AMMONIA EMISSIONS FROM BROILER HOUSES AND MITIGATING TECHNOLOGIES

by

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ABSTRACT

In recent years, increased attentions have been given to ammonia (NH_3) emissions from poultry due to its environmental and health impacts. NH_3 is generated from the chemical decomposition of bird feces by certain bacteria in the litter. NH_3 was considered as a precursor to fine particulate matter (PM2.5), and the US Environmental Protection Agency (EPA) has been petitioned to regulate NH_3 as a criteria pollutant. Furthermore, NH_3 emission represents a significant loss of valuable nitrogen fertilizer. NH_3 can be deposited from the atmosphere, if excess nitrogen (N) is deposited, it may impact the ecosystem negatively. Potential environmental issues associated with exceeding N in the environment include nitrate contamination of drinking water; eutrophication of surface water bodies; vegetation or ecosystem changes due to higher concentrations of N; and soil acidification through nitrification and leaching. Several approaches have been suggested and evaluated for mitigating NH_3 emissions from concentrated animal feeding operations (CAFOs). Litter amendment can produce hydrogen irons (H^+) when it dissolves and inhibit the free NH_3 production by converting it to the ammonium (NH_4^+). The commonly used litter amendments include aluminum sulfate, sodium bisulfate, and ferric sulfate. Acid scrubber can absorb NH_3 from exhausted air emitted from CAFOs. The scrubbers usually filled with packing materials and acid solution. Acid solution is sprayed from the top of the reactor. Mass transfer occurs from gas to liquid phase when the air and solution get contact. The vegetative environmental buffer (VEBs) has been used around CAFOs as a best management practice to reduce downwind gas concentration

and emissions. Previous studies show VEBs can also mitigate odor and particulate matters. Some studies have been done with those technologies for the NH_3 mitigation from poultry operations. However, the data from broiler operations is still limited. In this project, several different NH_3 mitigating technologies, include litter amendment, acid scrubber and VEBs, will be tested and evaluated in broiler operations. The data can be used as a reference for future studies and commercial use.

Chapter 1

GENERAL INTRODUCTION

1.1 Introduction

Ammonia (NH_3) is the primary aerial pollutant in poultry houses. It results from the chemical decomposition of bird feces by certain bacteria in the litter. Ammonia is considered as a particulate precursor, which plays an important role on the formation of PM2.5. Ammonia can be deposited from the atmosphere and may do benefit to plants as a nutrient source for growth. However, if excess nitrogen (N) is deposited, it may impact the ecosystem negatively. Potential environmental issues associated with exceeding N in the environment include nitrate contamination of drinking water; eutrophication of surface water bodies; vegetation or ecosystem changes due to higher concentrations of N; and soil acidification through nitrification and leaching. Besides the environment impacts, ammonia also effects human and animal health. Ammonia is a highly hydrophilic gas that has irritant properties. When combined with water, it can injure and burn the respiratory tract. Ammonia can also alter the uptake of oxygen by hemoglobin due to the increase of pH within the blood, which leads to decreased oxygenation of tissues, and decreased metabolic function. The American Conference of Governmental Industrial Hygienists (ACGIH) has recommended an 8-hour maximum exposure limit of 25 ppm to protect against the chronic effects of ammonia exposure. A 15 min short-term exposure limit of 35 ppm has been established by ACGIH and adopted by the Occupational Safety and Health

Administration (OSHA) to reduce irritant effects of ammonia exposure (i.e., eye and upper respiratory tract irritation).

Factors pertinent to litter and NH_3 generation include physical and chemical litter properties (temperature, moisture, pH, and N content), type of original bedding material, between flock management such as windrowing and decaking, effects and frequency of top dressing, and spatial characteristics of gas evolution within houses. Elliott and Collins (1982) indicated an increase in NH3 with temperature, moisture, and pH. Coufal et al. (2006) cited moisture and pH as more readily manipulated in houses than temperature, which is controlled for bird comfort. Separately, for reducing N volatilization when reusing litter (rice hull base and top dressing), Coufal et al. (2006) recommended that top dressing not be used. A comparative laboratory study of organic vs. inorganic bedding materials reported that wood shavings and rice hulls produced less NH3 than sand and vermiculite and increases in litter moisture increased NH3 produced for all materials (Miles et al., 2011). Spatial characterization of litter relative to NH3 volatilization has shown higher litter moisture content near waterers (Tasistro et al., 2004), increased NH3 volatilization just outside water lines (Brewer and Costello, 1999), and that litter between feeders and waterers can be consistently differentiated from surrounding samples from mid to late growout, but the magnitude of moisture is not reliably higher or lower between winter and summer (Miles et al., 2011). Chepete et al. (2012) conducted a laboratory-scale study to determine the effect of various percentages of exposed turkey litter surface area on NH_3 emission rate. With four different litter surface coverage rates (0, 25, 50, 75 %), there was no significant effect on 6-d total NH_3 emission.

Physical containment of nitrogen strategies has been widely used in poultry industries in recent years. Nitrogen loss from poultry litter mainly because the volatilization of NH_3, which is predominantly influenced by the concentrations of unionised NH_3 and ionised NH_4^+. Ammonia volatilization remains low when litter pH is below 7.0 but can be substantial when above 8.0. Uric acid decomposition is most favored under alkaline (pH>7) conditions. Litter amendments are suggested to improve litter conditions and keep NH3 in check. A variety of acidifiers have been tested for ammonia emission control, such as aluminum sulfate (Lefcourt and Meisinger, 2001; Moore et al., 1996), sodium bisulfate (Moor et al., 1996), ferric sulfate (Moor et al., 1996), ferric chloride (Moor et al., 1996), and phosphoric acid (Moor et al., 1996). These chemicals were found to effectively reduce litter pH, reduce NH3 volatilization, and inhibit microbial activity. Litter amendment improved bird health and production due to lower NH_3 concentrations and bacterial loads in broiler houses (Terzich et al., 1998a, 1998b). Sims and Luka-McCafferty (2002) suggested that further studies would be required to determine the most effective and economic application rate for the litter amendments to achieve different production and environmental objectives. The NH_3 emission reduction efficacy diminishes by the accumulation of litter and manure after 3 - 4 weeks because most of the NH_3 is emitted from the top surface (less than 5 cm: 2 in) of the manure within the first 48 hr after excretion (Li and Xin, 2010). Burns et al. (2007) found that the majority (more than 80 %) of total NH_3 emission was from birds older than 21 days of age. Currently most litter amendments are only applied into the broiler houses prior to chick delivery due to potential bird toxicity and hazardous exposure. However, information on the efficacies of frequent litter amendment application during broiler grow-out on broiler NH_3 mitigation is meager.

Another technology has been used to reduction ammonia emission from CAFOs is the use of acid scrubbers. With an acid scrubber, the exhausted air from CAFOs will go through a reactor filled with packing materials and acid solution. Acid solution is then sprayed from the top of the reactor. Mass transfer occurs from gas to liquid phase when the air and solution get contact. This transfer is dependent on the concentration gradient, contact time of gas and liquid phase, and the size of the contact area between the gas and water phase (Melse and Ogink, 2005). The acid scrubber has been used in Netherlands for more than 20 years (Melse and Ogink, 2005), and the removal efficiency ranged from 40 to 100 % in poultry facilities (Hol et al., 1998). Manuzon et al. (2007) developed a multi-stage wet scrubber prototype which can be operated with a maximum of three stages. In their research, the result showed a 60 -63 % ammonia removal rate from a typical building exhaust under simulated laboratory conditions at 5 ppmv inlet ammonia concentration (IAC) and a 27 - 36 % reduction rate at 100 ppmv IAC. Melse et al. (2009) reported that there were acid scrubbers on 790 farms in The Netherlands, with the vast majority located on swine farms. Ogink et al. (2008) stated that the use of acid scrubbers on poultry farms is restricted because heavy dust loadings lead to clogging in the packing of the scrubber, causing high pressure drops and poor performance. During the past decade researchers had conducted scrubber research with the goal of developing a relatively inexpensive acid scrubber which can handle heavy dust loadings, which are typical in air exhausted from poultry houses, without clogging. USDA-ARS recently designed a two-stage low-cost acid scrubber for poultry houses. The first stage was designed to capture most dust and feather from the exhausted air with water; and the second stage was designed to adsorb NH3 with acid solution. Laboratory test showed the relative efficiency of the scrubber can absorb 90 % NH_3 at flow rates of 3,000 cfm, and around 55% at 9,500 cfm (unpublished data).

Vegetative environmental buffer (VEB) is another promising technology to adsorb dust, odors and NH_3 in an efficient and environment friendly way. A VEB is a strategic planting of combinations of trees and shrubs around poultry houses to meet specific objectives on each side of the farm. The poultry industry has not previously recommended the planting of tall crops, shrubs, or trees around houses fearing they will interfere with natural ventilation during the summer in open sidewall housing. However, this no longer a major concern as industry shifts to tunnel ventilation, black-out, and totally enclosed housing systems. The three basic goals in the design of a VEB planting are a visual screen, windbreak and shade, and vegetative filter. A VEB may foster improved neighbor-relations by filtering dust, feathers, odor, and noises from houses; provide a visual screen of the houses and the routine farm activities; and improve public perception of the industry via a proactive, “green” initiative. The quantification of odor mitigation via the use of VEBs is a difficult process and is approached in a multi-analytic way by means of field experiments, wind tunnel examinations and computer simulation. A few studies have recorded incremental mitigation benefits in the form of reduced particulate and odor movement downwind. Malone et al., (2006) analyzed the impact of a simple VEB and recorded a 49% reduction in particulate movement, a 46% reduction in downwind ammonia concentration, and a 6% reduction in downwind poultry odor concentration. Lin et al. (2006) conducted a field examination on the influence if VEB on livestock odor dispersion and reported a 23% reduction of odor concentration at downwind side with the absence of VEB. Wind tunnel and computer simulations have also quantified reduced particulate and odor movement due to the presence of strategically located trees (Lammers et al., 2001).

Different NH3 mitigating technologies have their own advantages and limitations. The experimental examination and evaluation are necessary before practice and commercial use. In this project, all technologies mentioned above were examined under filed experiments.

1.2 Research Design and Methods:

1.2.1 Develop a model to estimate spatial distribution of NH_3 emission rate in broiler operation with broiler litter properties.

Broiler chickens are often grown in production houses at densities around 0.7 ft^2 $bird^{-1}$. They are normally raised on litter made up of wheat straw or wood shavings above an earthen floor. The mixture of litter and manure represents a significant source of ammonia emissions. The mechanisms related to ammonia emissions from manure involve many processes. Theoretically, the processes involved in ammonia emissions from litter based manure include conversion of uric acid to urea, hydrolysis of urea, enzymatic and microbial generation of ammonia, diffusion of ammonia in litter, partitioning between the adsorbed and dissolved phase ammonia, the chemistry of ammonia in aqueous solution, partitioning between solid/aqueous phase and gaseous phase ammonia, and the convective mass transfer of ammonia gas from the surface into the free air stream.

Litter temperature is a very important variable during the processes of ammonia emissions from litter-based manure. Air temperature may influence the convective mass transfer coefficient. Litter temperature may influence the Henry's constant, the dissociation constant, and also the diffusion and generation of ammonia in litter. Therefore, ammonia flux can be greatly affected by temperature variation. In the broiler houses air temperature are usually managed to optimize bird health and productivity. In warm weather, it is a common practice that the ventilation rate be increased to maintain the target air temperature. So the influences of climatic differences on ammonia fluxes from broiler litter are largely indirect. The variation of ambient temperature requires the adjustment of air exchange rate, and the variation of air exchange rate causes the variation of ammonia fluxes.

The pH value of litter is one of the most important factors that determines the aqueous phase ammonia concentration, and therefore influences ammonia release. Research has demonstrated that ammonia release from litter is negligible at litter pH below 7(Reece et al. 1985). Chemical treatments have been studied in laboratory tests as a way to suppress ammonia volatilization, by chemically lowering the litter-solution pH. Moore et al. (1996) tested several treatments for broiler litter and found that aluminum sulfate, phosphoric acid, and ferrous sulfate each worked well in reducing ammonia losses. However, control of litter pH over the life of the flock in practical scale has proven to be a difficult task (Lacey et al. 2004; Carr et al. 1990).

It would be reasonable to assume that ammonia emissions are positively related with litter nitrogen content(diet, litter age and bird age). An increase in feed protein level may significantly increase litter nitrogen content, and therefore increase ammonia emission rate (Elwinger and Svensson 1996). Built-up litter has more nitrogen content. It has been reported that ammonia flux from reused litter was six times higher than that from new bedding material J Atmos Chem (2007) 58:41–53 43 at the start of a grow-out (Brewer and Costello 1999). Several researchers reported that ammonia emissions increase with age of bird (Redwine et al. 2002; Elwinger and Svensson 1996). It may also due to increase of litter nitrogen content with increase of bird age.

Urea hydrolysis is a major source of ammonia, and the reaction need the absence of water. Therefore, litter moisture content may affect the conversion rate of uric acid to NH_4^+. It has been reported qualitatively that wet litter can lead to high ammonia levels in broiler houses (Elliott and Collins 1982). However, overly dry litter may result in more dust particulates, which can serve as a transport mechanism for ammonia. On the other hand, very wet conditions may slow/shut down microbial and enzymatic activities due to scarcity of oxygen. Litter moisture content may vary in a large range. In practice, litter moisture is also influenced by ventilation and drinking system management.

Mechanistic and deterministic algorithms have been used to estimate NH_3 emissions from animal housing under particular circumstances. A linear relation has been recently reported between NH_3 emission rate, bird age and litter condition (Wheeler et al., 2004) (Equation 1):

$$ER = 0.031 * age \tag{1}$$

Where,

ER = emissions rate (g NH_3 bird^{-1} d^{-1});

age = flock age (d) if built-up litter is used;

age = 0 d if new litter and flock age is <7 d;

age = (flock age − 6) d if new litter and flock age is >7 d.

Lima et al. (2015) introduced a deterministic algorithm model which can estimate NH_3 emission rate with the factors of bird age, litter temperature and pH (Equation 2):

$$ER = \exp(-0.6502 + 0.302d + 0.122T + 0.614pH - 0.004d^2) \quad (2)$$

Where,

ER = emission rate (mg m^{-2} hr^{-1});

d = day of grow out;

T = litter temperature (C);

pH = litter pH.

Due to the water lines distribution and the unevenly heat and ventilate, the litter properties varies even in a single house. To better estimate the overall emission rate, it's necessary to develop a model to estimate spatial distribution of NH_3 emission rate first. In this study, the existing poultry house ammonia emission rate model will be verified and modified under different litter properties. The flow chart was shown below (Figure 1):

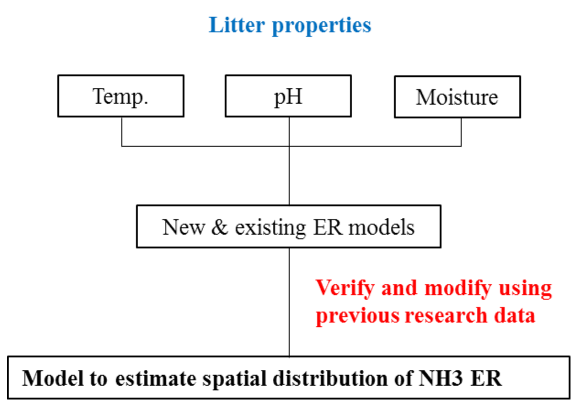


Figure 1 A brief flow chart for the development of NH_3 ER model

1.2.2 Modify a broiler house poultry litter amendment (PLT) application system, and evaluate the NH_3 mitigation efficacy in commercial broiler houses with frequent PLT application during grow-out.

