Prototype of horizontal bio-trickling air scrubber (HBAS) for ammonia removal in swine farm

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Abstract. Modelling of Bio-Trickling Air Scrubber (HBAS) system is one of the methods to treat biological odor and gas emission in air treatment of manufacturing facility management. A cheaper way of efficient gas elimination is using sprinkling water in the direction of air flow in the media microbial adhesion. Samples of ammonia gas was continuously collected throughout swine production for 20 weeks. The experimental systems consisted of six different conditions by varying the amount of scrubbed water, the space between water spray and media, and the amount of media materials. Microorganism species in media, which affected to ammonia removal, were also classified. The results indicated that the highest efficiency of ammonia removal was 51.9\% at the experimental condition as follows: 1) water spray rate of turn on: turn off - 60 : 30 seconds, 2) distance between water spray and media of 1 meter, and 3) a half of media microbial adhesion area. The treated ammonia concentration was lower than the standard value of the chemical in working atmosphere as determined by the American Conference of Governmental Industrial Hygienist (ACGIH TLV), giving ammonia not more than 25 ppm. Additionally, media bio-scrubber could classify five bacteria species (\textit{Brachybacterium sp.}, \textit{Micromonospora sp.}, \textit{Methylobacterium sp.}, \textit{Rhodococcus rubber} and \textit{Cellulosimicrobium sp.}), which ammonia was used as a natural resource. The main mechanism in gas removal was proposed by the liquid adsorption, whereas the microorganism adhering to the media did not affect in statistical signification. Improvement of removal efficiency could be achieved by an increase of gas retention time in the system and the space between water spray and media.

1. Introduction
Over the past several years, the demand of pork has been increasing significantly, which has led to the higher need for pig production. At present, the large scale of pig farming has a density of 400-1,000 pigs/house and provides an impact on environmental pollution, especially air pollution due to high odors and gases. There are many sources of pollution such as feed, manure and wastewater. Directly exhausted from the house to the atmosphere without treatment results in odor’s high concentration of gases, which can have a negative effect on both health and people’s quality of life in the community near the farm. Chemical composition of pig house gas is a group of volatile organic compounds (VOCs) such as ketone, carboxylic acid, alcohol, aromatic hydrocarbon, hydrogen sulfide, methane...
and ammonia etc. [1]. Ammonia is the important air pollutant because it is a strong gas causing respiratory irritation, coughing, searing, and lethargy [2]. Global release of ammonia was found that 39% of them came from agricultural sources while 15% belong to pig production [3]. In addition, more than 50% of gas production from pig farm is ammonia [4]. The study also found that the amount of ammonia released from swine production was 79.2 g per day and concentration ranged from 649 to 3,751 mg per hour in 500 kg of live pigs [5]. The concentration measured from the house is from 5 to 18 ppm [6] and the smell of ammonia is a nuisance to the farmer and the surrounding community. At present, the improved farm management is a closed system including the house’s ventilation system that can reduce the odor problem caused by ammonia; however, but it does not solve the problem at all. The technology to tackle the odor and gases concerns from the pig house is to treat the gases released from the house. One of the most widely used technologies is the air scrubber method, which the liquid is sprayed through the air in order to drain and absorb the gas. The system of bio-trickling air scrubber is the new application of microorganisms concept that functions as gas treatment at low concentration using media to adsorb and spray water to create moisture in the media. Principles of bio-trickling system for the treatment of gases from swine house comprises of ventilation system, liquid distributor, washing water trap and packing media etc. Ogawa et al. (2011) studied the microbiological-based air cleaning system in a two-step process: 1) the process of splashing water to filter the ammonia and 2) nitrification process which changes the ammonia to nitrile by microorganism [7]. The result of ammonia removal from pig houses was 55-95%. Melse et al. (2012) studied the efficiency of ammonia removal using packed-bed bio-trickling filter from pig house [8]. The results showed that the ammonia removal efficiency was 85% with an average rate 24 g NH₃ m⁻³/h. Furthermore, mass balance between ammonia concentration in the air vented with the ammonia dissolved in water showed that nitrogen was eliminated in ammonium and nitrate form for 86% and released in nitrous oxide form for 5%. Kafle et al. (2015) studied the use of wood bark as an intermediary of biofilters to remove the ammonia and hydrogen sulfide from piglet nursery [9]. Based on the depth of media and moisture content of biofilters, the amount of water required was between 3.8-556 L/m²/d, depending on the age of pigs. This study was able to reduce the odor from ammonia and hydrogen sulfide by 73.5-76.9% and 95.2-97.9%, respectively. The optimization was found that the media should have more than 254 mm depth and 35-50% of moisture content. Heyden et al. (2015) studied the design of equipment used for air scrubbers and biofilters in animal houses, including air flow, liquid rate and intermediate layers [10]. The study revealed that installation of air scrubbers is preferable to the back of ventilation and the direction of gas flow through the middle layer with co-current and counter-current. The flow of cross-current is shorter contact time, which does not affect the efficiency of the treatment. It can be seen that the bio-trickling system may be applied as a multi-stage system to optimize odor and gas treatment [11-15]. This work is intended to develop an ammonia removal model from a pig farm with Horizontal Bio-trickling Air Scrubber (HBAS) by integrating physical treatment with air scrubber and bio-trickling, which is a new way to handle odor from pig farming in Thailand. The purposes are to decrease the smell of pig farms, grow plants with high nitrogen water, minimize the odor problems in the community and promote the environmental image of the entrepreneurs.

