	1,600	Natural	-	Front of Manure	HB
		Compost depot	Open	5.6 m^3					
	C	Animal house	Confinement	1,925 m^3	200	Mechanical	2	1/3 spot of Building Center of Building 2/3 spot of Building	HB, AB[2]
		Slurry Storage Tank	Open	320 m^3	2,500	Natural	-	Front of Manure	HB
		Compost depot	Open	180 m^3					
	D	Animal house	Partially confinement	735 m^3	200	Mechanical	5	1/3 spot of Building Center of Building	HB, AB
		Slurry Storage Tank	Open	1,404 m^3	2,700	Natural	-	Front of Manure	HB
		Compost depot	Open	540 m^3					
Poultry	E	Animal house	Confinement	4,050 m^3	26,000	Mechanical	10	1/3 spot of Building Center of Building 2/3 spot of Building	HB, AB
		Compost depot	Open	299 m^3		Natural	-	Front of Manure	HB

Type of Animal		Farm	Sampling Area	Type of Building	Area	No. of Animals	Type of Ventilation	No. of Fans	Sampling Spot	
Poultry		F	Animal house	Confinement	6,750 m^3	40,000	Mechanical	16	1/3 spot of Building Center of Building 2/3 spot of Building	HB, AB
			Compost depot	Open	228 m^3		Natural	-	Front of Manure	HB
		G	Animal house	Open	2,592 m^3	18,000	Natural	2	1/3 spot of Building Center of Building 2/3 spot of Building	HB, AB
		H	Animal house	Confinement	3,240 m^3	20,000	Mechanical	9	1/3 spot of Building Center of Building 2/3 spot of Building	HB, AB
		I	Animal house	Confinement	3,240 m^3	17,000	Mechanical	5	1/3 spot of Building Center of Building 2/3 spot of Building	HB, AB
Cattle	Dairy Cow	I	Animal house	Open	11,250 m^3	200	Natural	22	Center of Building	HB, AB
			Compost depot		500 m^3			-	Front of Manure	HB
		J	Animal house	Open	6,375 m^3	145	Natural	16	Center of Building	HB, AB
			Compost depot		540 m^3			-	Front of Manure	HB
	Beef Cattle	K	Animal house	Open	3,096m^3	150	Natural	10	Calf Rearing calf	HB, AB
			Compost depot		367 m^3			-	Front of Manure	HB

Type of Animal		Farm	Sampling Area	Type of Building	Area	No. of Animals	Type of Ventilation	No. of Fans	Sampling Spot	
Cattle	Beef Cattle	L	Animal house	Open	3,160 m^3	71	Natural	11	Calf Rearing calf	HB, AB
			Compost depot		-			-	Front of Manure	HB
		M	Animal house	Open	6,213 m^3	150	Natural	15	Calf Rearing calf	HB, AB
			Compost depot		730 m^3			-	Front of Manure	HB

1) HB: Human Breathing zone, 2) AB: Animal Breathing zone

3.2 Assessment of H_2S and NH_3 concentrations in farms

3.2.1 Concentrations of H_2S and NH_3 in total facilities

Concentrations of hydrogen sulfide and ammonia across the total facilities are shown in Table 2. Concentrations of ammonia in most facilities are higher than hydrogen sulfide except in the swine housing.

Concentrations of hydrogen sulfide are the highest in swine housing, while not being detected in the whole facility at poultry farms. Peak concentrations of hydrogen sulfide and ammonia in slurry storage are the highest from all the facilities. Manure compost storage of dairy cattle and beef cattle farms detected a trace of hydrogen sulfide. However, the peak concentration of hydrogen sulfide is higher than STEL (25 ppm) at dairy cattle farms.

Concentrations of ammonia are the highest in slurry storage at swine farms, followed by manure compost storage in cattle farms and poultry housing. Peak concentration of ammonia in animal housing is at beef cattle farms.

Table 2. Concentrations of H_2S and NH_3 in animal farms

Animal	No. of Farms	Type of Building	No. of Facilities	Agitation	N	Sampling Time (min)	Concentrations(ppm) Hydrogen Sulfide AM (SD)	Hydrogen Sulfide GM (GSD)	Hydrogen Sulfide Range	Ammonia AM	Ammonia GM (GSD)	Ammonia Range	Temperature (℃) Mean±SD	Relative humidity (%) Mean±SD	Air velocity (m/sec) Mean±SD
Swine	4	Animal House	2	-	4,878	406.5	0.8 (0.5)	0.5 (4.0)	0-61	21.8 (10.9)	10.1 (8.6)	0-61	28.2±0.8	75.0±4.2	0.2±0.2
		Slurry Storage	4	Agitation	182	15.2	26.9 (37.0)	9.2 (4.5)	0.8-100≤[1)]	30.8 (28.1)	24.1 (1.8)	12-100≤	28.0±1.8	73.4±5.7	0.1±0.1
				Non-Agitation	1322	110.2	11.6 (23.5)	0.4 (17.1)	0-99.1	27.4 (30.4)	15.4 (3.1)	0-100≤			
		Manure Compost Storage	4	Agitation	189	15.8	2.1 (3.3)	0.3 (8.8)	0-13.3	12.5 (9.1)	8.3 (2.8)	1-25	29.3±4.3	66.0±11.1	0.1±0.1
				Non-Agitation	1045	87.1	0.6 (1.4)	0.1 (4.8)	0-8.4	7.4 (5.3)	5.5 (2.4)	0-23			
Total			10		7,521	626.8	3.0 (11.7)	0.5 (4.3)	0-100≤	20.7 (17.0)	13.8 (4.0)	0-100≤	28.2±3.6	69.5±10.2	0.2±0.2
Poultry	5	Animal House	5	-	14,377	1,198.6	ND[2)]	ND	ND	12.8 (8.8)	8.9 (2.8)	0-56	28.5±1.4	61.5±5.7	0.7±0.4
		Manure Compost Storage	2	Agitation	66	5.5	ND	ND	ND	15.9 (10.7)	13.4 (1.7)	7-51	26.1±1.6	65.3±7.0	No data
				Non-Agitation	680	56.7	ND	ND	ND	8.1 (3.4)	7.4 (1.5)	3-30			
Total			7		15,123	1260.3	-	-	-	12.7 (9.1)	8.8 (2.7)	0-56	28.3±1.3	61.9±6.0	0.7±0.5