Experiments were conducted in two commercial tunnel ventilated broiler houses in Bridgeville, Delaware. These two houses were located side by side and shared the same design and production schedule. The houses had a dimension of 500 ft long × 60 ft wide. Each house had three 36” sidewall fans and fifteen 48” tunnel fans. Fresh air came into the house from 46 box inlets located between ceiling and sidewalls. The inlets were controlled by computer program and operated on static pressure. During the warm weather, the water cooling pad at opposite end of tunnel fans also served as air inlet based on different ventilation mode. The brooding part was located at the middle of each house, and occupied 40% of the total house area. For each flock, the chicks stayed in brooding part for two weeks, and spread to the other two ends on 3rd and 4th week. The bedding material used during monitoring period was wood shaving, and the surface cakes were removed every flock.

In this experiment, two sampling ports were selected in each house (Figure 2). The sampling ports were at the middle of the houses and 36 ft away from the endwalls. The sampling tubing was hanging up from the ceiling, and sample inlets were 6 ft high from floor. Fuel filter was installed at the end of sampling tubing to keep the dust out. Air samples from each sampling port and an outside fresh air point were taken sequentially by a programmed pump, and analyzed by a photoacoustic gas analyzer INNOVA 1412 (LumaSense Technologies Inc., Santa Clara, CA.). Another analyzer, Chillgard® RT Refrigerant Monitor (MSA Safety Inc., Cranberry Twp, PA.), was used as a backup. Each sampling port was measured for 3 min to ensure sufficient time to obtain stabilized readings. It resulted a 15 min measurement circle. The data was collected by a LabVIEW (National Instruments Co., Austin, TX) program at a 1-sec interval. HOBO Data Loggers (U23-001, Oneset Computer Co., Bourne, MA) were installed at each sampling port and outside the house to collect the temperature and relative humidity (RH) data at a 30-sec interval. PM_{10} concentration in exhausted air was monitored by DUSTTRAK Aerosol Monitor (Model 8520, TSI Inc., Shoreview, MN) with a 1-min interval nearby the tunnel fans. The DUSTTRAKs were maintained every week. The fans ON/OFF status were monitored by the switch sensors attached on the power cable of the fan. The static pressure (S.P.) of each house was measured by Diffential Pressure Transducer (Model 264, Setra Systems., Boxborough, MA). These data was also recorded by the LabVIEW program at a 1-sec interval.

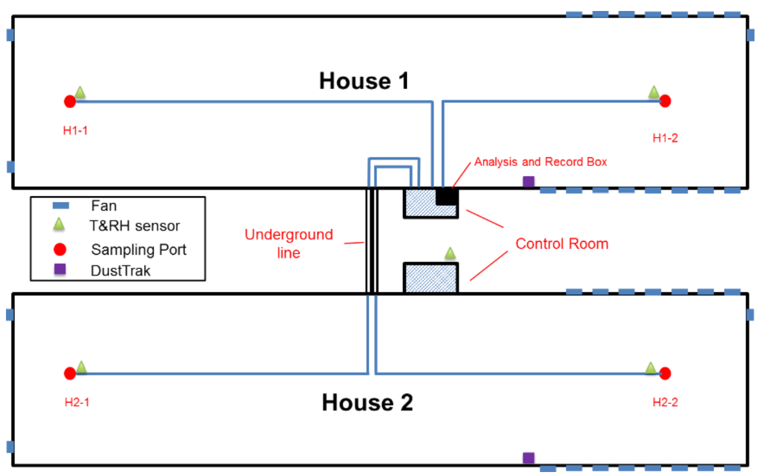


Figure 2 Schematic layout of the air sampling system in the broiler houses

The broiler house ventilation rate was determined by measuring the airflow rate of the ventilation fans with a Fan Assessment Numeration System (FANS) device (Gates et al., 2002; Wheeler et al., 2002), static pressure, and monitoring the runtime of the fans. Every fan was tested under three different S.P.s within the normal operation range. The data was then fitted to two order polynomial, as following (Equation 3):

$$VR = a \times SP^2 + b \times SP + c \tag{3}$$

where:

VR = broiler house fan ventilation rate, cfm

SP = static pressure difference between ambient and inside broiler house

a, b, c = two order polynomial coefficients

To determine the total ventilation rate of a broiler house, the following equation was used (Equation 4):

$$Q_T = 0.5886 \times \sum_{i=1}^{n} \left(\sum_{j=1}^{3600} (VR_i \times FS_j) \right) \tag{4}$$

where:

QT = Exhaust total ventilation rate of the house at field temperature and barometric pressure, $m^3\ hr^{-1}\ house^{-1}$

VR_i = the NO. i fan ventilation rate, cfm

FS_j = fan status at j second, = 1 if the fan was on and = 0 if the fan was off

n = total fan number in the house

The NH_3 emission rate (ER) calculation from a broiler house was based on the NH_3 concentration and the total VR, as following (Equation 5):

$$ER = Q_T \times G_e \times 10^{-6} \times \frac{T_{std}}{T} \times \frac{w_m}{V_m} \tag{5}$$

where:

ER = Gas emission rate for the house, $g\ hr^{-1}\ house^{-1}$

Q_T = Exhaust total ventilation rate of the house at field temperature and barometric pressure, m^3 hr^{-1} $house^{-1}$

G_e = Gas concentration of exhaust house ventilation air, parts per million by volume (ppm_v)

w_m = molar weight of the gas, g $mole^{-1}$ (17.031 for NH_3)

V_m = molar volume of gas at standard temperature (0 °C) and pressure (101.325 kPa) or STP, 0.022414 m^3 $mole^{-1}$

T_{std} = standard temperature, 273.15 °K

T = absolute temperature of exhaust air, °K

This study monitored three flocks from November, 2013 to May, 2014. Outside daily mean temperature during the three flocks ranged from -12.5 C to 20.9 C with a mean of 4.1 C. Outside RH ranged from 42.3 % to 100 % with a mean of 77.4 %. The environmental conditions in these two houses were similar during the monitored period.

Daily mean NH_3 concentration in control house ranged from 7.1 to 84.0 pm with a mean of 36.2 ppm; while it ranged from 5.0 to 92.9 ppm with a mean of 36.8 ppm in treated house (Figure 3). These two houses used middle brooding area at the first week, and then used the pad end and tunnel end at the second and third week. To reserve the heat, they had a relative lower ventilation rate during the first two week, caused a high NH_3 concentration. After PLT application in the treated house, the NH_3 concentration had a suddenly drop and could last for 2-3 days.

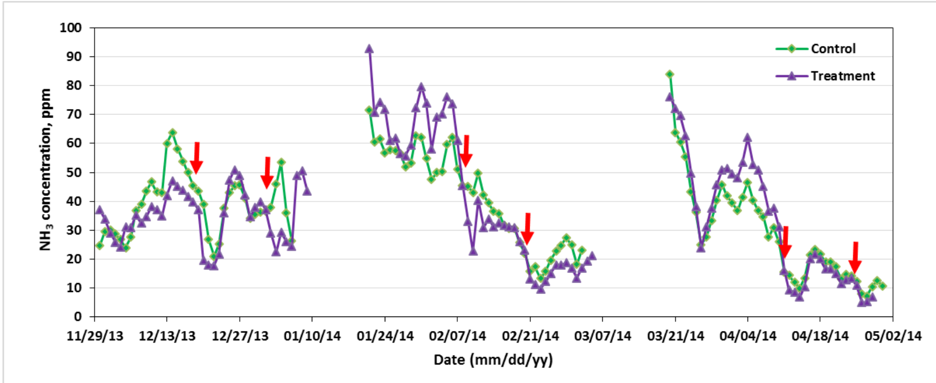


Figure 3 Daily mean NH_3 concentrations in control and treated houses (red arrows showed the day applied PLT to treated house)

The mean NH_3 and PM_{10} emission rate were summarized in Table 1. The control house had a mean daily ER of 0.41 g bird^{-1} d^{-1} during the monitoring period. In comparison, the treated house had a lower ER, averaging 0.32 g bird^{-1} d^{-1}. The Application of PLT reduced 28.1 % NH_3 ER from the treated broiler house. During the PLT application, some fine PLT particle dispersed in the air cause PM_{10} concentration increase. The average PM_{10} ER in treated house was 71.3% higher than the control house (19.7 g hr^{-1} vs. 11.5 g hr^{-1}).

Table 1 Mean NH_3 and PM_{10} emission rate (NH_3: g bird^{-1} d^{-1}; PM_{10}: g hr^{-1})

Flock	NH_3 ER		PM_{10} ER*	
	Control	Treatment	Control	Treatment
1	0.48	0.36	14.6	21.5
2	0.35	0.27	7.6	10.9
3	0.39	0.31	12.4	26.7

Table 2 summarized the broiler mean mortality rate and body weight gain during the monitoring period. The treated house had a 21.8 % lower mortality rate compared with control house (1.58 ‰ vs. 2.02 ‰), while the body weight gain was 8.3 % higher (51.3 g d^{-1} vs. 47.3 g d^{-1}).

Table 2 Mean mortality rate and body weight gain

Flock	Mortality rate, ‰		Body weight gain, g d^{-1}	
	Control	Treatment	Control	Treatment
1	0.65	0.50	47.2	54.8
2	1.28	2.40	47.9	52.1
3	4.12	1.84	46.9	46.9

1.2.3 Evaluate long-term performances of a two-stage scrubber for broiler operations under field conditions.

Three two-stage NH_3 scrubbers were tested in this research. The scrubbers were mounted outside of exhaust fans in three broiler houses located in (Pennsylvania) PA and (Delaware) DE. Each of the scrubber contains two stages (Figure 4.); the first scrubber (dust scrubber) used water to remove most particulate matters (dust, feather, etc.) from exhausted air and the second scrubber (acid scrubber) used acid solution to capture NH_3. A commercial poultry litter treatment (PLT®, Jones-Hamilton co.) was used to create acid solution in the second stage.

Both scrubbers had a length of 1.6 m, and the overall width and height were 1.6 m and 2.2 m, respectively. The shield of the scrubber was 63.5 mm thick and made by fiberglass. Each scrubber had a V-shaped reservoir which had a capacity to hold 360 L liquid. A float switch was equipped in each reservoir to control the water level. Both scrubbers also had an immersion heater (Vulcan Industries), which had a 75 cm long heating tube. The heaters were designed to heat the liquid during winter section.

A liquid deliver system was built in each of the scrubber which included a pump, delivery pipes and wooden slats. In dust scrubber, a 1/2 HP (0.372 kW) immersion pump (Little Giant, 6EN-CIA-SFS) was used to recirculate water through reservoir and delivery pipes. Water from the pump was delivered into three 5 cm OD. PVC pipes at the top of the dust scrubber. The pipes had two rows of holes (0.1 cm) faced to the slats and from where the water was delivered. The holes were 5 cm apart on the side near the pump, 3.5 cm apart in the middle third of the pipes and 2.5 cm apart on the side further away from the pump. The dust scrubber hold up to 8 rows wooden slats at a 45^o angles. The center 6 rows slats helped to deliver water evenly in the scrubber and the end two rows helped to prevent the water drops coming out of the scrubber. A removable screen was equipped at the top of dust scrubber reservoir to trap feather and other large particulate maters which may cause clog in pump and delivery pipes. The acid scrubber used a 1/3 HP (0.249 kW) magnetically driven pump (IWAKI MK-100RCT), which can withstand extremely acidic conditions. The delivery pipes and slats were same with dust scrubber. The acid scrubber also equipped a plastic tray at the front of the opening to recover the spilled water drops.

The scrubber control and record units were located in a control box mounted on the side wall. A solid state reply was used to turn on/off the pumps synchronously with the house fan on/off. An electrical water meter was used in the water supply line. Both scrubber on/off status and water consumption were recorded by a HOBO data logger (HOBO U12-006, Onset Computer Corporation) at a 10-sec interval. The acid scrubber in PA also equipped a pH electrode (PHE-7353-15-PT100, OMEGA Engineering Inc.) and temperature probe at the bottom of reservoir to record the pH and temperature changes of the acid solution. The changes were recorded by three HOBO data logger for a 30-sec interval.

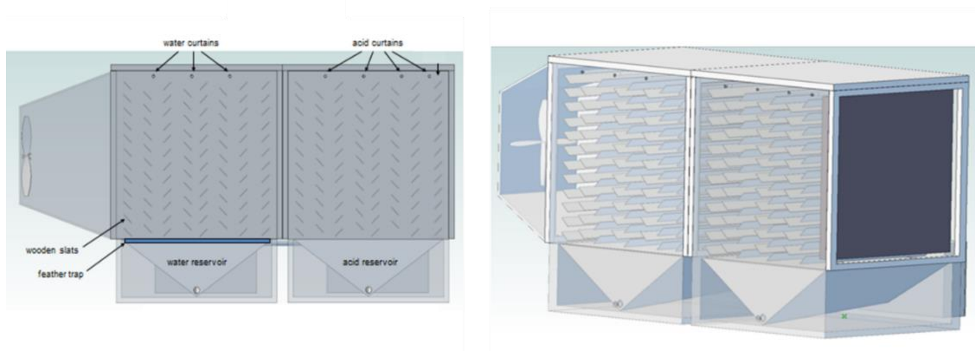


Figure 4 Schematic diagram of the scrubber

In this research, an air sampling and analysis system was used in each research site (Figure 5). Two sampling port located in front of fan (inside house) and acid scrubber opening (outside house), respectively. The air sample went through a polytetrafluoroethylene (PTFE) tubing before arrived to a solenoid valve (Model 456654, Burkert, Irvine, Calif.). A fuel filter was used at the end of the tubing to get rid of particulate maters. The filter was replaced every week or when found dirty. An additional stainless steel filter was used before fuel filter to keep liquid water out of the tubing. The outside house part of sampling tubing was wrapped by polyethylene pipe insulation material and companied with a heating cable. The sampling air was heated to 90 ^{o}F to avoid any water vapor condensation. The solenoid valve was controlled by a Programmable Logic Controller (SG2-12HR-D, TECO Electric & Machinery Co., Ltd.). During operation, the pump took sample from inside house when the fan didn’t running, and the valve would switch the sampling to the outside once the fan was running. If the fan kept running, the valve switched between outside and inside every 3 min and if the fan stopped, the sampling went back to inside immediately. The air sample was sent to a PTFE manifold by pump and then analyzed by a photoacoustic gas analyzer (Chillgard RT, Mine Safety Appliances Company, Pittsburgh, PA.). The NH_3 concentration data from Chillgard RT and the valve on/off status were recorded by a HOBO data logger at a 30-s interval. Water samples from dust and acid stage tank were taken daily in two site in DE, and weekly in the site in PA. Ammonia concentration in water samples were measured.