2. Materials and methods

2.1. Research location
Pig farm of American Market Co., Ltd. located at amphoe Phrayaeng, Chachoengsao province, Thailand was selected in this study. There are 35,000 fattening pigs with a total of 6 experimental conditions from 20 farms.

2.2. Experimental method
A study on the efficiency of ammonia treatment from pig farm using the Horizontal Bio-Trickling Air Scrubber (HBAS) was designed in a pig farm with 900-1,000 pigs per house. Daily ammonia concentration data was collected continuously throughout the pig age from entering house to capturing pigs (20 weeks of age). Water absorption coefficients for ammonia absorption and area of cross...
section of plastic media were studied. pH of ammonia (electrometric method), BOD (dilution water method) and COD (titration method) in ponds from the scrubber system were carried out. Wastewater from the pig manure was analyzed by colorimetric analysis and the colonies of isolated ammonia-decomposing bacteria from dust in the house since the first week, week 10 and week 20. The work was divided into 6 experimental groups to measure the concentration of ammonia at various points (before entering the house, out of the fan and out of the house after media) in the day. Optimum condition of scrubbing for ammonia removal was conducted by adjusting the open and closing time of water pump and the distance between nozzle and media. Type and total of deodorized microorganisms on the medium were also determined.

2.3. Designing prototype system of Horizontal Bio-trickling Air Scrubber (HBAS)

In the pig house, temperature was controlled by exchanging heat with water using cooling pad. The air was transferred from the front of the house to rear by ventilation fans with ventilation rate relating to temperature and humidity control in the house depending on the age of pig. The house was approximately 10 meters wide and 100 meters long. Ammonia gas was vented through the HBAS system at the back of the house with 8-meter length. Plastic materials used was honeycomb pads with 0.4 meters thick and 3.6 square meters of installed space as shown in Figures 1 and 2.

![Figure 1](image1.png) Design of HBAS system with 1 meter distance spray after fan.  
![Figure 2](image2.png) Design of HBAS system with 1 meter distance spray before media.

2.4. Sampling

2.4.1 Air sampling. Air samples of ammonia gas were collected from inlet air at the end of the house, before the ventilator, and air outlet from HBAS system for twice a day (9.00 am and 4.00 pm).