Table 2. Continued

Animal	No. of Farms	Type of Building	No. of Facilities	Agitation	N	Sampling Time (min)	Concentrations(ppm) Hydrogen Sulfide AM (SD)	Hydrogen Sulfide GM (GSD)	Hydrogen Sulfide Range	Ammonia AM (SD)	Ammonia GM (GSD)	Ammonia Range	Temperature (℃) Mean±SD	Relative humidity (%) Mean±SD	Air velocity (m/sec) Mean±SD
Cattle		Animal House	2	-	1,679	139.9	ND	ND	ND	6.1 (3..8)	2.3 (4.7)	0-15	24.1±2.4	48.3±1.6	0.7±0.3
		Manure Compost Storage	2	Agitation	65	5.4.	3.1 (4.2)	0.3 (21.1)	0-19	15.7 (8.6)	13.7 (1.7)	8-33	23.6±2.1	53.8±0.9	0.1±0.1
				Non-Agitation	760	63.3	0.1 (0.8)	00.1 (2.6)	0-14.5	13.7 (6.8)	12.3 (1.6)	0-19			
	Total		4		2,504	208.7	0.1 (1.0)	0.1 (1.4)	0-19	8.6 (6.3)	6.5 (2.4)	38.4	24.0±2.3	50.5±3.0	0.5±0.4
	Beef Cattle	Animal House	3	-	8,146	678.8	ND[2)]	ND	ND	6.1 (3.8)	4.8 (2.1)	0-78.6	31.0±3.8	60.8±7.9	0.4±0.5
		Manure Compost Storage	3	Agitation	47	3.9	0.02 (0.1)	0.01 (3.5)	0-2.3	4.0 (7.0)	6.7 (3.3)	0-28.6	36.7±2.9	51.3±5.4	0.3±0.2
				Non-Agitation	1694	141.1	0.01 (0.1)	0.01 (0.1)	0	18.8 (17.4)	6.7 (4.8)	0-78.6			
	Total		6		9,887	823.9	0.001 (1.6)	0.01 (1.6)	0-2.3	13.5 (15.4)	6.0 (2.0)	0-78.6	31.2±4.2	61.2±9.2	0.4±0.5

1) Limitation of detection in ammonia sensor is 100 ppm, 2) Not detected

3.2.2 Concentrations of H_2S and NH_3 in animal house.

The average concentration of ammonia in swine housing was highest at 21.8 ppm and the poultry housing was highest at 12.8 ppm. Dairy cattle housing and beef cattle housing gave similar results of 6.1 ppm. However, peak concentration of ammonia in beef cattle housing was the highest, at 78.6 ppm.

Figure 3 presents the difference of concentrations of hydrogen sulfide and ammonia at the human breathing zone and the animal breathing zone of animal housing units.

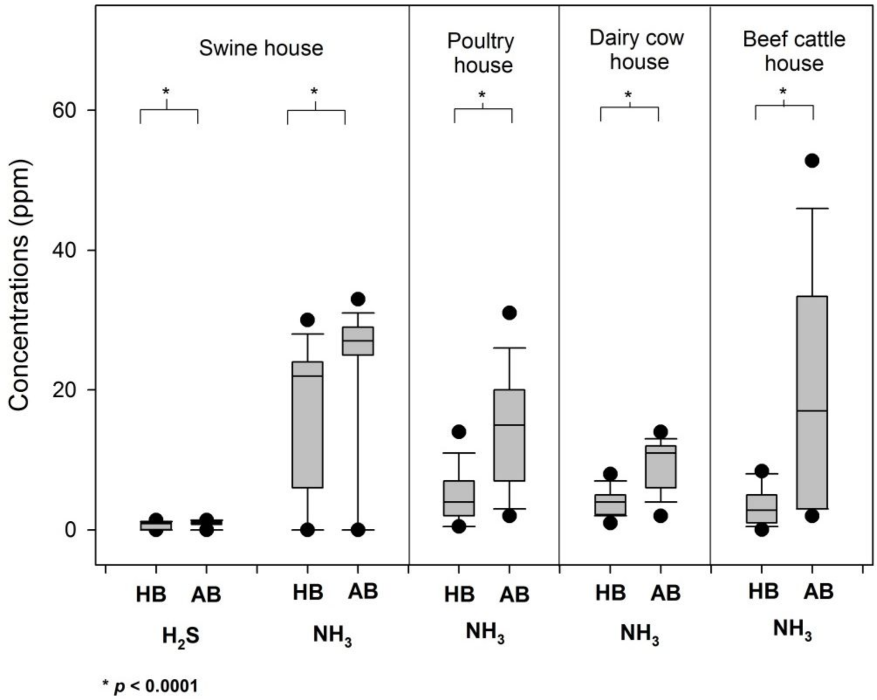

Figure 3. Concentrations of hydrogen sulfide and ammonia at human breathing zone and animal breathing zone of animal house.