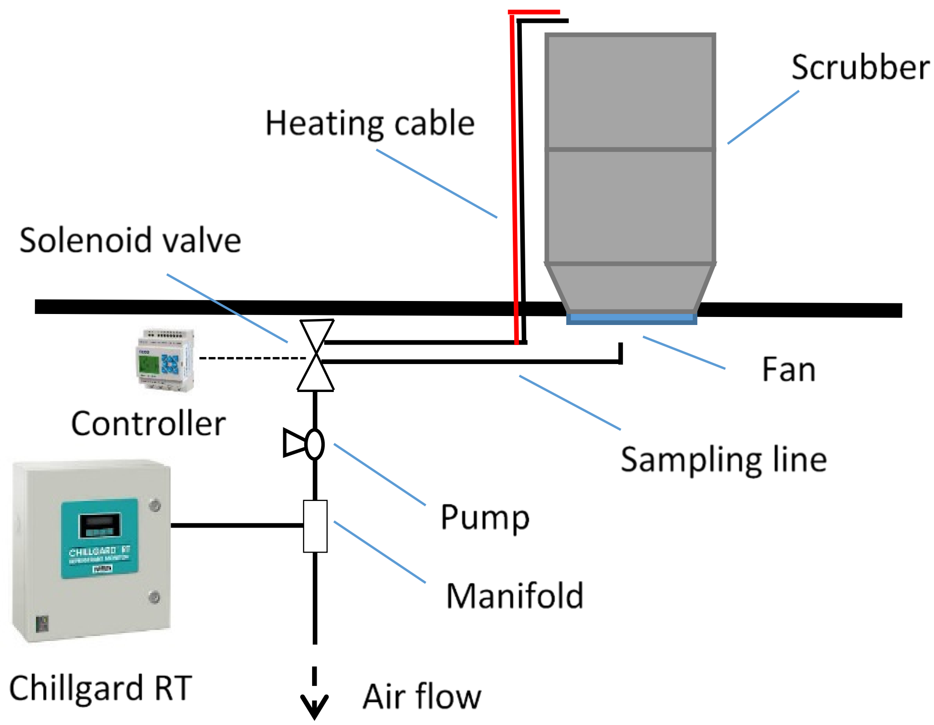


Figure 5 Schematic diagram of air sampling and analysis system

The PLT, water and electricity consumptions during monitoring period were summarized in Figure 6. PLT consumption ranged from 0.70 to 4.69 kg d^{-1}, and had an average of 2.91 kg d^{-1}. PA site had a lower PLT consumption rate (63.8 and 44.5 % less than two DE sites) was because the acid solution was checked every week while two DE sites checked every day. Exclude the leakages, water consumption rate for the three sites ranged from 0.074 to 0.17 m3 d-1 and averaging 0.103 m^3 d^{-1}. The electricity consumption ranged from 399 to 888 kWh, and averaging 677kWh. Table 3 summarized the consumptions for every 1 kg NH_3 absorbed by scrubber. The average consumptions for water, electricity and PLT were 0.25 L, 46.56 kWh and 8.37 kg, respectively.

Table 3 Consumptions for every 1 kg NH_3 absorbed by scrubber

Site	Fan, in	Water, L	Electricity, kWh	PLT, kg
DE-1	36”	0.17	20.30	7.49
DE-2	24”	0.33	72.81	9.25
Ave	--	0.25	46.56	8.37

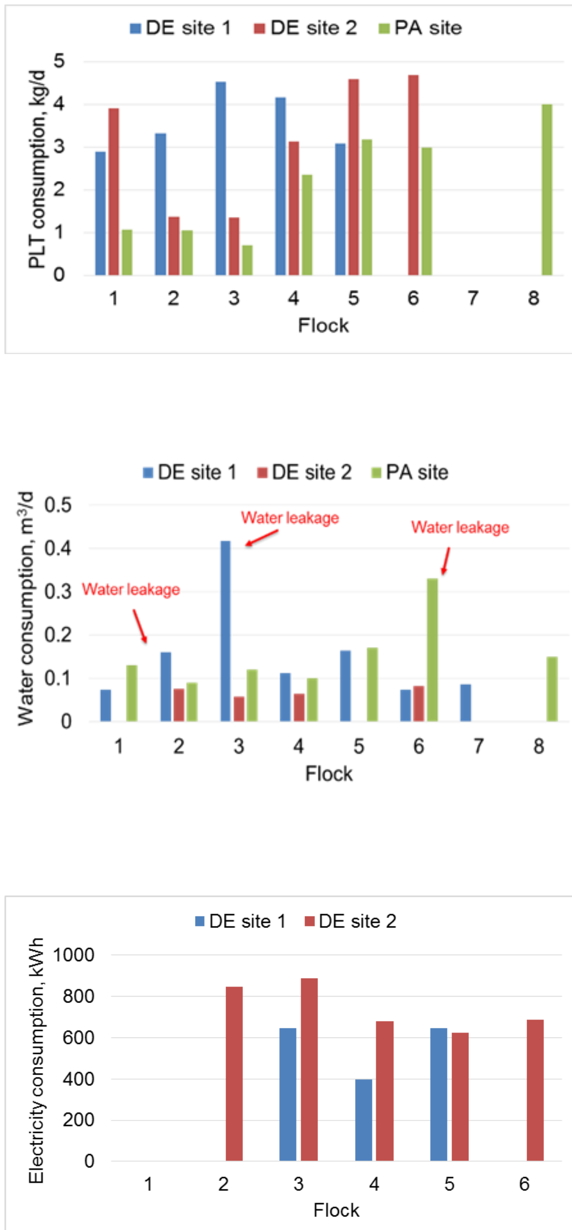
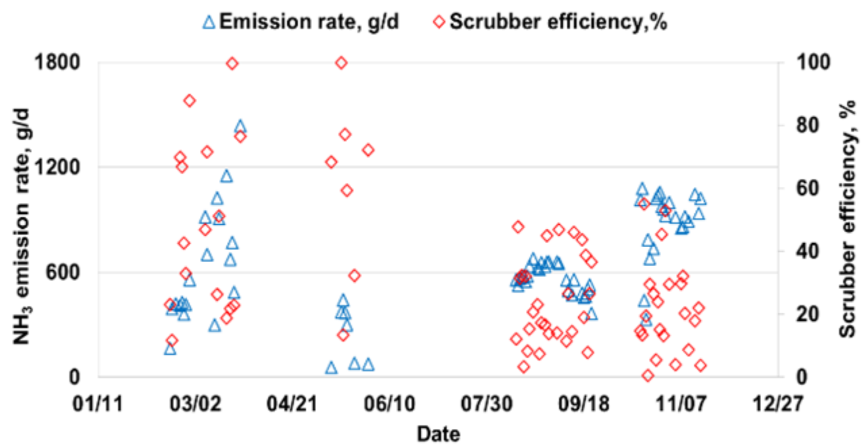


Figure 6 PLT, water and electricity consumptions during monitoring period

Figure 7 shows the NH_3 emission rate and scrubber efficiency changes during the monitoring period. The scrubber efficiency was calculated based on the ratio between NH_3 in exhausted air and NH_3 absorbed in the acid solutions. There was a negative relationship between NH_3 emission rate and scrubber efficiency at both DE sites ($P<0.01$ and $P<0.05$). The average efficiency for DE site 1 and 2 were 31.3 and 34.3 %.



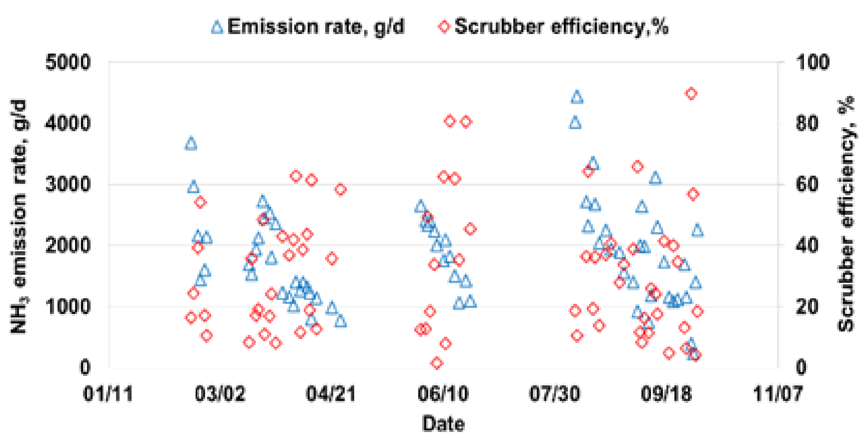


Figure 7 NH3 emission rate and scrubber efficiency changes

1.2.4 Evaluate the effects of vegetative environmental buffers on downwind ammonia concentration emission from broiler houses.

In this study, the experiments were conducted in three broiler farm with VEBs. Two of them located in Delaware (DE), and one located in Pennsylvania (PA).

DE house 1 was an experimental broiler house, which had a dimension of 44 ft x 100 ft. This house was surrounded with tree buffers except the outlet at east corner, and the distance between walls to tree buffers was shown in Figure 8. Trials at this site was did when the wind direction was west or southwest. The background path was set to northeast of the house. The measuring paths before and after VEB were moved between the two locations marked on Figure 8.

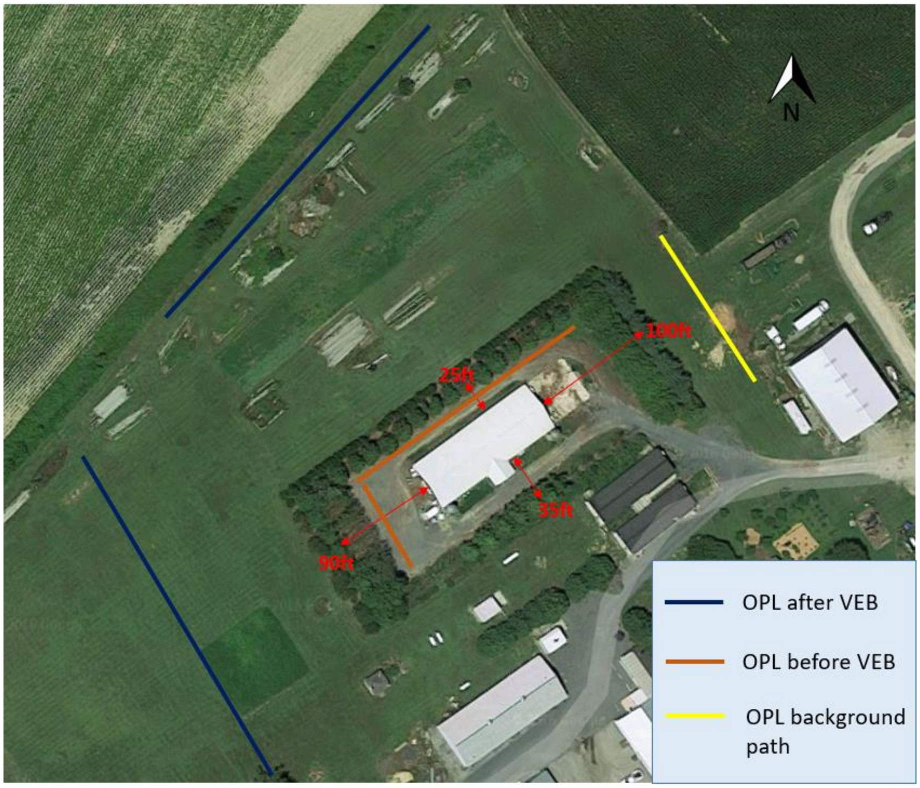


Figure 8 Schematic map of DE house 1 and OPL paths

DE house 2 was a commercial broiler house with tunnel ventilation system. The dimensions of the house was 66 ft x 400 ft. Two rows of tree buffers were planted 50 ft away from south wall. Trials in this site were done when the wind direction was north. The background path was located at the west side of the house, and the measuring paths were located on the south (Figure 9).

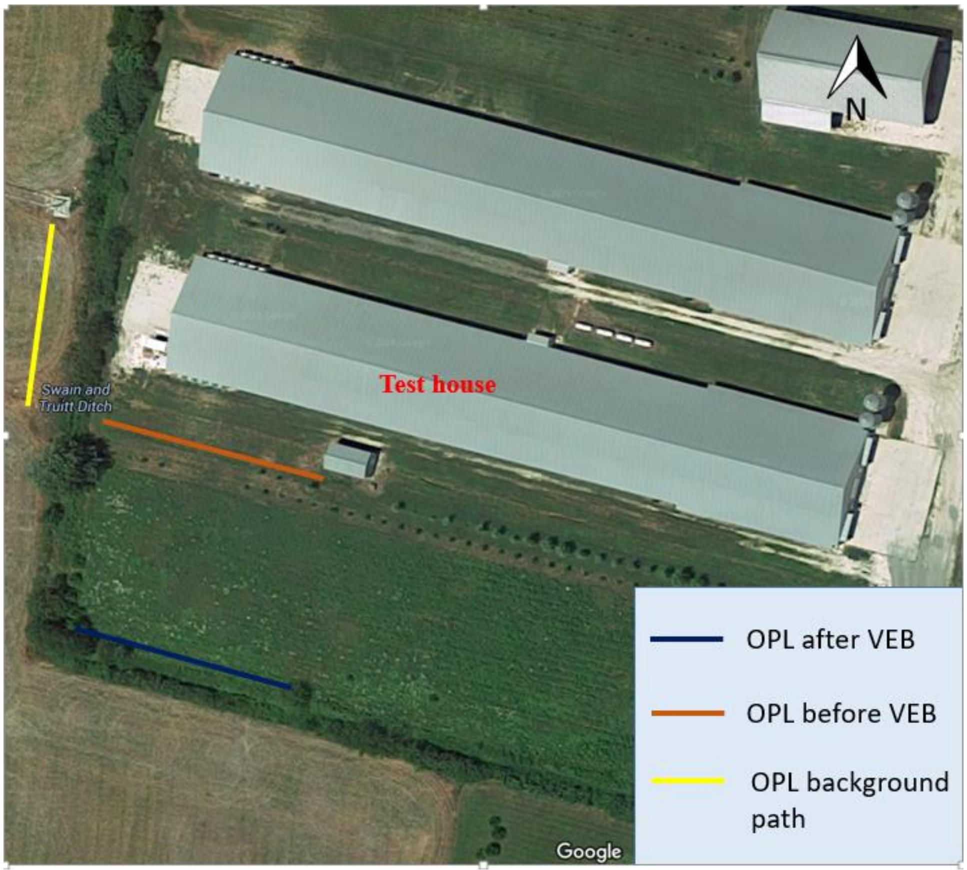


Figure 9 Schematic map of DE house 2 and OPL paths

PA house was an organic broiler house, measured 46 ft x 500 ft. A tree buffer was planted 30 ft away from south wall, and there was a crop field 80 ft away from south wall which can be concerned as a second vegetative buffer. Trials in this site were done when the wind direction was north or northwest. The background path was set to either north or northwest of the house according to the wind direction. The measuring path were set on the south side (Figure 10.).