2.4.2 Media sampling. Dust samples were collected for analysis in three areas: left, middle, and right of the media. The samples were collected at three locations which each point depends on the size of sample areas as shown in Figures 3 and 4. Swab test was used as a technique to detect bacteria on surface. Phosphate buffer pH 7.4 was applied to sterile laboratory swab. Dust mark on the media was determined at various points throughout the area and then returned to the phosphate buffer pH 7.4.

![Figure 3](image3.png) Point of dust collector on the media.  
![Figure 4](image4.png) Experimental kit for swab sampling.
2.5. Microbiological study

2.5.1. Bacterial separation from dust samples  After collecting, separation of bacteria from swab kit by shaking with vortex mixer provided a suspension solution to count the bacteria that used ammonia as a resource.

2.5.2. Bacteria counting  Classifications of taxonomic classes of selected bacteria were studied for morphology such as colour and colonies of bacteria. Moreover, study of species levels and selected strains were analyzed for the identification of a variety of bacterial species by sequencing of 16s-rDNA.

2.6. Tools  
Aeroqual portable gas collection model ver. 200 was used to collect samples of ammonia. Analysis of water parameters from scrubber and pig manure were carried out using standard method of water and wastewater analysis.

2.7. Statistic study and translation  
Loading rate and removal efficiency (%) of ammonia were calculated using statistic of Least Significant Difference (LCD) at the confidence level of 90%.

3. Results and discussion  
The efficiency of ammonia treatment was carried out from pig farms with HBAS system at various control conditions. The study was conducted throughout the life cycle of pigs from 5 to 20 weeks with 112 days samplings. The sampling was divided into 2 areas i.e., the side of swine latrines with wastewater from house washing and workers walkaway. Two samples were collected at 9 am and 4 pm. The details of 6 experimental samples were shown in Table 1.

Table 1. A series of experiments for this research.

| Experiments | Control conditions of the experiment |  |  |
|-------------|-------------------------------------|---|---|
|             | Water spray range | Area installation of media filter | Water supply rate |
| 1           | 1 meter after ventilation fans | full area | Open 60 seconds Close 30 seconds |
| 2           | 1 meter after ventilation fans | full area | Open 30 seconds Close 30 seconds |
| 3           | 1 meter after ventilation fans | half area | Open 60 seconds Close 30 seconds |
| 4           | 1 meter after ventilation fans | half area | Open 30 seconds Close 30 seconds |
| 5           | 1 meter before media filter | full area | Open 60 seconds Close 30 seconds |
| 6           | 1 meter before media filter | full area | Open 30 seconds Close 30 seconds |
3.1. Efficiency of ammonia treatment

From collecting the data, it was found that the measuring point played a significant role in ammonia concentration. The samples in swine latrines side generated higher ammonia concentrations than the walkways in all day. As a result, the concentration of excreta from pigs, especially in the back of the house, was higher than the front of the house. It has been observed that many traces of several samples from walkway cannot be identified because the concentration was lower than detection limit. At the front of HBAS area, inlet air from walkway was mixed with the air from the latrines, therefore: the outlet air concentrations were higher than those found in walkway inside the house. Table 2 shows the efficiency of gaseous removal and the treated concentration of ammonia. It was found that the maximum ammonia treatment efficiency at sampling point of latrines was found in experimental set 3 (51.9% in the afternoon). The treated ammonia gas in all experiments showed the lower concentration than 2 ppm, which was not harmful to their community according to ACGIH TLV standard.