3.2.3 Concentrations of H_2S and NH_3 in manure facilities

Figure 4 presents concentrations of hydrogen sulfide and ammonia in manure facilities. Concentration of hydrogen sulfide in swine slurry storage was highest at 100 ppm. However, in most manure compost storage, it was either very low or not detected at all. Hydrogen sulfide from manure compost in poultry farms (not detected), dairy cattle farms and beef cattle farms were not added in the figure.

The peak concentration of ammonia in slurry storage at swine farms was 100 ppm, which is the highest in all facilities of animal farms. The manure compost storage in beef cattle farms was the second highest, with a highest average concentration at 16.2 ppm. The lowest average concentration of ammonia was 8.2 ppm from the manure compost storage in swine farms.

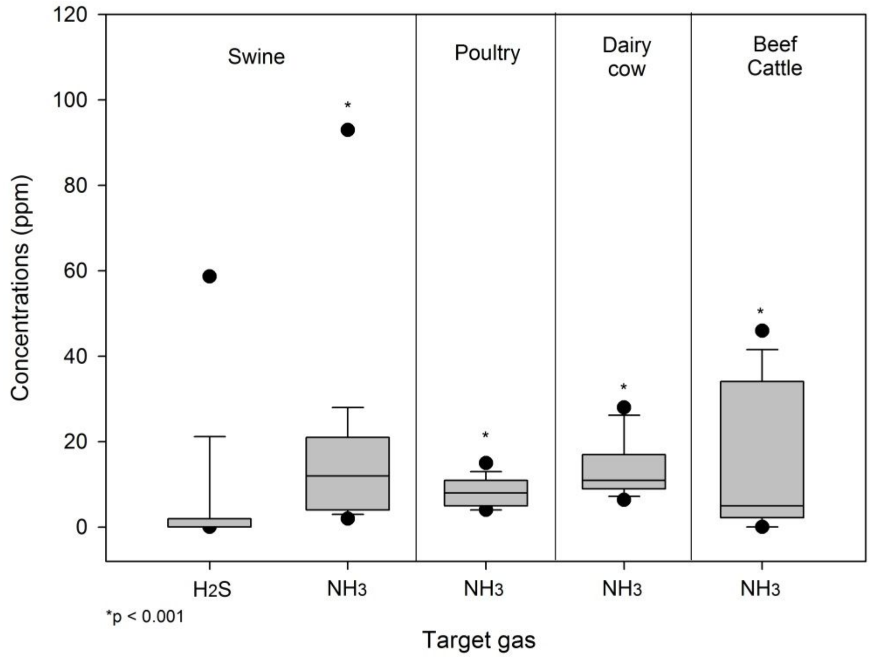

Figure 4. Concentrations of H_2S and NH_3 in manure facilities

3.2.4 Concentrations of H_2S and NH_3 different between agitation and non-agitation in manure facilities

Figure 5 presents concentrations of hydrogen sulfide and ammonia between agitation and non-agitation methods at manure facilities. When agitated at the slurry storage, the average concentration of hydrogen sulfide was 43.8 ppm, whilst when non-agitated, the average concentration was 10.7 ppm and average concentration of ammonia was 48.2 ppm, non-agitated was 26.4 ppm at the slurry storage. Ammonia did not show much difference from hydrogen sulfide.

Hydrogen sulfide was either not detected, or only at very low concentrations, at the manure compost storage in poultry, dairy cattle and beef cattle farms. Concentrations of ammonia of non-agitation were higher than agitation in the beef cattle farm because the manure with moisture began to evaporate, so ammonia level increased rapidly. The peak concentration of ammonia was 78.6 ppm.