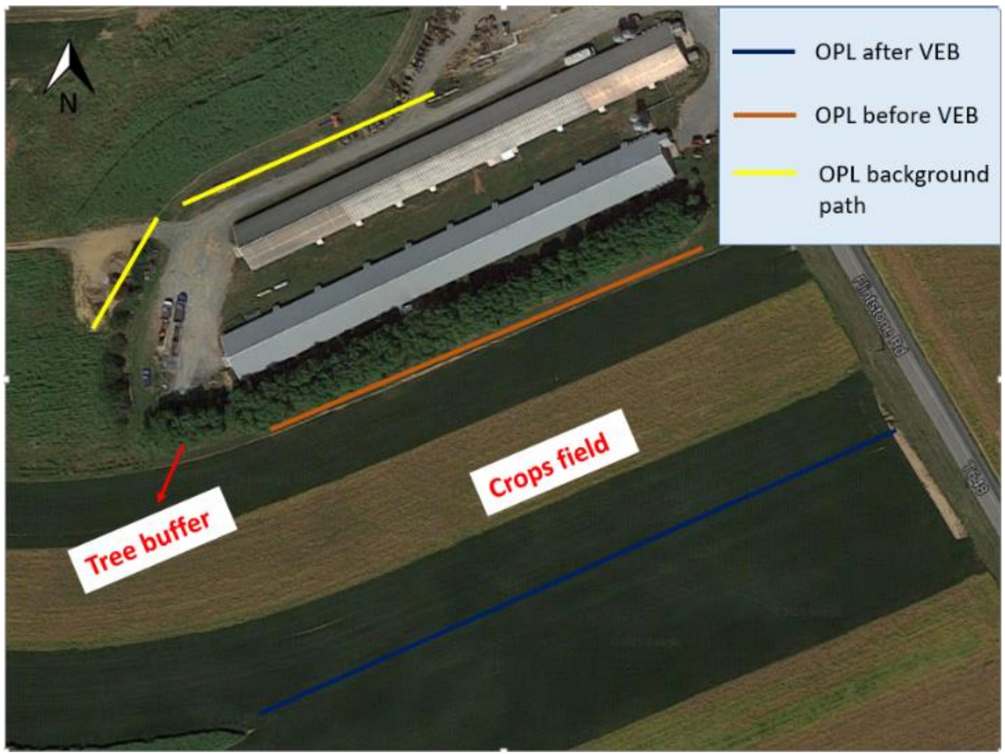


Figure 10 Schematic map of PA house and OPL paths

A tunable diode laser open-path monitor (GasFinder 2.0, Boreal Laser Inc.) or OPL was used to monitor the NH_3 concentration before and after VEB. OPL measured gas concentration over an open path and consists of an integrated transmitter/receiver unit and a remote, passive retroreflector array, shown in Figure 11. The remote retroreflector was initially targeted by the operator using a two-axis monitor mount, assisted by a telescopic sight and an on-board visible aiming laser. The transceiver housed the laser diode source, drive electronics, detector module, and microcomputer subsystems. The transceiver unit was in a weatherproof enclosure and had connectors for power input and data input/output. The reflector had a 15 W light powered by a portable battery to prevent the water vapor condensation on the window.

Figure 11 Schematic representation of GasFinder 2.0

The laser light emitted from the transceiver unit propagated through the atmosphere to the retroreflector and returned, where it was focused onto a photodiode detector. Simultaneously, a portion of the laser beam was passed through an onboard gas cell to provide a continuous calibration update. These two optical signals were converted into electrical waveforms, which the microcontroller processed to determine the actual concentration of the target gas along the optical path. The data was stored in its own memory first and sent to a computer via RS-232 port after each trial. Three OPLs were used at each trial. One OPL was set to the upwind location and served as background measurement; one OPL was set to the downwind location before VEB, and the last OPL located after VEB. All transceivers' and reflectors' locations were recorded by a portable GPS. The measurement path between transceiver and reflector covered all exhausted fans from the broiler house.

The wind direction was monitored with an Ultrasonic Anemometer (81000, R. M. YOUNG Company). The 3D wind speed was recorded by a data acquisition module at a 1-sec interval. The data was then averaged by 15-min segment usinga Matlab (The MathWorks, Inc.) program.

In-house NH_3 concentration was determined by Chillgard RT. In DE house 1, the sampling port was located in front of one of the exhaust fan at downwind side, while in the other two houses, the sampling port were located at the tunnel end, in the middle of the houses. The gas samples went through a PTFE tubing and analyzed continuously by Chillgard. The data was recorded by a HOBO logger at 30-sec interval. A fuel filter was installed at the end of sampling tubing to get rid of particulate matters. The filter was replace before every trial or when needed. All Chillgards were calibrated with zero and span (about 50 ppm) gas before each trial. The fans ON/OFF were monitored by the switch sensors attached on the power cable of the fan. The static pressure of each house was measured by Differential Pressure Transducer (Model 264, Setra Systems., Boxborough, MA). The data was also collected by HOBO logger at a 30-sec interval.

In study, a free software WindTrax (www.thunderbeachscintific.com) was used to estimate NH_3 emission rate. WindTrax uses numerical models called Lagrangian stochastic models to simulate the transport of trace gases from sources that emit them. It can calculate both unknown emission rates from sources emitting these gases and their unknown concentrations anywhere in the vicinity of the sources.

WindTrax requires at least four parameters are known: the surface roughness length z_0, which is related to the height of the plants, soil, or other elements covering the ground; the friction velocity u_*, which is determined by the vertical transport of horizontal momentum near the surface; a measure of atmospheric stability called the Monin-Obukhov length, L; and the mean horizontal wind direction θ. In practice, the u_* and θ can be calculated from 3D wind directions. The factors z_0, and L from standard empirical relationships published in the literature.

The actual NH_3 emission rate was calculated based on the in-house NH_3 concentration, static pressure and fan running time using the Equation 1, 2, 3. With the WindTrax model, the estimated emission rate also can be calculated based on the NH_3 concertation data acquired from OPL. Comparison of actual NH_3 emission rate with estimated emission rate before VEB can evaluate the accuracy of WinTrax model, while comparison of estimated NH_3 emission rate before and after VEB can evaluate the effects of vegetative environmental buffers on downwind ammonia concentration emission. The flow chart is shown in Figure 12.

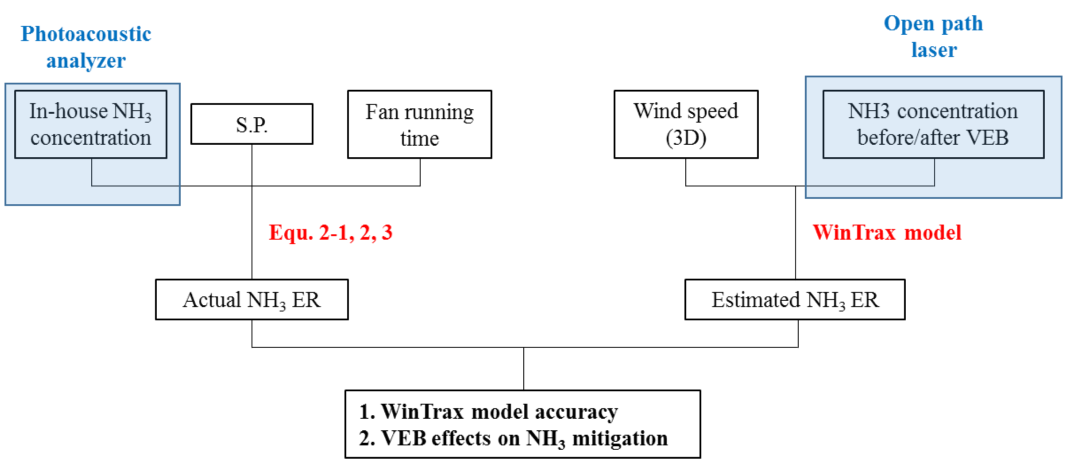


Figure 12 A brief flow chart for the VEB study

1.3 Objectives

The objectives of this study were to: (1) introduced and modified different NH_3 mitigating technologies to commercial broiler houses; (2) examined the efficacy of different NH_3 mitigating technologies under field-scale experiments.

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Chapter 2

USING WET SCRUBBER TO CAPTURE AMMONIA EMISSION FROM BROILER HOUSES

2.1 Abstract

Ammonia (NH_3) emission is one of the greatest challenges in the broiler industry for now and in the future. The EPA issued the National Ambient Air Quality Standards (NAAQS) for PM2.5 in 1997 (EPA, 1997). Because NH_3 is a precursor of PM2.5, regulations aimed at reducing PM2.5 concentrations and emissions will likely require reductions in NH_3 emissions from animal production operations. A lot of litter management technologies were used to reduce the NH_3 emission from poultry litter. However, only a few studies focus on the NH_3 reduction from poultry house exhaust air. In this study, a two-stage wet scrubber was developed to recover NH3 in exhaust air from three broiler houses in Delaware and Pennsylvania. Each stage of the scrubber consisted a 300-L liquid tank, a water pump, spray pipes and wood baffles. During operation, the liquid in the tank was pumped to the spray pipe at the top of the scrubber. Water drops fell down from the holes on the spray pipes, and the wood baffles helped to distribute the drops evenly in the scrubber. The first stage mainly was used to capture dust and feather with water and the second stage contained sodium bisulfate solution to absorb NH3 from exhaust air. The second stage liquid will be replaced weekly if the pH exceeds 7, and the whole unit will be cleaned every flock. The scrubber was able to remove up to 34.3 % NH_3 from broiler house exhaust air.

For every kg NH_3 absorbed by acid solution, the water, PLT and electricity consumption were 0.23 m3, 15.10 kg and 43.74 kWh, respectively.

2.2 Introduction

Ammonia emitted from concentrated animal feeding operations (CAFOs) in the USA has been a concern and may cause environmental issues. Ammonia is considered has a strong relationship with secondary particulate matter (Beak et al., 2004). The U.S. Environmental Protection Agency (EPA) has set National Ambient Air Quality Standards for the PM2.5 which may eventually require a reduction of ammonia emission from CAFOs. The deposition of nitrogen also contribute to the atmospheric, aquatic, and terrestrial ecosystem change (Boyer et al., 2002).

Several researches on ammonia emission quantity have been done in the U.S. Wheeler et al. monitored the ammonia emission data from twelve commercial broiler houses over on year in in Kentucky and Pennsylvania. The emission rates from all houses on the three farms using built-up litter and one farm using new litter were 0.028, 0.034, 0.038 and 0.024 g NH_3 $bird^{-1}$ d^{-1} per day of age. Pescatore et al. (2005) conducted a measurement of ammonia emission from two Kentucky sites for over a one year cycle and had an emission rate range of 0 to 2.34 g NH_3 $bird^{-1}$ d^{-1} with different bird ages. Moore et al. evaluated four broiler houses in northwest Arkansas for one year. They found the average ammonia emission during flock, between flocks, during storage and after application were 28.3, 9.09, 0.18, and 7.91 g NH_3 $bird^{-1}$ d^{-1}.

To mitigate ammonia emission, some technologies were studied and applied to commercial broiler houses. Poultry litter amendment (PLA) application has been a common used technology to reduce the ammonia emission from poultry facilities in the U.S. Typical PLAs like alum ($Al_2(SO_4)_3 \cdot 14H_2O$), sodium bisulfate ($NaHSO_4$), ferrous sulfate ($FeSO_4 \cdot 7H_2O$), zeolite or clay are applied either on the surface of litter or mixed with it (Moore et al., 1995; Kithome et al., 1999). Choi et al. (2008) reported a 77 to 96 % reduction of ammonia volatilization from stored poultry litter with alum, fly ash and Poultry Litter Treatment (PLT). Li et al. (2008) conducted a laboratory scale experiment to evaluate the efficacy of 4 commercially agents (Zeolite, Al+ Clear, Ferix-3 and PLT), topically applied to laying hen manure, in decreasing ammonia emissions from the manure storage. They found all the tested agents showed appreciable NH3 emission reduction of 33 to 94 %. Do et al. (2005) tested six different PLAs in two commercial farms in Korea and get a reduction rate of ammonia concentration in broiler house up to 97.2 %.

Another technology has been used to reduction ammonia emission from CAFOs is the use of acid scrubbers. With an acid scrubber, the exhaust air from CAFOs will go through a reactor filled with packing materials and acid solution. Acid solution is then sprayed from the top of the reactor. Mass transfer occurs from gas to liquid phase when the air and solution get contact. This transfer is dependent on the concentration gradient, contact time of gas and liquid phase, and the size of the contact area between the gas and water phase (Melse and Ogink, 2005). The acid scrubber has been used in Netherlands for more than 20 years (Melse and Ogink, 2005), and the removal efficiency ranged from 40 to 100 % in poultry facilities (Hol et al., 1998, 1999). Manuzon et al. developed a multi-stage wet scrubber prototype which can be operated with a maximum of three stages. In their research, the result showed a 60 -63 % ammonia removal rate from a typical building exhaust under simulated laboratory conditions at 5 ppmv inlet ammonia concentration (IAC) and a 27 - 36 % reduction rate at 100 ppmv IAC.

Use of acid scrubbers on poultry farms is restricted because heavy dust loads lead to clogging in the packing of the scrubber, causing high pressure drops and poor performance. During the past decade researchers have conducted scrubber research with the goal of developing a relatively inexpensive acid scrubber which can handle heavy dust loadings, which are typical in air exhausted from poultry houses, without clogging (Moore et al., 2013). Furthermore studies were needed to evaluate the long-term performance of the low cost two-stage acid scrubber.

In this study, two-stage wet scrubbers with sodium bisulfate solution were used on three broiler houses at three sites in DE and PA. The objectives of this study were to: examine the NH_3 removal efficiency of the scrubbers over a prolonged period and evaluate the operation consumption of wet scrubber under commercial broiler farms, include acid, water, and electricity.

2.3 Materials and Methods

2.3.1 Scrubber Construction

Three full-scale NH_3 scrubbers were tested in this research. The scrubbers consisted two stages (Figure 13): the first stage scrubber used water to remove particulate matters (dust and feather) from exhaust air and the second stage used acid solution to capture NH_3. In this research, sodium bisulfate (PLT®, Jones-Hamilton co., Walbridge, OH) was used as acid agent.

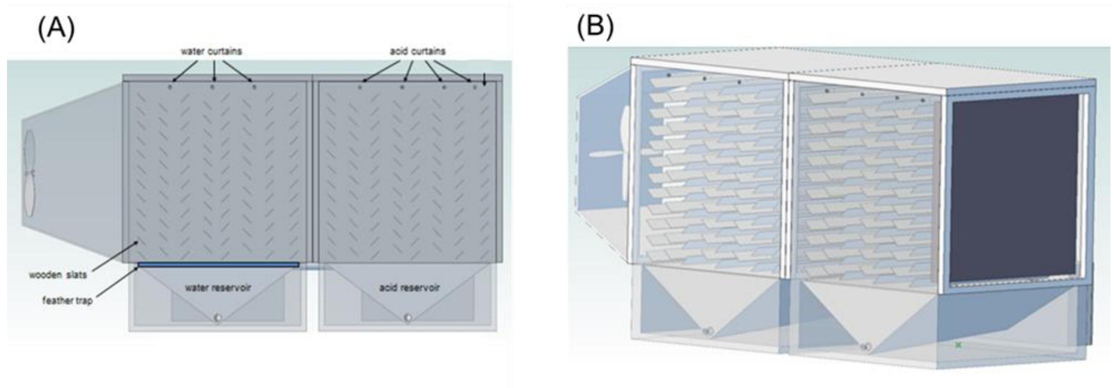

Figure 13 Schematic diagram of the scrubber

The dimensions of each stage of the scrubbers were of 1.6 m length, 1.6 m width and 2.2 m height, respectively. The shield of the scrubber was 63.5 mm thick and made of fiberglass. Each scrubber had a V-shaped tank that had a capacity of 360 L. A float switch was equipped in each tank to control the liquid level. Both scrubbers also had an immersion heater (Model, Vulcan Industries, CITY, STATE) with a 75 cm long heating tube. The heaters were designed to heat the liquid during cold seasons.