| Set | Sampling points | Efficiency (%) | Treated concentration (ppm) |
|-----|----------------|----------------|----------------------------|
|     | Latrines-morning | 48.1±24.6     | 1.95±1.59                  |
|     | Latrines-afternoon | 45.3±24.8 | 2.02±1.48                 |
| 1   | Corridors-morning | 34.9±33.5     | 1.26±1.08                  |
|     | Corridors-afternoon | 20.6±28.6 | 1.43±1.30                 |
|     | Latrines-morning | 48.4±25.9     | 0.83±0.57                  |
|     | Latrines-afternoon | 49.7±23.8 | 0.96±0.59                 |
| 2   | Corridors-morning | 30.5±37.1     | 0.58±0.43                  |
|     | Corridors-afternoon | 14.8±29.1 | 0.70±0.41                 |
|     | Latrines-morning | 46.9±23.4     | 0.85±0.54                  |
|     | Latrines-afternoon | 51.9±21.3 | 1.39±1.01                 |
| 3   | Corridors-morning | 26.8±32.3     | 0.62±0.40                  |
|     | Corridors-afternoon | 23.4±29.8 | 1.00±0.77                 |
|     | Latrines-morning | 44.0±29.4     | 0.67±0.69                  |
|     | Latrines-afternoon | 42.5±28.9 | 0.80±0.72                 |
| 4   | Corridors-morning | 18.7±28.7     | 0.63±0.85                  |
|     | Corridors-afternoon | 16.1±28.6 | 0.67±0.57                 |
|     | Latrines-morning | 33.0±24.6     | 0.82±0.76                  |
|     | Latrines-afternoon | 33.6±26.6 | 1.01±0.81                 |
| 5   | Corridors-morning | 8.4±16.7      | 0.67±0.70                  |
|     | Corridors-afternoon | 15.3±27.0 | 0.66±0.56                 |
|     | Latrines-morning | 38.2±29.8     | 0.67±0.55                  |
|     | Latrines-afternoon | 37.6±32.3 | 0.61±0.33                 |
| 6   | Corridors-morning | 13.5±21.4     | 0.68±0.59                  |
|     | Corridors-afternoon | 20.1±26.3 | 0.50±0.26                 |
The results also revealed that workers’ activities played a vital role in ammonia concentration. The ammonia tended to accumulate from the afternoon to evening due to pig house cleaning every morning resulting in washed away of pig manure. The overall concentration of gas was likely to increase with the age of pigs. However, the highest concentration of treated ammonia with HBAS was 6.60 ppm, which was still lower than the ACGIH TLV (2011) standard (not exceeding 25 ppm).

3.2. Water analysis from treatment system
The analysis of water from the treatment system was also considered. Two water samples were collected from scrubber system and pig manure once a week during whole 20 weeks. The samples were analyzed for pH, conductivity, COD, BOD, and ammonia. Unfortunately, there was pandemic situation in swine farm in week 12 to 15 of the experiment. Hence, it was not able to collect the sampling water for analysis every week.

3.2.1. Water samples from scrubber system. The surprising results showed that pH values were not changed during the experiment with ranged from 6 to 7 although the theory predicates that dissolved ammonia resulted in increasing pH of water. Due to the design of experiment, fresh water was constantly replenished to the system; therefore, pH of water from scrubber system did not increase. Ogawa et. al., (2011) revealed that controlling pH less than 7.5 resulted in the efficiency of ammonia removal of 55-95%. There was no correlation between the age of the pigs and the concentration of ammonia in the scrubbed water as shown in Figure 5 because of replenished water. However, BOD values were very low in experimental sets 1 to 6 which ranging from 1.00-17.0, 1.00-28.0, 1.00-17.0, 2.00-45, 1.00-27.0 and 1.00-30.0 mg/L, respectively. According to the data, it can be estimated that water from the scrubber system was less polluting and can be reused in the new system.

![Figure 5. Ammonia concentration in the sampling water from scrubber system of experimental sets 1 to 6](image)

3.2.2. Water samples from pig manure. pH values of pig manure were 6-8. The results showed that ammonia, COD, BOD and conductivity in the sampling water from pig manure were higher than scrubber system. The reason behind this is the older the pigs became, the more excreta they had. The ammonia concentrations of wastewater from pig manure in experimental sets 1 to 6 were 321-3,471, 588-1,862, 103-2,232, 387-3,361, 117-1,678 and 51.8-1,993 mg/L, respectively. This ammonia concentration had enough carbon source to use as a biogas system of the farm.
3.3. Microorganism in the medium