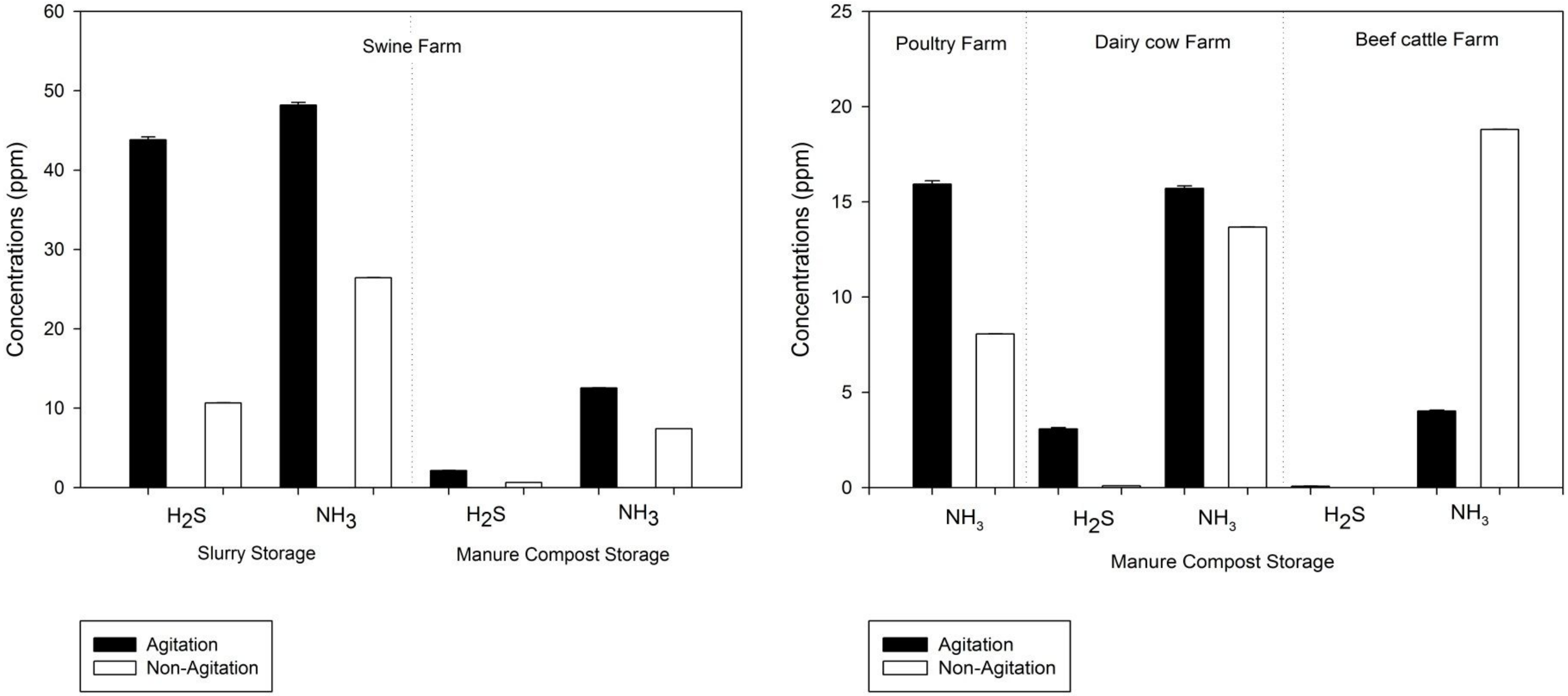

Figure 5. Concentrations of H_2S and NH_3 different between agitation and non-agitation in manure facilities.

3.3 Factors associated with H_2S and NH_3 concentrations

3.3.1 Factors associated with H_2S and NH_3 concentrations in animal house

A simple linear regression analysis was performed to determine the effect of each environmental factor on concentrations of hydrogen sulfide and ammonia in animal house (Table 3).

Hydrogen sulfide and ammonia of most farms correlated with environmental factors. Velocity was not correlated with hydrogen sulfide of swine housing ($p = 0.225$) and dairy housing ($p = 0.287$). Ammonia of the poultry ($p < 0.001$) and dairy cattle housing ($p < 0.001$) showed a negative correlation with the temperature.

Table 3. Simple linear regression analysis of the effect of environmental factors on hydrogen sulfide and ammonia at the animal house.

Farm	Target gas	Environmental Factors	β	standard error	95% CI	p-value
Swine	H_2S	Temperature	0.408	0.008	0.392 – 0.424	< 0.001**
		RH	0.086	0.001	0.083 – 0.088	< 0.001**
		Velocity	0.049	0.040	-0.030 – 0.128	0.225
	NH_3	Temperature	3.315	0.215	2.894 – 3.737	< 0.001**
		RH	1.895	0.027	1.842 – 1.949	< 0.001**
		Velocity	-2.809	0.876	- 4.526 – - 1.092	< 0.001**
Poultry	NH_3	Temperature	-0.757	0.055	- 0.864 – - 0.649	< 0.001**
		RH	0.183	0.014	0.156 – 0.211	< 0.001**
		Velocity	4.133	0.254	3.635 – 4.630	< 0.001**
Dairy Cow	NH_3	Temperature	-0.182	0.043	-0.226 – -0.099	< 0.001**
		RH	-0.198	0.056	-0.307 – -0.089	< 0.001**
		Velocity	-0.335	0.314	-0.951 – -0.282	0.287
Beef Cattle	NH_3	Temperature	2.595	0.034	2.527 – 2.662	< 0.001**
		RH	-1.485	0.014	-1.512 – -1.458	< 0.001**
		Velocity	14.591	0.300	14.004 – 15.178	< 0.001**

Table 4 shows the multiple regression analysis between hydrogen sulfide, ammonia and environmental factors and the number of animals, the number of fans, the size of animal housing and the type of building in the animal housing. Hydrogen sulfide and ammonia of most farms showed a correlation with the environmental factors.

The number of animals showed a correlation with poultry and beef cattle housing. In dairy housing there was a correlation with the size of animal housing($p < 0.001$). The type of building had a strong correlation with swine housing ($p < 0.001$). Cattle are influenced by size of animal housing ($p < 0.001$).

Table 4. Multiple regression coefficients between H_2S, NH_3 and factors in animal house

Animal	Target gas	Factors		Variable estimate	95% Confidence limit	*P*
Swine	H_2S	Temperature		- 0.153	(-0.162 -0.145)	p<0.001
		RH		- 0.077	(-0.08 -0.075)	p<0.001
		Velocity		0.06	(0.036 0.084)	p<0.001
		Type of Building[1)]	Closed	Reference		p<0.001
			Opened	-1.863	(-1.893 -1.833)	
	NH_3	Temperature		-3.522	(-3.974 -3.069)	p<0.001
		RH		1.409	(1.27 1.548)	p<0.001
		Velocity		7.118	(5.893 8.344)	p<0.001
		Type of Building	Closed	Reference		Reference
			Opened	-8.906	(-10.461 -7.35)	
Poultry	NH_3	Temperature		0.941	(0.831 1.051)	p<0.001
		RH		0.373	(0.344 0.402)	p<0.001
		No. of animal[2)]		0.01	(0.009 0.01)	p<0.001
		No. of fans[3)]		-7.427	(-7.688 -7.166)	p<0.001
		Area (m^3)[4)]		-0.037	(-0.038 -0.036)	p<0.001
		Type of Building	Closed	Reference		p<0.001
			Opened	-42.604	(-44.472 -40.736)	
Dairy Cow	NH_3	Temperature		2.140	(1.764 2.515)	p<0.001
		RH		1.438	(1.161 1.714)	p<0.001
		Velocity		-0.467	(-1.111 0.176)	p<0.001
		Area (m^3)		-0.003	(-0.004 -0.003)	p<0.001
Beef Cattle	NH_3	Temperature		9.754	(9.397 10.112)	p<0.001
		RH		-0.061	(-0.159 0.037)	p<0.001
		Velocity		6.779	(6.333 7.226)	p<0.001
		No. of animal		0.04	(0.033 0.047)	p<0.001
		Area (m^3)		0.018	(0.018 0.019)	p<0.001

* 1) Type of animal house, closed or opened

2) The number of animals in animal house

3) The number of fans in animal house

4) Size of animal house (width*length*height)

3.3.2 Factors associated with H_2S and NH_3 concentrations in manure facilities

Table 5 shows simple linear regression analysis of the effect of environmental factors on hydrogen sulfide and ammonia at the manure facilities.