A liquid deliver system was built in each of the scrubber that included a pump, delivery pipes and wooden slats. In dust scrubber, a 1/2 HP (0.372 kW) immersion pump (Little Giant, 6EN-CIA-SFS, Franklin Electric Co., Fort Wayne, IN) was used to recirculate water from the tank to delivery pipes. Water was delivered into three 5 cm OD. PVC pipes at the top of the dust scrubber. The pipes had two rows of holes (0.1 cm) face to the slats and from which the water was delivered. The holes were 5 cm apart on the side near the pump, 3.5 cm apart in the middle third of the pipes and 2.5 cm apart on the side further away from the pump. The dust scrubber held up to 8 rows of 10 pieces of wooden slats at a 45^{o} angles. A removable screen was also equipped at the top of the tank of dust scrubber to trap feather and other large particulate maters to prevent clogging in pump and delivery pipes.

The acid scrubber used a 1/3 HP (0.249 kW) magnetically driven acid compatible pump (IWAKI MK-100RCT, Iwaki America Inc., Holliston, MA). The delivery pipes and slats were same with dust scrubber. The acid scrubber also equipped a plastic tray at the front of the opening to recover large water drops.

2.3.2 Scrubber operation and maintenance

The scrubber control and record units were located in a control box mounted on the side wall. A solid-state relay was used to turn on/off the pumps synchronously with the house fan on/off. A water meter with pulse generator was used to monitor the water consumption. Both scrubber on/off status and water consumption were recorded by a HOBO data logger (HOBO U12-006, Onset Computer Co., Bourne, MA) at 10-sec intervals.

The scrubbers, included all removable units, were thoroughly cleaned by power washers after every flock and the liquid was drained out. One day before the new flock started, the tanks were fulfilled with tap water. 25 or 50 lb. sodium bisulfate was added into acid scrubber water and fully dissolved. During the flock, acid solution pH in two DE sites was checked twice per day and sampled before sodium bisulfate was added. In PA site, the acid solution pH was checked and sampled every week. Additional 25 lbs PLT was added into the acid solution if the pH was above 7 when checked in all three sites.

2.3.3 Air sampling and analysis system

An air sampling and analysis system was used at each research site (Figure 14). Two sampling ports were installed in front of fan (inside) and after acid scrubber (outside), respectively. A liquid block filter was used at the sampling end of the tubing to remove liquid droplets and particulate maters. The filter was replaced every week or when found dirty.. The PTFE air sampling tubing was wrapped with a heating cable set at 32 ^oC (90 ^oF) and polyethylene pipe insulation material to prevent water condensation in the sampling tubing. A solenoid valve (Model 456654, Christian Bürkert GmbH & Co. KG.) was controlled by a programmable logic controller (SG2-12HR-D, TECO Electric & Machinery Co., Singapore). During operation, a pump took sample from inside through the valve when the fan was off. The valve switched to the outside sampling port when the fan was on. When the fan ran longer than 3 min, the controller made the valve switch from outside/inside every 3 min. When the fan stopped, the valve was switched back to inside. The air sample was sent to a PTFE manifold by the pump and a photoacoustic gas analyzer (Chillgard RT, Mine Safety Appliances Co., PA.) continuously took sample from the manifold and determined the NH_3 concentration. Only the last reading from Chillgard over each 3-min measurement circle was used for data process. The NH_3 concentration from Chillgard RT and valve on/off status were recorded by a HOBO data logger at a 30-sec intervals.

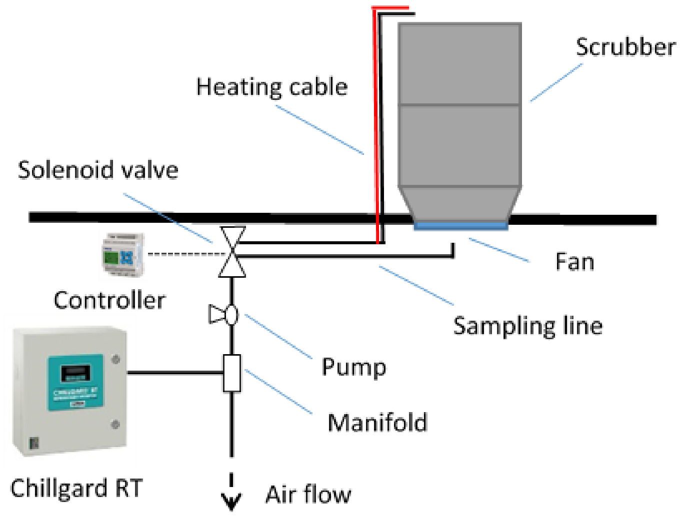

Figure 14 Schematic diagram of air sampling system

2.3.4 Emission rate measurement

The fan airflow rate was determined by a Fan Assessment Numeration System (FANS) device (Gates et al., 2002; Wheeler et al., 2002), static pressure (S.P.), and fan running time. Every fan was tested under three different S.P.s within the normal operation range before test. The NH_3 emission rate (ER) from was determined by the flowing equation:

$$ER = Q_T \times G_e \times 10^{-6} \times \frac{T_{std}}{T} \times \frac{w_m}{v_m} \tag{6}$$

where:

ER = Gas emission rate for the house, g hr^{-1} $house^{-1}$

Q_T = Exhaust total ventilation rate of the house at field temperature and barometric pressure, m^3 hr^{-1} $house^{-1}$

G_e = Gas concentration of exhaust house ventilation air, parts per million by volume (ppmv)

w_m = molar weight of the gas, g $mole^{-1}$ (17.031 for NH_3)

V_m = molar volume of gas at standard temperature (0 °C) and pressure (101.325 kPa) or STP, 0.022414 m^3 $mole^{-1}$

T_{std} = standard temperature, 273.15 K

T = absolute temperature of exhaust air, K

The fans ON/OFF status were monitored by the switch sensors attached on the power cable of the fan. The static pressure (SP) of each house was measured by Differential Pressure Transducer (Model 264, Setra Systems., MA). All the data was recorded by a HOBO logger at a 30-sec intervals.

2.3.5 Testing sites

Three broiler houses, two located in DE (Delaware) and one located in PA (Pennsylvania), were chosen for this study. DE site 1 was a commercial broiler house measured 121.92 m × 18.29 m (400 ft × 60 ft) (Figure 15a.). This house used build-up and only removed top cakes after every flock. The scrubber was installed on a 36’’ endwall fan. The airflow of the fan was 2.67 m^3/s (5669 cfm) under 12.44 Pa (0.05” w.c.) S.P. without the scrubber. DE site 2 was an environmental house at the research and education center of University of Delaware (Figure 15b). This house was measured 16.76 m ×12.19 m (55 ft × 40 ft), and equipped with two 36’’ and two 24’’ fans. The scrubber was installed on one of the 24’’ fan. The airflow of this fan under 12.44 Pa (0.05” w.c.) S.P. was 0.97 m^3/s (2062 cfm). PA site was an organic broiler house measured 152.40 m × 15.24 m (500 ft × 50 ft). This house used new bedding for every flock (Figure 15c). The scrubber was connected to a 36’’ sidewall fan through a

90-degree tunnel due to the space limitation on the farm. The sidewall fan had an airflow rate of 2.25 m^3/s (4768 cfm) under 12.44 Pa (0.05 w.c.) S.P.

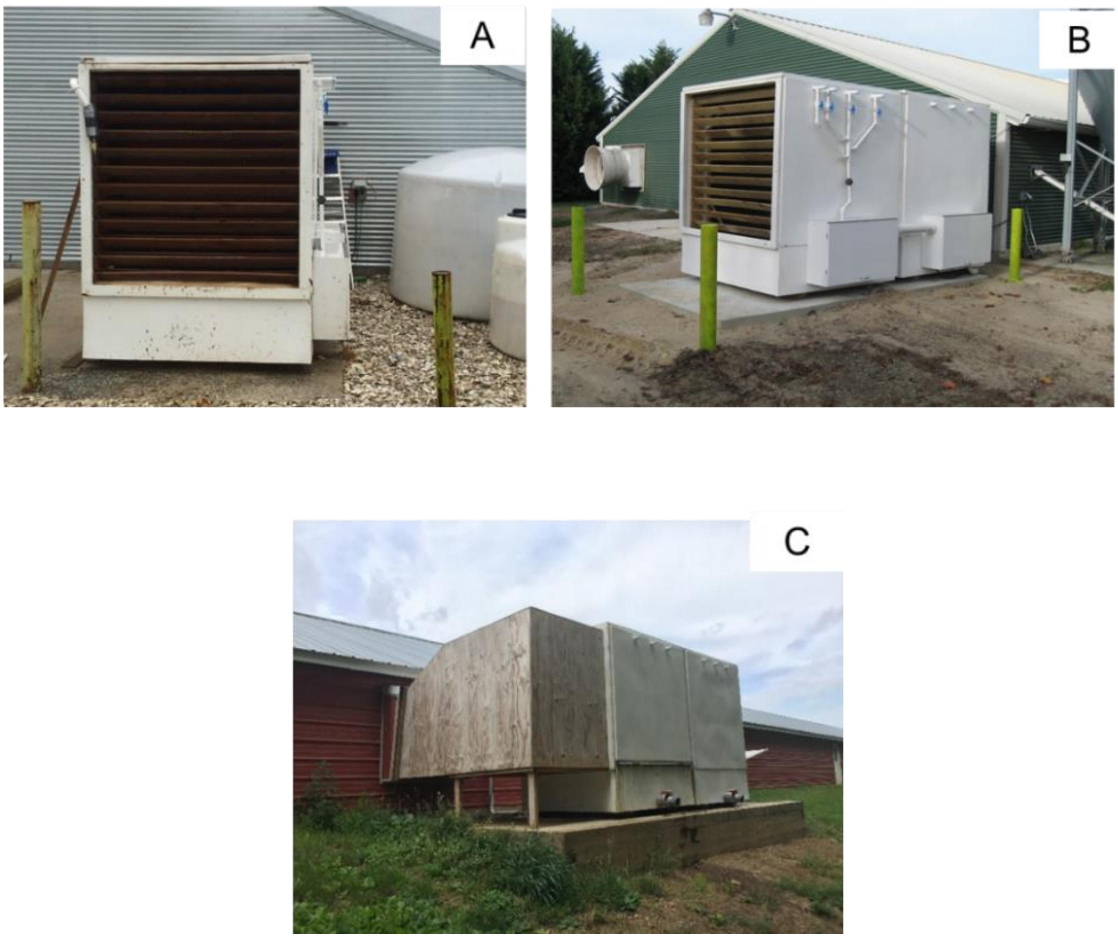

Figure 15 Photographs of the three testing sites (A: DE site 1; B: DE site 2; C: PA site)

The test was started on October 2013 and ended on June 2015. A total number of 25 flocks were monitored in three sites. The flock information was summarized in Table 4.

Table 4 Flock information for the three sites

Flock #	Period		
	DE site1	DE site2	PA site
1	10/21/13 – 12/16/13	01/27/14 – 03/24/14	01/09/14 – 02/20/14
2	12/31/13 – 02/10/14	04/14/14 – 06/10/14	03/05/14 – 04/17/14
3	03/14/14 – 04/28/14	07/28/14 – 09/26/14	04/17/14 – 06/03/14
4	05/31/14 – 07/23/14	10/15/14 – 12/02/14	06/10/14 – 08/05/14
5	08/08/14 – 10/06/14	01/27/15 – 03/25/15	08/08/14 - 09/23/14
6	10/31/14 – 12/30/14	04/14/15 – 06/10/15	10/27/14 – 12/15/14
7	01/13/15 – 03/05/15		01/02/15 – 02/18/15
8	03/27/15 – 05/25/15		03/04/15 – 04/22/15

2.3.6 Scrubber efficiency

Scrubber performance, in term of NH_3 removal efficiency, in the field tests was evaluated using equation 2:

$$E = \frac{m_s}{m_a} \times 100 \tag{7}$$

where,

e = NH_3 removal efficiency, %

m_s = NH_3-N in scrubber solution (both dust and acid scrubber), g

m_a = NH_3 in exhaust air, g

The NH_3-N in solution was determined in the lab with the water samples from dust and acid scrubber.

2.4 Results and Discussion

2.4.1 Scrubber running time

Figure 16 shows the monthly scrubbers running time in three sites during the test (exclude the down time between flocks). The running time varied from time and farms, and the overall running time during test were 61.44% in DE site 1; 82.80 % in DE site 2, and 57.42 % in PA site. Since the scrubber was running with the connected fan, its running time depended on the broiler house ventilation strategies. To achieve a higher use efficiency, it is recommended the manager set the scrubber-connected fan as primary fan.

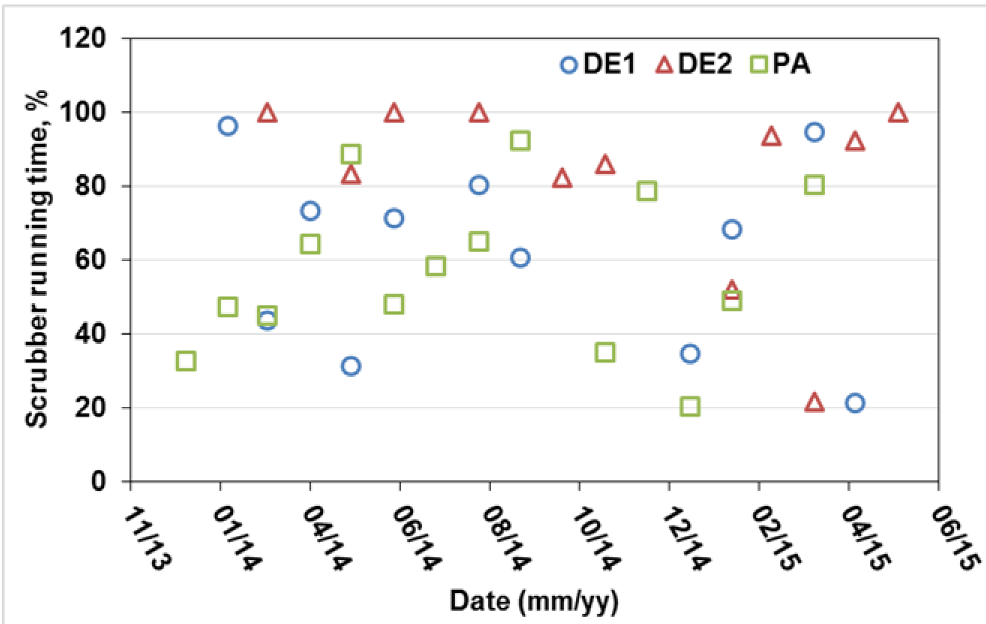

Figure 16 Monthly scrubbers running time during the test (%)

2.4.2 Scrubber efficiency

The scrubber efficiency was calculated based on the NH_3 in exhaust air and NH_3 absorbed by solutions as showed in equation 1. Daily average NH_3 emission rate and scrubber efficiency are shown in Figure 17. The Daily NH_3 emission rate in DE site 1 and PA site can up to 5000 g/d. while DE site 2 was less than 1600 g/d due to the low ventilation rate. The overall scrubber efficiency for the three sites were 31.3, 34.3 and 11.0 %, respectively. PA site scrubber only achieved 1/3 performance compared with the other two sites. It was due to PA site acid solution was checked and replaced every week while the other two sites were done every day. It was observed that with high NH_3 emission rate the acid solution could neutralized in two days.