3.3.1. Total bacteria. The total bacteria in all samples by spread plate method on nutrient agar were determined at 3 points. It was found that the total number of bacteria in the house was equal to $2.10 \times 10^9 \pm 2.03 \times 10^9$, $3.80 \times 10^9 \pm 3.50 \times 10^9$ and $9.22 \times 10^8 \pm 9.81 \times 10^8$ CFU/mL, respectively, as shown in Figure 6. These numbers indicated the possible trend of bacteria accordance with Zhao et. al., (2011) [16] and Seedorf et. al., (1998) [17], which reported that general number of bacteria counted in swine house was between $1.00 \times 10^{11}$ and $2.00 \times 10^{16}$ CFU/mL.

![Figure 6. Total isolated bacteria from the dust in pig houses.](image)

3.3.2. Classification of taxonomic species of bacteria using ammonia as a source. The number of bacteria using ammonia as a source of food in the sample by spread plate on Burk’s N-free medium at week-0 was equal to $1.06 \times 10^5 \pm 6.61 \times 10^4$ CFU/mL. After 10 weeks, samples were collected from each house to count the number of bacteria in experimental sets 1 to 6, which was equal to $3.20 \times 10^7 \pm 3.16 \times 10^7$, $3.51 \times 10^4 \pm 1.57 \times 10^4$, $5.22 \times 10^4 \pm 5.36 \times 10^4$, $3.41 \times 10^5 \pm 5.30 \times 10^5$, $1.56 \times 10^6 \pm 9.10 \times 10^5$, and $1.38 \times 10^6 \pm 2.34 \times 10^6$ CFU/mL, respectively. After 20 weeks, the number of bacteria was $1.55 \times 10^4 \pm 1.08 \times 10^4$, $4.33 \times 10^5 \pm 5.79 \times 10^5$, $2.58 \times 10^5 \pm 2.76 \times 10^5$, $3.23 \times 10^5 \pm 5.29 \times 10^5$, $5.90 \times 10^6 \pm 9.61 \times 10^5$, and $5.19 \times 10^6 \pm 6.19 \times 10^5$ CFU/mL, respectively, as shown in Figure 7.

![Figure 7. Isolation bacteria using ammonia as food sources in each experimental set over a period of 10 and 20 weeks.](image)

For separation of bacteria using ammonia as a source by spread plate method on nutrient agar, the results showed that bacteria over 10 and 20 weeks presented different colour and bacterial colonies. At the morphological study, 10 isolates of bacteria were selected for screening to analyze the 16s rDNA nucleotide sequences in the level of species. The results were similar to the bacterial nucleotides in the database that revealed 5 specified species consisted of *Brachybacterium* sp., *Micromonospora* sp., *Methylobacterium* sp., *Rhodococcus rubber*, and *Cellulosimicrobium* sp. It was also discovered that 5 species in swine house, especially of *Brachybacterium* sp., which was investigated in poultry manure, pig manure and organic fertilizer similar to the research of Tian et. al., (2016) [18].
4. Conclusion
The study of odor and gas removal from swine houses with Horizontal Bio-trickling Air Scrubber (HBAS) system presented the average efficiency of ammonia treatment for all of experiments at 43.9%. The highest ammonia treatment efficiency was 51.9% with the following factors: opening and closing rate of water spray (60 seconds and 30 seconds, respectively), distance of head nozzle 1 meter behind the fan and a half media filter area. From the study, the main mechanism affecting the efficiency of gas removal was the absorption mechanism of gas into liquid. In addition, factors influencing the efficiency of the treatment were water spray rate and distance of the water dispenser to the media filter. Increasing water spray duration or rate was likely to result in higher efficiency. The distance of spray nozzle and media filter affected the growth and adhesion of microorganism. Although microbial degradation treatment was not the main mechanism, it also affected the removal efficiency of ammonia. The HBAS system features to promote speedy efficient on atmospheric odor treatment, and then favors to develop for animal industrial facility management in the future.

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