In swine housing, the velocity did not have enough data for statistical analysis of hydrogen sulfide. There is no velocity data in the poultry housing. Hydrogen sulfide and ammonia from most farms showed a correlation with the environmental factors. Concentrations of ammonia in manure compost storage in dairy cattle and beef cattle showed a strong negative correlation with velocity, ($p < 0.001$) respectively. In the manure compost storage of beef cattle farms, concentrations of ammonia had a negative correlation with temperature ($p<0.001$).

Table 5. Simple linear regression analysis of the effect of environmental factors on hydrogen sulfide and ammonia at the manure facilities.

Farm	Target gas	Environmental Factors	B	standard error	95% CI	p-value
Swine	H_2S	Temperature	0.833	0.148	0.544 – 1.123	0.001
		RH	0.349	0.059	0.233 – 0.465	0.001
		Velocity	-	-	-	-
	NH_3	Temperature	1.344	0.187	0.977 – 1.711	0.001
		RH	0.186	0.076	0.036 – 0.335	0.015
		Velocity	9.044	3.978	1.227 – 16.861	0.023
Poultry	NH_3	Temperature	0.450	0.116	0.222 – 0.678	0.001
		RH	-0.075	0.026	-0.127 – -0.023	0.005
Dairy Cow	NH_3	Temperature	2.571	0.074	2.425 – 2.717	0.001
		RH	2.903	0.258	2.397 – 3.410	0.001
		Velocity	-45.583	2.866	-51.208 – -39.958	0.001
Beef Cattle	NH_3	Temperature	-1.393	0.066	-1.523 – -1.263	0.001
		RH	0.599	0.026	0.547 – 0.651	0.001
		Velocity	-15.540	2.218	-19.714 – -11.365	0.001

Table 6 shows a multiple regression analysis between hydrogen sulfide, ammonia, environmental factors and influential factors.

In manure facilities, most farms also showed a correlation with environmental factors. Hydrogen sulfide and ammonia at the swine manure facilities showed a strong negative correlation with the type of building ($p < 0.001$). The number of animals showed a correlation with gases in swine manure facilities ($p<0.001$). The size of the facilities showed a correlation with ammonia at all farms ($p < 0.001$).

Table 6. Multiple regression coefficients between H_2S, NH_3 and factors in manure facilities

Animal	Target gas	Factors		Variable estimate	95% Confidence limit	P
Swine	H_2S	Temperature		2.504	(2.208 2.799)	p<0.001
		RH		1.523	(1.418 1.628)	p<0.001
		Area (m^3) [1)]		-0.004	(-0.034 -0.029)	p<0.001
		No. of animals [2)]		-0.032	(-0.034 -0.029)	p<0.001
		Type of Building[3)]	Closed	Reference		p<0.001
			Opened	-14.01	(-15.274 -12.746)	
	NH_3	Temperature		3.78	(3.390 4.170	p<0.001
		RH		1.25	(1.111 1.388)	p<0.001
		Velocity		3.15	(-0.483 6.784)	p<0.001
		Area (m^3)		0.017	(0.015 0.02)	p<0.001
		No. of animals		-0.05	(-0.053 -0.047)	p<0.001
		Type of Building	Closed	Reference		p<0.001
			Opened	-27.951	(-29.621 -26.281)	
Poultry	NH_3	Temperature		1.264	(0.499 0.631)	p<0.001
		RH		0.393	(0.093 0.128)	p<0.001
		Area (m^3)		0.041	(1.17 1.559)	p<0.001
Dairy Cow	NH_3	Temperature		36.387	(35.862 36.911)	p<0.001
		RH		20.947	(20.624 21.271)	p<0.001
		Velocity		31.381	(30.116 32.645)	p<0.001
		Area (m^3)		-2.354	(-2.389 -2.319)	p<0.001
		No. of animals		-4.572	(-4.641 -4.502)	p<0.001
Beef Cattle	NH_3	Temperature		7.243	(6.095 8.392)	p<0.001
		RH		3.064	(2.648 3.479)	p<0.001
		Velocity		-6.435	(-10.023 -2.847)	p<0.001
		Area (m^3)		-0.007	(-0.008 -0.006)	p<0.001

* 1) Size of manure facility (width*length*height)

2) The total number of animals in farm

3) Type of manure facility, closed or opened

4 Discussion

Animal farms have various facilities that are emitted hydrogen sulfide and ammonia from the waste products of animals. This study assessed the concentrations of hydrogen sulfide and ammonia emitted from swine, poultry, dairy and beef cattle, and attempted to determine influential factors such as temperature, RH, velocity, the type of building, the number of animals, the number of fans, and the size of an area. Concentrations of hydrogen sulfide and ammonia were different at the facilities at each farm. Animal housing and the manure storage facility of swine farms was the highest and hydrogen sulfide was either not detected or only at very low concentrations among the three farms. Ammonia was higher at the manure storage facilities than the animal housing, except for at poultry farms.