Although the scrubbers in this study have two stages, only the second stage is designed to absorb NH_3. The scrubber efficiency is comparable to some previous studies. Melse and Ogink (2005) reviewed different air scrubbing techniques used in Europe for NH_3 and odor reduction and reported 40% to 100% NH_3 removal efficiencies. Hadlocon et al. reported a 51 %, 89% and 94 % NH_3 removal rate for one-stage, two-stage and three-stage acid scrubbers used in a swine farm. The low efficiency is attributed to several factors, including buildup or accumulation of ammonium precipitates inside the scrubber or combined with dust, possible leaks happened in the reservoir, and loss of droplets that escape from the scrubber opening. Error may also be attributed to the measurement method used for determining the ammonia concentration from acid solution samples, which required dilution of the samples to reach detectable limits. Another potential cause of error was obtaining representative samples, as the samples were taken from water drops from the slats. Although the tank inflow and outflow create a dynamic system, perfect mixing cannot be guaranteed.

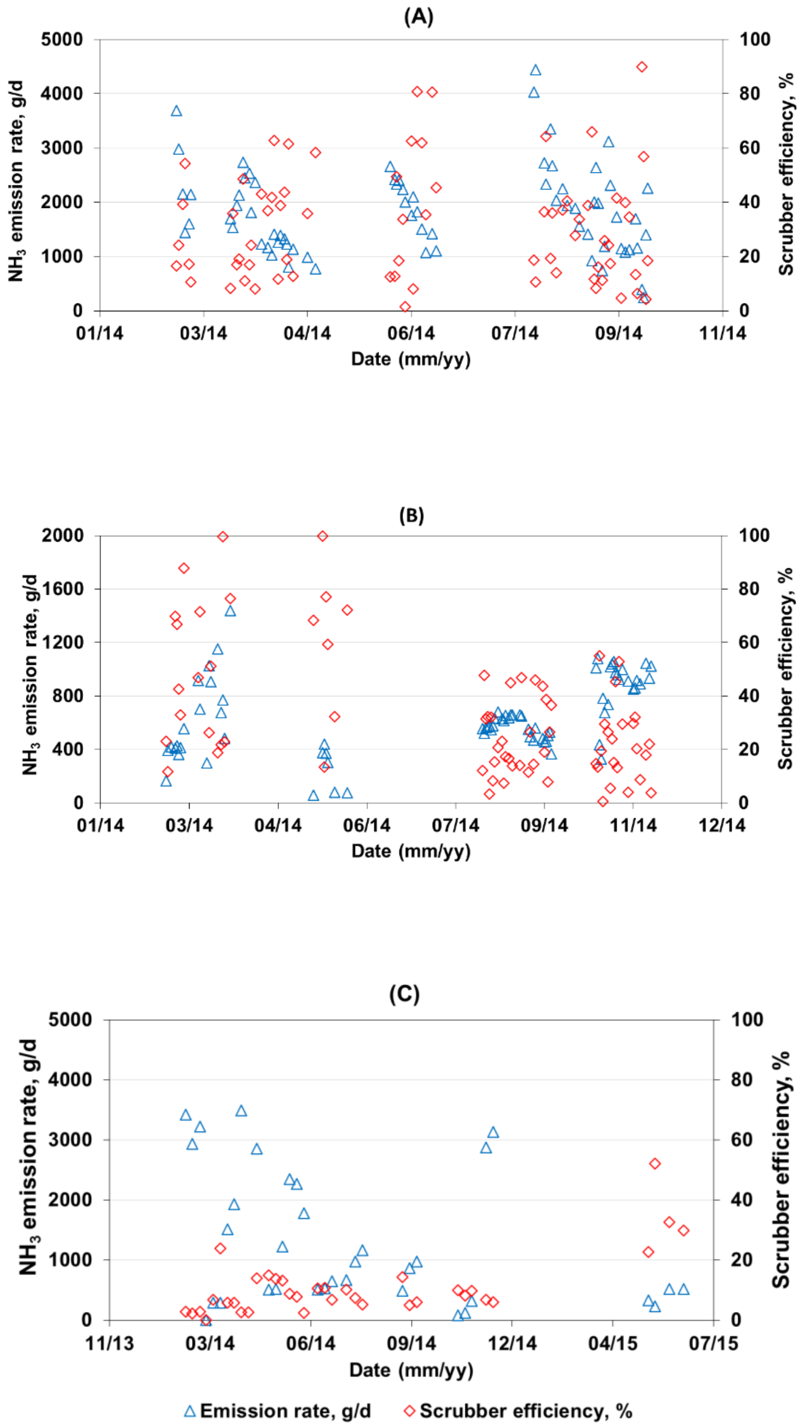

Figure 17 Daily average NH_3 emission rate and scrubber efficiency in three sites (A: DE site 1; B: DE site 2; C: PA site)

Figure 18 shows the scatter plot of NH_3 emission rate and scrubber efficiency. The scrubber efficiency has a significant negative relationship with NH_3 emission rate (DE site 1, $P<0.01$; DE site 2, $P<0.05$; PA site, $P<0.01$). It is because when exhaust air cross the scrubber, mass transfer of ammonia occurs from the gas to liquid phase. This transfer is dependent on the concentration gradient, contact time of gas and liquid phase, and the size of the contact area between the gas and water phase (Melse and Ogink, 2005). With a high NH_3 emission rate, it usually indicate a high NH_3 concentration and short contact time between exhaust air and acid solution.

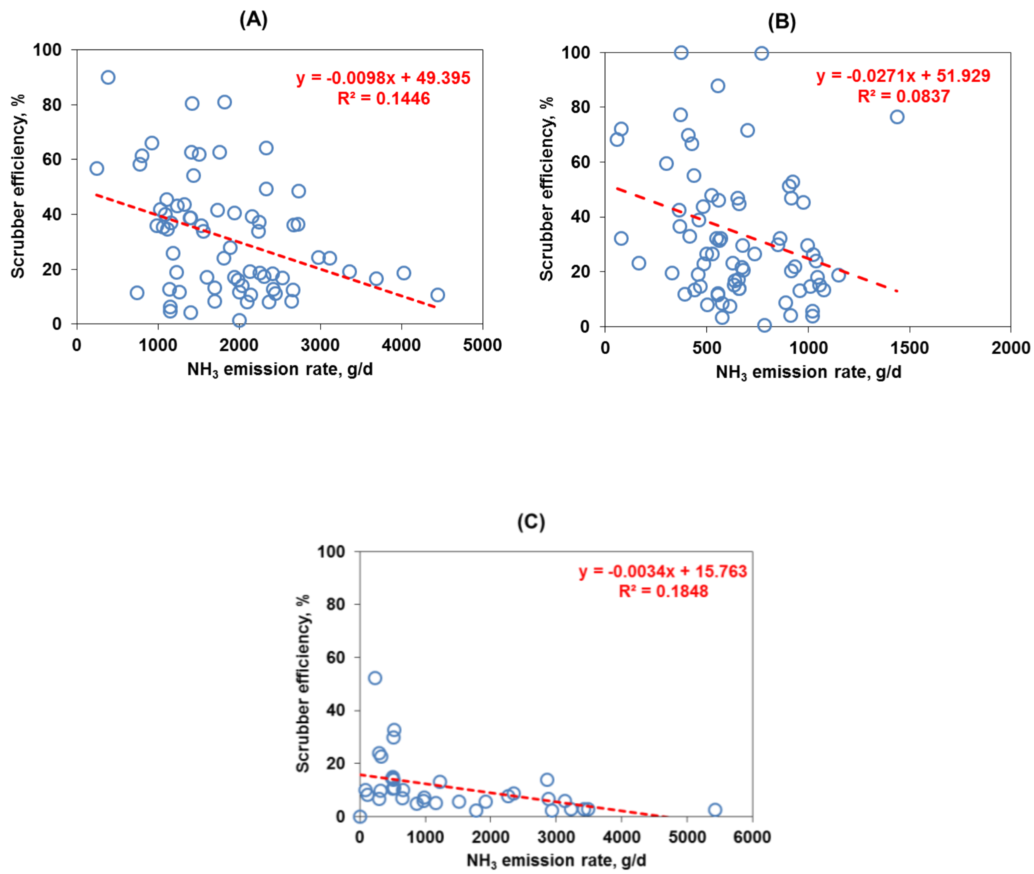

Figure 18 Scatter plots of NH_3 emission rate and scrubber efficiency

2.4.3 Water, PLT, and electricity consumption

Table 5 shows the average daily consumption of water, PLT and electricity in three test sites. Scrubber operation entails consumption of water, chemicals, and energy. Water was consumed due to evaporation and droplets carried by through air. H^+ ionized from PLT in acid solution combined with NH_3 continuously. Therefore, the amount of PLT in the acid solution decreased with scrubber operation. PLT was consumed also due to the water loss as the spilled droplets. The resources of electricity consumption included two pumps in each stage, heating tube in acid scrubber and heating lamps in control boxes.

The average daily water consumption ranged from 0.070 to 0.127 m^3/d and had an overall average of 0.103 ± 0.036 m^3/d. Hadlocon et al. (2014) reported a water loss rate of 0.0025 m^3/d in a three-stage acid scrubber used in pig farm. That may because their scrubber equipped with a demister at the end of the scrubber which minimized water evaporation and droplet. However, the demister was the major cause of static pressure drop of the scrubber (Hadlocon et al., 2014). The overall average PLT consumption was 2.987 ± 1.281 kg/d. It showed a large difference between PA site and two DE sites, which was due to the acid solution check and replacement frequency. The pump was main source of energy consumption, with a theoretical consumption rate of 9.69 kWh per day (base on the rated power and average scrubber running time). The monitored temperature of acid solution demonstrated the liquid can obtain enough heat to prevent ice during scrubber running. Thus, it is not necessary to heat the liquid and the electricity consumption here was overestimated.

Table 5 Average daily water, PLT and electricity consumption

Site	Water (m3/d)		PLT (kg/d)		Electricity (kWh/d)	
	Mean	±SD	Mean	±SD	Mean	±SD
DE site 1	0.102	±0.038	3.538	±0.816	10.877	±2.529
DE site2	0.070	±0.011	3.175	±1.512	13.410	±1.817
PA site	0.127	±0.030	2.197	±1.277	NA	NA

Table 6 summarized the water, PLT and electricity consumption for every kg NH_3 absorbed by the acid solution. Theoretically, each kg NH_3 can neutralize 7.06 kg PLT ($NaHSO_4$). The PLT loss may cause by water loss or reaction with other components in exhaust air.

Table 6 Water, PLT and electricity consumption for every kg NH3 absorbed

Site	Water, m^3	PLT, kg	Electricity, kWh
DE site 1	0.17	6.86	21.08
DE site 2	0.33	15.72	66.39
PA site	0.19	22.72	NA
Average	0.23	15.10	43.74[a]

[a] The average of two DE sites

2.5 Conclusion

In this study, three scrubbers in three different sites were tested to capture the NH_3 comes from broiler house. The following conclusion can be drawn:

The two-stage scrubber can remove 11.0 to 34.3 % NH_3 from broiler house exhaust air. To achieve a higher removal efficiency, the acid solution should check and replace frequently.

In this study, for every kg NH_3 absorbed by acid solution, the water, PLT and electricity consumption were 0.23 m^3, 15.10 kg and 43.74 kWh, respectively.

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Chapter 3

USING POULTRY LITTER-DERIVED BIOCHAR AS LITTER AMENDMENT TO CONTROL AMMONIA EMISSIONS

3.1 Abstract

The literature documents large ammonia (NH_3) emission to the atmosphere from poultry litter (PL) occurring during poultry grow-out, causing not only potential health impacts to humans and animals, but also environmental concerns. Furthermore, NH_3 emission represents a significant loss of valuable nitrogen fertilizer. In the face of more stringent nutrient management and air quality regulations, it is strategically important to explore innovative technologies for alternative use of poultry litter to not only curtail NH_3 emission but also recover its fertilizer value to protect the environment and health. The current technology for ammonia control is based on aluminum sulfate, sodium bisulfate, and ferric sulfate for absorbing or reacting with the ammonia released during the biodegradation of the animal manure. Biochar would be applied in the same manner as the other amendments. Due to its higher absorptive properties, the acidified biochar with low pH as litter amendment will result greater reduction on NH_3. Converting poultry litter to biochar as litter amendment will potentially increase the value of the poultry litter. Another advantage of using biochar is that biochar based litter amendment has less soil salinization potential than other litter amendments that contain metal irons. Al^+, Na^+, and Fe^+ in the other litter amendments could cause metal iron accumulation and increase soil salinity. In this study, an emission vessel system with poultry litter was used and a series experiments

were conducted to evaluate the performance of acidified poultry litter-derived biochar as litter amendments. The results showed, to achieve a similar performance, twice amount acidified biochar was needed compared to PLT (sodium bisulfate). With the application rate of 200 lb/1000 ft^2 acidified biochar, the NH_3 emission reduction from poultry litter can up to 47%.

3.2 Introduction

For poultry industry, concerns about NH_3 are multifaceted, including issues of production performance, animal health, welfare, and environmental impacts. Ammonia in poultry houses originates from decomposition of uric acid and organic nitrogen in bird excreta by certain bacteria in the litter (Schefferle, 1965; Carlile, 1984). The main factors affecting aerial NH_3 concentrations in poultry houses are litter conditions and house ventilation. Ammonia production is favored by high temperatures and pH (>7) of litter. Ammonia is particularly high in houses where litter is reused for successive flocks (Wheeler et al., 2006; Burns et al., 2007). NH_3 is irritating to mucous membranes of the respiratory tract and the conjunctivae and corneas of the eyes. Damage to the mucous membranes of the respiratory system increases the susceptibility of birds to respiratory infection (Anderson et al., 1964). High NH_3 levels also have a negative impact on the overall livability, weight gain, feed conversion, immune system function, and thus condemnation rates of broiler at processing (Reece et al., 1980). Retail industry marketers, as a component of their evolving animal care audit programs, are issuing guidelines for control and reduction of NH_3 within poultry facilities to address animal welfare concerns. Reducing NH_3 levels in-house can result in better bird performance and health and higher profits to the growers and the integrator.

In principle, the volatilization of NH_3 from poultry litter (PL) is predominantly influenced by the equilibrium between aqueous NH_3 and NH_4^+ when other environmental factors are constant. Therefore, a rational way of reducing NH_3 volatilization is the application of litter amendments to reduce the concentrations of aqueous NH_3 in the litter, i.e., to shift the NH_3-NH_4^+ equilibrium towards the NH_4^+ side. The NH_3-NH_4^+ equilibrium is strongly pH-dependent, with low pH values favoring the formation of NH_4^+. Thus, adding acids and/or acidic salts (namely acidifiers) may effectively suppress the escape of NH_3 from the litter. A variety of acidifiers have been tested for ammonia emission control, such as aluminum sulfate (Lefcourt and Meisinger, 2001; Moore et al., 1996), sodium bisulfate (Moor et al., 1996), ferric sulfate (Moor et al., 1996), ferric chloride (Moor et al., 1996), and phosphoric acid (Moor et al., 1996); these chemicals were found to effectively reduce the NH_3 emission in controlled experiments. Today, many acidifiers as litter amendment are commercialized, under the brands of such as Al^+ Clear™ (aluminum sulfate), Alum (aluminum sulfate), Klasp™ (ferric sulfate), and PLT™ (sodium bisulfate). They have been applied to PL as best management practices (BMPs) to control NH_3 volatilization (Moore et al., 1995, 1996, 2000; Terzich et al., 1998a, 1998b; Worley et al., 2000; Sims and Luka-McCafferty, 2002; Armstrong et al., 2003). However, concerns still remain over the possible negative effects of acidifiers on animal health. Besides, many acidifiers are strongly water-absorbing and quickly draw moisture from the air, causing difficulty in material storage and handling. In addition to altering the NH_3/NH_4^+ balance, acidifiers also inhibit bacterial and enzyme activities involved in the formation of NH_3, thus reducing the NH_3 production in the litter. Ammonia volatilization starts from microbial decomposition of nitrogenous compounds, principally uric acid, in poultry manure. Uric acid decomposition is most favored under alkaline (pH>7) conditions; and the effect of uricase – the enzyme that catalyzes uric acid to breakdown – reaches its maximum at pH=9. Other chemicals known to inhibit the activity of microbial uricase in poultry manure include zinc sulfate and copper sulfate (Kim and Patterson, 2003). However, they are relatively expensive and can hardly be applied at large scales.

Another method for reducing the volatilization of NH_3 is to cover the litter floor with adsorbents. With a large surface area or cation exchange capacity, those adsorbents can help immobilize NH_3, NH_4^+, and/or their precursors in the litter via gas-solid or liquid-solid adsorption. As malodorous volatiles can be concurrently adsorbed, odor control represents the other benefit of the application of adsorbent materials. For the purpose of litter amendment, the most studied adsorbents are zeolite, montmorillonite (also known as bentonite), and charcoal (or char). Zeolites can be naturally occurring materials (e.g., clinoptilolite) or artificially synthesized. Kithome et al. (1999) investigated the efficacy of zeolite on the reduction of NH_3 loss from poultry manure during composting, reported a 44 % reduction in NH_3 release when 38 % zeolite was placed on the surface.

Charcoal is a black porous solid material consisting of mostly carbon and slightly mineral ash. It is usually produced via pyrolysis of organic substrates (e.g., wood, paper and bones), i.e., heating them in oxygen-absent environment. Along with the solid charcoal, a gaseous production syngas (a mixture of CO, H_2, CO_2, CH_4, and etc) and bio-oil (also named pyrolysis oil) can also be harvested from a typical pyrolysis process. The adsorption properties of charcoal are highly diverse, depending on feedstock raw materials, preparation conditions, and post-treatment processes.

Freshly-prepared charcoal often shows a relatively small surface area and low porosity because of the blockage of the inherent micropores by inorganic and organic residues. To increase the surface area and accordingly the adsorption capacity, activation of charcoal is often practiced, which involves a variety of physical (e.g., steam activation) or chemical processes (zinc chloride activation) to remove the residues and enlarge the pores; and the end product is referred to as activated charcoal (or activated carbon). Activated charcoal is one of the best studied and extensively used adsorbents. Similar to zeolite, the pore structure and surface functional groups of charcoal can be tailored by treating it with different chemicals under different conditions, so as to optimize the charcoal's adsorption performance towards the adsorbate of interest. For example, charcoal can be partially oxidized in air or with nitric acid, or treated with sulfuric acid to increase the its surface acidity, making it suitable for capturing alkaline chemicals such as NH_3. Acidified charcoal products were found to scrub NH_3 in the air stream very efficiently. Asada et al. (2006) reported that a bamboo charcoal treated with diluted sulfuric acid delivered an enhanced NH_3 adsorption capacity than untreated ones.

According to Spokas et al. (2012), adsorption of NH_3 on carbon surface involves a variety of physical and chemical processes. Physical adsorption involves no changes in the molecular formula or oxidation state of adsorbents and adsorbates, and is exclusively caused by van de Waals force. The physical adsorption of NH_3 on activated charcoal has been extensively investigated. Chung et al. (2005) reported a physical adsorption capacity of 0.73 mg NH_3 per gram of granular activated carbon (GAC). A later study by Rodrigues et al. (2007) reported that physical adsorption of NH_3 on GAC was strongly dependent on temperature, with the adsorption capacity dropping from 0.6 - 1.8 mg NH_3/g GAC at 40 ºC, to 0.2 - 0.7 mg NH3/g GAC at 80ºC and further to 0.15 - 0.35 mg NH_3/g GAC at 120ºC. In contrast, chemical adsorption is caused by chemical reactions between adsorbents and adsorbates, in this particular case, between charcoal and NH_3. The adsorption mechanism, capacity, rate, and reversibility are strongly influenced by the functional groups on the charcoal surface. For example, on oxidized carbon surfaces (containing carbonyl groups), NH_3 adsorption occurs through the formation of amines and amides at ambient temperature and ringed nitrogen-containing organic compounds (e.g., pyridines and pyrroles) at high temperature (Jansen and van Bekkum, 1994). In addition, the existence of acidic species on the carbon surface strongly affects the adsorption process. Liquid water and vapors can compete for adsorption sites with NH_3. Liquid water also leads to the formation of water films on charcoal, which absorbs NH_3 molecules and converts part of them to NH_4^+ ions (Spokas et al. 2012).

Biochar, by definition, is charcoal used for agricultural purposes. The application of biochar as soil and compost amendments to reduce NH_3 loss is not a new idea. Kastner et al. (2009) showed that woody charcoal and biochars generated at low pyrolysis temperatures adsorbed NH_3. Steiner et al. (2010) showed that biochar reduced the NH_3 volatilization loss by 52 % during PL composting. Taghizadeh-Toosi et al. (2012) reported that land application of a wood-based biochar at 15-30 ton ha^{-1} reduced NH_3 volatilization losses by 45 % from a silt loam soil spiked with ruminant urine. However, no attempts of applying PL derived biochar (PL biochar) as litter amendment during broiler grow-out have been reported. Those previous laboratory trials, along with the knowledge about NH_3 adsorption on charcoal or similar carbon materials, suggest the promising use of biochar to effectively control NH_3 emission from PL.

The objective s of this laboratory-scale study were: a) to compare the NH_3 reduction efficiency between acidified PL biochar and PLT at different rates onto broiler litter, and b) to examine the NH_3 reduction efficacy of the combination of acidified PL biochar and PLT at different broiler litter moisture content.

3.3 Materials and Methods

3.3.1 Air emission vessels

Twelve emission vessels were used (Figure 19) and placed in an environmentally controlled room that hosted the vessel system with controlled temperature to mimic the broiler house temperature, which gradually decreases from 28 at day old to 20 °C at 4-wk of age during a typical grow-out. The 19-L (5-gal) vessels were made of plastic containers with airtight lid and air inlets and outlets on the lids. The vessels were operated under positive pressure. A diaphragm pump (DDL80-151, Gast Co., Benton Harbor, MI) was used to supply NH_3-free fresh air to the emission vessels. Flow rate of the fresh supply air was controlled and measured with an air mass flow controller (GFC47, Aalborg Instruments & Controls, Inc., Orangeburg, NY). The supply air was connected to a distribution manifold, where air was further divided via 12 identical flowmeters (RMA-1-SSV, Dwyer Instruments, Inc., Michigan City, IN). A flow rate of 3 LPM was introduced into each vessel, resulting in an air exchange rate of 10 air changes per hour (ACH) that is similar to normal ventilation rate of broiler houses with birds at 4wk of age. Teflon tubing (0.25 in. OD and 0.125 in. ID) was used for the emission vessel system. Samples of the exhaust air from each of the 12 vessels, and the room air were sequentially taken and analyzed at 5-min intervals to ensure sufficient time to obtain stabilized readings. This yielded a measurement cycle of 1 h for each vessel. The successive sampling was achieved by controlled operation of solenoid valves (Type 6014, Bürkert Contromatic Co., Charlotte, NC). The NH_3 concentrations were measured with a photoacoustic multi-gas analyzer (model 1412, Innova AirTech Instruments A/S, Ballerup, Denmark) that uses an internal pump to draw sample air. The NH_3 analyzer was checked and calibrated before each experiment. Air temperature and RH of the room were monitored with a temperature-RH data logger (U23-001, Onset Computer Co., Bourne, MA). Analog outputs from the NH_3 analyzer and the mass flow meter were recorded by a LabVIEW program (National Instruments Co., Austin, TX) at a 1-sec interval.

For each trial, a broiler litter sample with an initial weight of 2.0 kg (4.4 lb) was used as the experimental unit. The 2.0 kg sample was placed in a 3.8 L (1 gal) container (surface area of 0.02 m^2 or 0.22 ft^2) that was further placed inside the 19-L emission vessel. The acidified PL biochar or PLT was incorporated into the top 1.3 cm (1/2 in.) litter in the vessels by surface spreading and immediate mixing. This mixing simulated the disturbance factor by bird activities.

Figure 19 Emission vessel setup for evaluating efficacy of litter amendments on ammonia emission reduction from broilers.

3.3.2 Broiler litter and acidified PL biochar

Broiler litter was collected from a commercial broiler house. Before the experiment, the litter was mixed with deionized water to get three different moisture content (MC). The broiler litter properties are shown in Table 7. Sample 1 was used in the first experiment and sample 2 and 3 were used in the second experiment as low and high MC litter. The PL biochar was derived from slow pyrolysis at two different temperatures, 400 and 500 ^{o}C with pelletized poultry litter. Then biochar was either water or air dried. In this study, all four types biochar were mixed together for the test. The acidified biochar was prepared by contacting 200 g of dry biochar with 186 g H_2SO_4 solution (6M). Upon soaking time of 1 h at room temperature (24 – 25 °C), the samples were drained, dried in an oven at 105°C, and cooled to room temperature in a desiccator.

Table 7 Litter properties of broiler litter used in this study

	Sample 1		Sample 2		Sample 3	
	Mean	SD	Mean	SD	Mean	SD
NH_3-N, % (DM)	0.63	0.03	1.03	0.01	1.74	0.03
Org-N, % (DM)	2.61	0.13	2.52	0.00	2.51	0.01
TKN, % (DM)	3.23	0.15	3.54	0.01	4.26	0.03
MC	19.45	2.05	35.80	0.85	38.95	0.49
pH	8.45	0.07	8.30	0.14	8.30	0.00

Note: NH3-N = ammonia nitrogen; Org-N = organic nitrogen; TKN = total Kjeldahl nitrogen; MC = moisture content; DM = dry mater basis

3.3.3 NH_3 reduction test

In the experiment 1, two PLT dosages (100 and 200 lb/1000ft^2), three PL-biochar dosages (50, 100, and 200 lb/1000ft^2) were applied, leading to 5 additive regimens plus control. The 5 additive regimens along with control were randomly assigned to 6 emission vessels. Two trials were conducted to obtain 4 replicates of each treatment, each trial contained 2 replicates and lasted 14 d. The room temperature was controlled between 26.7 to 29 ^oC to simulate the brooding condition.

In the experiment 2 that examine NH_3 reduction under different litter MC, 6 emission vessels were randomly assigned to 2 groups, each group had 3 vessels and filled with high (40 %) or low (35 %) MC litter. In each group, 1 vessel was used as control, and the other 2 vessel applied PL biochar (200 lb/1000ft^2) and PL biochar with PLT (100 lb/1000ft^2 PL-biochar and 50 lb/1000ft^2 PLT). Two trials were conducted to obtain 4 replicates of each treatment, each trial contained 2 replicates and lasted 14 d. The room temperature was set at 24 ^oC to simulate the grow-out after 4 wk of age.

3.3.4 Data analysis

From the hourly air flow rate and NH_3 concentration data, the corresponding NH_3 emission rate of the litter (g/h per m^2) was calculated for each vessel. Summation of 24 hourly NH_3 emission values yielded the daily NH_3 emission rate (g/d per m^2). Multiple comparison (t-test) was conducted to compare the daily emission rates and emission reductions of treatments. Differences in all comparisons were considered significant at $P < 0.05$.

3.4 Results and discussion

3.4.1 Environmental room air temperature and relative humidity (RH)

The temperature of the environmental room was set to simulate the commercial broiler house temperature during broiler grow out period (24 - 29 ^oC, or 70 - 85 F). Figure 20 showed the daily average room temperature and RH changes during this study. For the first experiment, the daily average temperature ranged from 27 - 30 ^oC (80 - 86 F), and had an average of 28 ^oC (83 F), while the RH ranged from 26 - 45 % and had an average of 36 %. For the second experiment, the daily average temperature ranged from 23 - 24 ^oC (73 - 75 F), and had an average of 24 ^oC (75 F), while the RH ranged from 19- 50 % and had an average of 35 %.

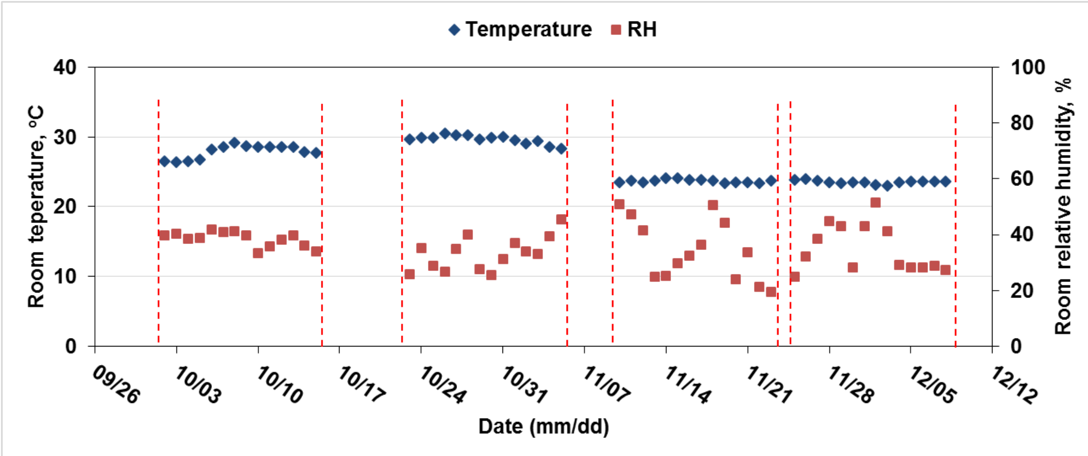

Figure 20 Environmental room temperature and RH changes during the study (red dash lines show the periods for the 4 trials)

3.4.2 Effects of PL biochar and PLT treatment on broiler litter NH_3 emission

Daily NH_3 ER from emission vessels with different dosage of PL biochar and PLT are shown in Figure 21. The adsorption of NH_3 took effect right after the application and had highest emission reduction on d 1. NH_3 emission reduction rates varied from 81 to 100 % in trial 1 and 70 to 100% in trial 2 at the end of d 1. NH_3 emission from the Ctrl vessels stabilized after 3 d in both trials, whereas concentrations of treatment (Trt) vessels continued to increase. For low PL biochar dosage (B50), NH_3 emission increased rapidly after d 1 and reach to the same level as Ctrl after 5 d. The high PL biochar (B200) and low PLT (P100) dosages showed the same trend on the effect of NH_3 emission. It took effects on NH_3 emission for 10 d in trial 1 and 9 d in trial 2. Daily NH_3 emission rates of PLT100, PLT200, B100 and B200 were significantly lower than Ctrl ($P < 0.01$) through the 14-d period in both trials while B50 was not ($P = 0.14$ in trial 1 and 0.47 in trial 2).