Hydrogen sulfide is formed by the decomposition of organic compounds containing sulfur to sulfide in manure under anaerobic conditions. Under anaerobic conditions, bacteriologic decomposition of protein and other sulfur-containing organic matter is responsible for hydrogen sulfide production (Smithe et al., 1979). The sulfide then combines with hydrogen ions to form hydrogen sulfide. Sulfate in a swine deep-pit can come from water used for drinking or for washing the swine housing, and from feed waste or swine manure (Randy., 2010). Ammonia exists in the form of ammonium ions and free ammonia. Some of the ammonia in manure is generated from biomass by means of enzymatic and microbial activities. An ammonia molecule binds to a proton to form an ammonium ion (Ni., 1999).

The release of hydrogen sulfide depends on the components of manure. Under anaerobic conditions, the decomposition of proteins and other sulfur-containing organic matter is responsible for production of hydrogen sulfide (Smith et al., 1979), which is influenced by the pH of animal manures (Snoeyink et al., 1980), while ammonia is more influenced by temperature and air velocity than the components of manure (Srinath et al., 1974; Olesen et al., 1993; Zhang et al., 1994; Ni et al., 2000d).

Previous studies have shown that the waste emissions of main livestock species, feces of swine, poultry, dairy and beef cattle is 1.6 kg, 127.4 g, 10.1 kg, 24.6 kg per day and urine is 2.6 kg, none, 4.5 kg, 11.0 kg, respectively (National Institute of Animal Science in Korea, 2000). Unlike the other three animals, the urine of swine is heavier than feces and pit of swine housing stores a ton of manure in a slurry state (a mixture of feces and urine). Hydrogen sulfide is generated under anaerobic conditions and the urine of animals is the main component for turning it into manure under anaerobic conditions.

Slurry storage units from swine farms had the highest concentrations of hydrogen sulfide. When waste in slurry storage was agitated, the peak concentration was 100 ppm, the highest concentration of all the facilities of all the farms. Previous studies have shown a peak concentration of hydrogen sulfide, when agitated waste or working in the slurry storage (Panti et al., 2003; Hoff et al., 2006). Peak concentration of hydrogen sulfide is very dangerous, and can cause acute poisoning in people, leading to death (Lisa,. 1999; Gregg., 2007; Czeslaw., 2011). One slurry storage of four swine farms was type of a aeration tank that supplied oxygen to slurry storage. Peak concentration of hydrogen sulfide in this facility was 0.7 ppm, despite the enclosed structure. For the elimination of hydrogen sulfide from odor from animal farms, various studies have been proceeding (Jung et al., 1998; Lee et al., 2004; Yoon et al., 2009).

In poultry housing, the average concentration of ammonia was the second highest and hydrogen sulfide was not detected in any facility. This study measured gas at three points, the front, middle and end. The end spot had the highest concentrations among the three points due to the effect of fans. Concentrations of ammonia would be influenced by not only the products of poultry but also dead poultry in the poultry housing. Poultry is shipped every 30 days and the sawdust is changed at the same time. At this time, the dust level increased rapidly (Kim et al., 2014).

Waste products of cattle were the largest among all the animals, however the concentrations of ammonia were low because all cattle housing is open and the biggest among all the animal housing. In a study conducted by Ercan et al. (2012), ammonia concentrations were measured between 0.39 and 8.77 ppm. This result was similar to that of this study (average concentration 6.1 ppm). In beef cattle housing, peak concentration of ammonia was 78.6 ppm, which is the highest peak concentration among animal housing. The sampling area was mainly two spots of cattle housing, calf and rearing calf. The highest peak concentration was from breathing at the calf area. Calves usually drink water more than rearing calves, which is subsequently excreted in urine too. Thus, the floor of the calf housing was muddier than the floor of the rearing calf housing. When in light, waste products on the floor of calf house had urine evaporated and the concentration of ammonia increased. Hydrogen sulfide was not detected at the dairy cattle and beef cattle housing. These results are similar to other previous studies (Guarrasi et al., 2015; Park et al., 2015). In the manure compost storage at beef cattle farms, the average concentration of ammonia was the highest among the manure compost storage units of three animals. Because the waste products of cattle had the most amount of manure, the waste products were quickly moved to the manure compost storage.

Statistical results showed a correlation between hydrogen sulfide, ammonia and influential factors at the animal facilities respectively. Hydrogen sulfide was not compared with poultry, dairy cattle and beef cattle farms because hydrogen sulfide was either not detected or only at very low concentrations there. Animal housing was mainly influenced by the temperature and relative humidity and velocity. In previous studies, temperature and humidity were the main variables affecting the target gases in animal housing (Kim et al., 2004; Thorne et al., 2009; Ni et al., 2010; Park et al., 2015).

In swine housing, Hydrogen sulfide and ammonia was influenced by the type of building. Concentrations of hydrogen sulfide and ammonia in confined building were higher than in open buildings. Previous studies have shown that among hazard factors in confined swine buildings (Donham et al., 1990; Kafle et al., 2015; Hong et al., 2012) ammonia showed a correlation with velocity and the release of ammonia was largely affected by the airflow rate. In previous studies, convective mass transfer governed the release process of ammonia (Ni et al., 2001).

In poultry housing, ammonia concentration was influenced by the number of fans ($p<0.001$) because ventilation of all poultry farms depend on fans. Thus the more fans, the more it helps to decrease ammonia concentrations. In previous studies, mechanical ventilation systems affect gases in animal housing (Ni et al., 1999; Kim et al., 2004; Blanes-Vidal et al., 2007). Concentrations of ammonia in poultry housing were also strongly affected by type of building ($p<0.001$).

Cattle farms were also influenced by velocity ($p<0.001$). Cattle housing has a lot of fans, as cattle are the largest animals. The fans make the cattle's urine dry quickly and then the manure hardened. Previous studies showed that ammonia emission decreases over the process of time (Sommer et al., 2001). Cattle waste dried easily and quickly due to fans. However, despite the correlation between velocity and dairy cattle, beef cattle farms were the opposite ($p<0.001$). This is because dairy cattle housing had wide open spaces, except for the partition, whereas beef cattle housing was divided by the ages of the cattle. Thus, the wind from outside the farms has affected measured velocity.

Manure facilities also showed a correlation with the environmental factors. Concentrations of hydrogen sulfide and ammonia from manure facilities on swine farms had a strong negative correlation with the type of building ($p<0.001$). The most accidents happened in slurry storage confinement buildings. (Lisa., 1999; Zaba et al., 2011). Hydrogen sulfide and the ammonia from manure facilities on swine farms showed a negative correlation with the number of animals because high concentrations of gases were detected from the farm with less number of animals. Ammonia from manure facilities on beef cattle farms had a strong positive correlation with temperature and velocity ($p<0.001$). Evaporation of manure is started by high temperatures and velocity that augments the concentrations of ammonia. On dairy cattle farms, ammonia showed a negative correlation with the number of animals because the ammonia of a smaller number of animals was higher than a larger number of animals on the farm.

This study had several limitations. Firstly, a limited number of sampled animal farms could not represent all farms. Secondly, this study was unable to perform a statistical comparison between the hydrogen sulfide levels of poultry and cattle farms because most of the necessary data could not be detected on cattle farms. Thirdly, the hydrogen sulfide and ammonia concentrations at the animal farm can be affected by feed-stuff, the components of manure and the ages of animal. However, these factors are not considered in this study.

5 Conclusion

In this study, we assessed hydrogen sulfide and ammonia concentrations in swine, poultry, and cattle farms and attempted to determine influential factors such as temperature, relative humidity, velocity, size of facilities, the type of building, the number of animals, and the number of fans.

Concentrations of hydrogen sulfide were the highest at the slurry storage units, whilst at other facilities they were either not detected or only in very low concentrations. Ammonia concentrations at the slurry storage units were also the highest. In animal housing, ammonia was the highest at the swine farm and at the poultry farm, it was the second highest. Concentrations of ammonia on dairy farms and in beef cattle gave similar results. Hydrogen sulfide and ammonia ,from most of the facilities on farms, were influenced by environmental factors. Poultry and beef cattle housing showed a correlation with the number of animals, and dairy cattle and beef cattle showed a correlation with size of animal housing.

The concentrations of hydrogen sulfide and ammonia varied greatly depending on a farm's condition and by the environmental factors, among others. Therefore, hydrogen sulfide and ammonia concentrations should be monitored periodically and they should be considered as potential health risks to the individuals who work on farms.

6 References

C Zhou., T S Hurst, D W Cockcroft, J A Dosman. (1991). Increased airways responsiveness in swine farmers. *CHEST Toxicology*. 99:941-944.

C. W. Chang., H. Chung, C. F. Huang, H. J. J. Su (2001). Exposure Assessment to Airborne Endotoxin, Dust, Ammonia, Hydrogen Sulfide and Carbon Dioxide. *British Occupational Hygiene Society.* 45: 6, 457–465.

Czesław Żaba., Jerzy T. Marcinkowski, Andrzej Wojtyła., et al. (2011). Acute collective gas poisoning at work in a manure storage tank. *Annals of Agricultural and Environmental Medicine*. 18:2, 448-451.

David B. Richardson. (1995). Respiratory Effects of Chronic Hydrogen Sulfide Exposure. *American Journal of Industrial Medicine.* 28:99-108.

E Zuskin,. Z Zagar, E Neil Schachter, J Mustajbegovic, J Kern. (1992). Respiratory symptoms and ventilatory capacity in swine confinement workers. *British Journal of Industrial Medicine.* 49:435-440.

F. M. Mitloehner., M. S. Calvo. (2012). Worker Health and Safety in Concentrated Animal Feeding Operations. *Journal of Agricultural Safety and Health.* 14(2): 163-187.

Guohua Li., Haigang Li, Peter A. Leffelaar, Jianbo Shen, Fusuo Zhang. (2009). Characterization of Phosphorus in Animal Manures Collected from Three (Dairy, Swine, and Broiler). *PLoS ONE*. 9:7.

Jae-Hyun Kim., Jong-Sun Moon, Tae-Gu Lee, Choong-Hyun Choi, Jae-Heon Lee. (2004). Distributions of Air flow, Temperature and Concentration of Noxious Gases of Various Ventilation. *SAREK*. p.336-344.

James A. Zahn., Jerry L. Hatfield, Young S. Do, Alan A. DiSpirito. (2000). AIR Pollution from swine production facilities differing in waste management. *Proceedings of the Odors and Emission 2000 Conference.*

Ji-Qin Ni., Albert J. Heber, Claude A. Diehl, Teng T. Lim (2000). Ammonia, Hydrogen Sulphide and Carbon Dioxide Release from Pig Manure in Under-floor Deep Pits, Ammonia, Hydrogen Sulphide and Carbon Dioxide Release from Pig Manure in Under-floor Deep Pits. *J. agric. Engng Res.* 77(1): 53-66.

Kelley J. Donham. LOUIS J. SCALLON, WILLIAM (1986). Characterization of Dusts Collected from Swine Characterization of Dusts Collected from Swine Confinement Buildings. *American Industrial Hygiene Association Journal*. Volume 47, Issue 7

Kelley Donham., P Haglind, Yvonne Peterson, R Rylander, L Belin (1989). Environmental and health studies of farm workers in Swedish swine confinement buildings. *British Journal ofIndustrial Medicine*. 46:31-37.

Kelley J. Donham. (1990). Health Effects From Work in Swine Confinement Buildings. *American Journsl of Industrial Medicine*. 17:17-25

M. Syed, G. Soreanu., P. Falletta, M. Béland. (2006). Removal of hydrogen sulfide from gas streams using biological processes - A review. Canadian Biosystems Engineering. 48:2.1-2.14.

Nanh Lovanh., John Loughrin, Kimberly Cook, Phil Silva, Byung-Taek Oh. (2014). Effect of Windrow Management on Ammonia and Nitrous Oxide Emissions from Swine Manure Composting. *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering*. 8:6

Randy John Swestka. (2010). Hydrogen sulfide spatial distribution and exposure in deep-pit swine housing. *Iowa state university Graduate Theses and Dissertations.*

Randy L. Beaver., William E. Field. (2007). Summary of Documented Fatalities in Livestock Manure Storage and Handling Facilities-1975-2004. *Journal of Agromedicine*. 12:2, 3-23.

Stephen B. Hooser., William Van Alstine, Matti Kiupel, Janice Sojka. (2000). Acute pit gas (hydrogen sulfide) poisoning in confinement cattle. *J Vet Diagn Invest*. 12:272–275.

Steve Wing., Susanne Wolf. (2000). Intensive Livestock Operations, Health, and Quality of Life among Eastern North Carolina Residents. Environmental Health Perspectives. 108:3.

Steven J. Hoff., Dwaine S. Bundy, Minda A, Nelson, Brian C, Zelle et al. (2012). Emissions of Ammonia, Hydrogen Sulfide, and Odor before, during, and after Slurry Removal from a Deep-Pit Swine Finisher. *Journal of the Air & Waste Management Association.* 56:581–590.

Susanna G. Von Essen., Brent W. Auvermann. (2011). Health Effects from Breathing Air Near CAFOs for Feeder Cattle or Hogs. *Journal of Agromedicine.* 10:4, 55-64.

V. Blanes-Vidal. M.N. Hansen, A.P.S. Adamsen, A. Feilberg, S.O. Petersen, B.B. Jensen (2009). Characterization of odor released during handling of swine slurry: Part I.. *Atmospheric Environment.* 43, p. 2997–3005

X.-R. Dai., D. García, G.-Q. Zhang, V. Blanes-Vidal. (2012). Ammonia, carbon dioxide and hydrogen sulfur emissions from stored slurry as affected by spatial and emporally distributed slurry additions. *ASABE*. Paper Number: ILES12-0459.

X.-R. Dai., Chayan Kumer Saha, Ji-Qin Ni., et al. (2015). Characteristics of pollutant gas releases from swine, dairy, beef, and layer manure, and municipal wastewater. *water research 76*. p.110-119.

XufeiYang., Xinlei Wang, Yuanhui Zhang. (2014). Assessment of Airborne Endotoxinat the Air Exhaustof Swine and Poultry Confinement Buildings. *ASHRAE Transactions*. 120:1.

국문초록

돼지, 닭, 소 농장에서의

황화수소와 암모니아 노출평가

석 지 원

서울대학교 보건대학원

환경보건학과 산업보건전공

지도교수 윤 충 식

연구배경: 가족단위의 소규모 중심으로 이루어졌던 축산업은 경제가 발전함에 따라 대규모로 바뀌었고, 축산시설 또한 효율적인 가축생산을 위해 현대화 되었다. 가축 두 수의 증가는 가축분뇨의 증가도 함께 불러일으켰다. 가축분뇨는 시간이 지나 혐기성분해 하면서 황화수소, 암모니아 등의 유해가스들이 발생한다. 이 물질들은 동물뿐만 아니라 농장에서 일하는 작업자들에게도 건강상 유해한 영향을 끼치는데 특히 자원화 시설에서의 유해가스 농도는 매우 높아서 질식사로 까지 이어지기도 한다. 따라서 본 연구의 목적은 축산업의 주요 축종인 돼지, 닭, 소 농장에서의 황화수소와 암모니아 농도를 평가하고, 환경요인과 그 외에 요인들이 농도에 미치는 영향을 파악하고자 하였다.

연구방법: 이 연구는 2012년 8월 그리고 2015년 6부터 10월까지 돈사 4곳, 계사 5곳, 우사 5곳의 사육장과 분뇨처리 시설에서의 황화수소와 암모니아를 측정하였다. 측정은 복합가스측정기를 이용하였고, 환경인자인 온도, 습도, 풍속을 함께 측정하였다. 자원화 시설에서는 분뇨처리 작업을 재연하기 위하여 교반을 실시하였다.

결과: 돈사의 슬러리 저장조에서 황화수소와 암모니아 농도가 가장 높게 검출되었고, 사육장에서 역시 돈사가 제일 높게 검출되었다. 계사와 우사에서는 황화수소가 검출되지 않거나 극히 미량만 검출되었다. 대부분의 농장시설에서 발생하는 황화수소와 암모니아는 환경적 요인으로부터 영향을 받았다.

결론: 황화수소와 암모니아 농도는 농장환경에 따라 큰 차이를 보이며 주로 환경적 요인들에 영향을 받는다. 축사와 자원화 시설에서 발생하는 유해가스는 동물과 작업자에게 유해한 영향을 끼치며 특히 자원화 시설에서는 질식사로 이어질 수 있는 위험한 환경이므로 사전관리 및 주의가 필요하다.

주요어: 황화수소, 암모니아,
돼지, 닭, 젖소, 한우, 가축, 농장

학번: 2011-23836