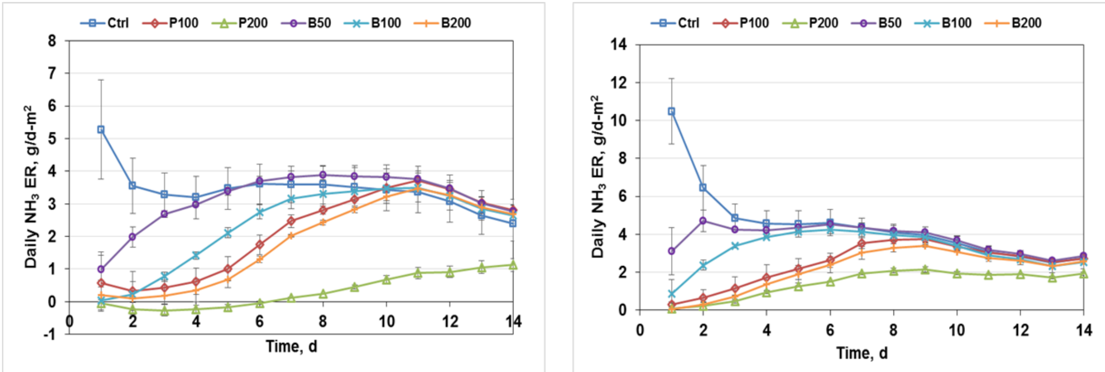

Figure 21 Daily NH_3 concentrations (mean and SE, n=2) of broiler litter vessels with various rates of PL biochar and PLT in trial 1 (left) and trial 2 (right) (Ctrl = no additive; P100 = 100 lb/1000ft^2 PLT; P200 = 200 lb/1000ft^2 PLT; B50 = 50 lb/1000ft^2 PLT; B100 = 100 lb/1000ft^2 PLT; B200 = 200 lb/1000ft^2 PLT)

Topical application of PL biochar and PLT considerably decreased NH_3 emission during the 14 d test. Cumulative NH_3 emission rate are illustrated in Figure 22 During the 14-d test period, significant difference between each Trt with Ctrl was observed ($P < 0.0001$) except B50 in trial 1 ($P = 0.181$). For the different additives and dosages (P100, P200, B50, B100, and B200) the cumulative NH_3 ER reductions over 14-d period were 41, 92, 9, 33, and 49 % in trial 1, and 47, 70, 16, 30, and 54 % in trial 2, respectively. Comparing the overall NH_3 ER reduction rate with different dosages PL biochar and PLT, P100 and B200 showed a similar performance whether in the NH_3 concentration profile or total NH_3 ER reduction rate (44 % vs. 52 %). The results indicate a twice amount acidified PL biochar is need to achieve the similar performance on NH_3 emission reduction of broiler litter with PLT.

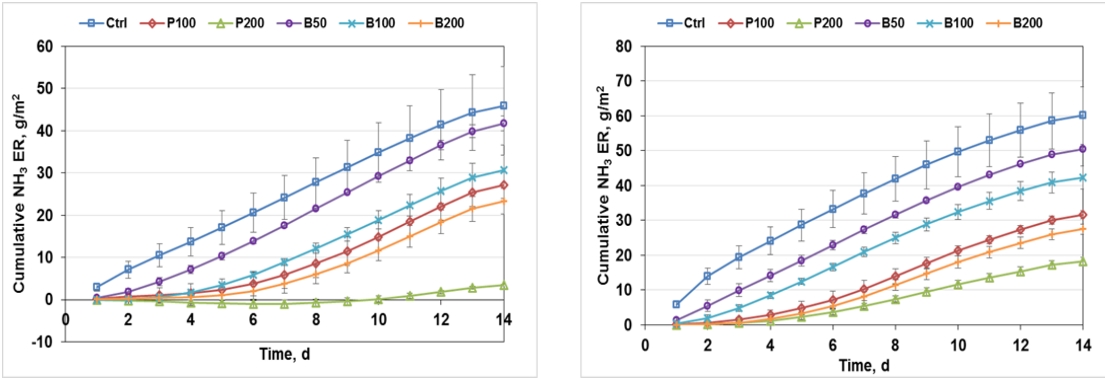

Figure 22 Cumulative NH_3 ER (mean and SE, n=2) from broiler litter vessels with various rates of PL biochar and PLT in trial 1 (left) and trial 2 (right) (Ctrl = no additive; P100 = 100 lb/1000ft^2 PLT; P200 = 200 lb/1000ft^2 PLT; B50 = 50 lb/1000ft^2 PLT; B100 = 100 lb/1000ft^2 PLT; B200 = 200 lb/1000ft^2 PLT)

3.4.3 Efficacy of combination of PL biochar and PLT at different litter MCs

As described previously, twice parts of PL biochar can achieve similar performance as one part of PLT on NH_3 emission reduction. A further study was conducted to evaluate NH_3 emission reduction of mixtures of PL biochar and PLT under different litter MCs.

Daily NH_3 emissions under different litter MCs were shown in Figure 23 Ammonia emissions at high litter MC were significantly higher than low litter MC in both trials with or without additives ($P < 0.01$). With high litter MC, NH_3 emissions from Ctrl decrease gradually for both trial during 14-d test period. The Trt regimens had significant reduction ($P < 0.05$) for the first 3 and 10 d compared with Ctrl in trials 1 and 2. With low litter MC, NH_3 emission from Ctrl were relative steady. The Trt regimens had significant reduction ($P < 0.05$) for the first 8 d compared with Ctrl. The results suggested that the acidified PL biochar could be used to control NH_3 during cold seasons and remain effective for 3 to 8 days depending on the litter MC when broiler houses are with high MC that is caused by limited ventilation.

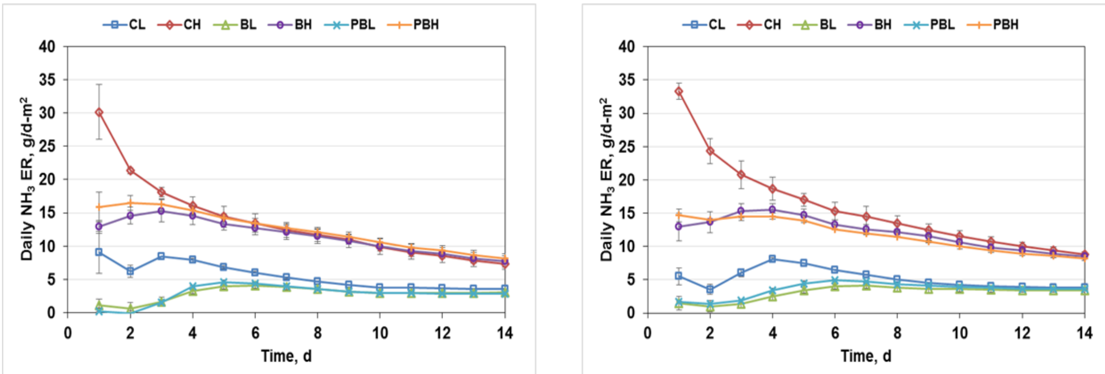

Figure 23 Daily NH_3 ER (mean and SE, n=2) at different litter MC in trial 1 (left) and trial 2 (right) (CL = no additive, 35 % MC; CH = no additive, 40 % MC; BL = 200 lb/1000ft^2 biochar, 35 % MC; BH = 200 lb/1000ft^2 biochar, 40 % MC; PBL = 100 lb/1000ft^2 biochar +50 lb/1000ft^2 PLT, 35 % MC; PBH = 100 lb/1000ft^2 biochar +50 lb/1000ft^2 PLT, 40 % MC)

The cumulative NH_3 emissions with different PL biochar and PLT combinations at different litter MC were shown in Figure 24 The application of PL biochar or PL biochar with PLT reduced NH_3 emissions both at high and low litter MC. After 14-d test period, the reductions rates for all additives at high and low litter MC were summarized in Table 8. Application of PL biochar achieved an average NH_3 emission reduction rate of 45.6 % at low litter MC and 20.2 % at high litter MC; while when replaced half biochar with equivalent PLT, the reduction rates were 40.9 % and 18.0 %, respectively. The comparison between two additives showed no significantly difference under both high and low litter MC.

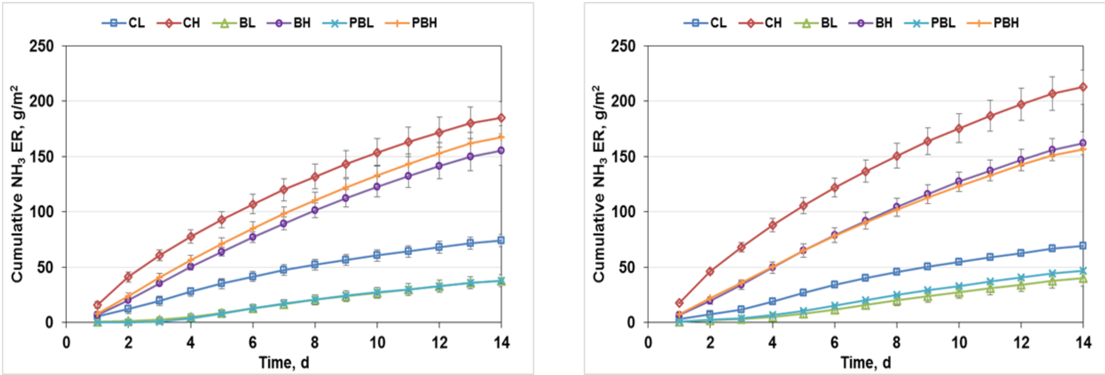

Figure 24 Cumulative NH_3 ER (mean and SE, n=2) at different litter MC in trial 1 (left) and trial 2 (right) (CL = no additive, 35 % MC; CH = no additive, 40 % MC; BL = 200 lb/1000ft^2 biochar, 35 % MC; BH = 200 lb/1000ft^2 biochar, 40 % MC; PBL = 100 lb/1000ft^2 biochar +50 lb/1000ft^2 PLT, 35 % MC; PBH = 100 lb/1000ft^2 biochar +50 lb/1000ft^2 PLT, 40 % MC)

Table 8 Compare of NH_3 emission reduction rate (%; mean ± SD) of different additives at high (40 %) and low (35 %) litter MC

	Low litter MC		High litter MC	
	Trial 1	Trial 2	Trial 1	Trial 2
PL biochar	49.0 ± 4.0	42.2 ± 8.1	16.3 ± 0.6	24.0 ± 10.4
PL biochar + PLT	49.1 ± 0.3	32.7 ± 4.8	9.6 ± 1.5	26.4 ± 4.8
P-value	0.98	0.80	0.57	0.91

Using acidifiers as litter amendments was demonstrated to be an effective way to control NH_3 volatilization. As an alternative litter amendment, PL biochar can not only effectively mitigate NH_3 emission, but also provide a low cost and environmental friendly way to utilize poultry litter. Although no attempts of applying PL biochar as litter amendment during broiler grow-out have been reported, we will plan to conduct further studies to evaluate the effect of acidified PL biochar litter amendment on broiler health.

3.5 Conclusion

A study was conducted to evaluate the effects of acidified PL biochar application on NH_3 emission from broiler litter. The following conclusions were made:

(1) Increased acidified PL biochar application rate could achieve the similar performance of PLT on NH_3 emission reduction from broiler litter;

(2) PL biochar with 200 lb/1000ft^2 of application rate reduced 45.6 % and 20.2 % NH_3 emission from broiler litter at high and low MC (40% vs. 35 %); and

(3) Replacement of 50% biochar with PLT didn't show significant difference on NH_3 emission reduction from broiler litter with high and low MC (40% and 35 %).

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Chapter 4

IMPACT OF FREQUENT LITTER AMENDMENT APPLICATION ON NUTRIENT COMPOSITION AND PROPERTY CHANGES OF STORED BROILER LITTER

4.1 Introduction

Ammonia (NH_3) not only is detrimental to animal health and production, but also contributes to acid deposition and eutrophication. The subsequent impacts of acid deposition can be significant, including adverse effects on aquatic ecosystems in rivers and lakes and damage to forests, crops and other vegetation. Eutrophication can lead to severe reductions in water quality with subsequent impacts including decreased biodiversity, changes in species composition and dominance, and toxicity effects. NH_3 also contributes to the formation of secondary particulate aerosols, an important air pollutant due to its adverse impacts on human health. NH_3 Emissions from the poultry houses in the Chesapeake Bay region are being considered on their impact to water quality; air emission regulations are expected especially as air quality standards become more stringent.

Litter amendment has been widely used in broiler and turkey operations, mostly at the early age for improving production performance. Mid-flock litter amendment application will further improving litter quality and maximize the potential of litter amendment on NH_3 reduction. A field study with three flocks with multiple mid-flock PLT applications showed >50% NH_3 emission reduction after 6-wk of age in a broiler facility.

Litter amendments can reduce the breakdown of uric acid and NH_3 formation, thus increasing the N value of litter/manure and reducing air and water quality concerns. Conserving NH_3 in poultry houses has other benefits as well including resource conservation (the original source of the NH_3 in litter was the fertilizer N used to grow the feed, which was produced using natural gas, a finite resource) and producing litter with higher N/P ratios which will more closely match crop uptake and thus be less likely to lead to P accumulations in soils.

By utilizing the litter amendment to control NH_3-N loss, the industry can demonstrate initial efforts to reduce air emissions before regulations come into effect, thereby appeasing regulators. In addition, estimating ACT effectiveness will allow regulators to consider their inclusion as a conservation practice in models, such as the US EPA Chesapeake Bay Model, and allow producers to receive credit for both implementation and decreases in pollutant emission.

In addition, there is increasing concern about the potential for N loss from litters stored in or near agricultural fields and the effects of storage practices on N losses from litters after land appli-cation. Furthermore, questions have been raised over the impact of changes in litter moisture content during storage on nutrient composition in the stored litter and the interaction of storage conditions and litter amendment.

The purpose of this study was to determine if NH_3-N, organic-N, pH, and moisture content change during different storage periods in a covered manure storage. Three profile samples from each stored litter were collected and analyzed monthly over a 7-month period. Litter pH, moisture content, organic-N, and NH_3-N concentrations were determined on an as-is sample. Evaluating the effect of storage time will help determine how storage time affects N compositi5on and litter properties in the two different litters.

4.2 Materials and Methods

The litter production was performed in an experimental house at the University of Delaware. The environmental house measuring 34.6 m x 12.1 m (114 ft x 37 ft) was east-west orientated and divided into two partitions, 17.3 m x 12.1 m (57 ft x 37 ft) each. The two partitions were symmetrical and shared the same end wall and control room. Each partition had insulated drop ceilings, static-pressure controlled box air inlets along the sidewalls, two radiant tube heaters (11,722Wor 40,000 British thermal units [Btu]/hr each), two gas-fired space furnaces (65,940Wor 225,000 Btu/hr each), two 0.6-m (24-in) and two 0.9-m (36-in) diameter fans located at each end of the building. Independent environmental controllers (Choretronics 2; Chore-Time Brock, Milford, IN) coordinated control of air temperature, ventilation fan and heater operation, and lighting programs. The houses were equipped with foggers for cooling, as needed. East partition was equipped a little amendment delivery system, which consisted of two overhead applicators with variable speed motors. The two partitions were managed separately, but had the same setup, bird genetics, and production stage.

Each partition had an initial placement of approximately 2,400 straight-run broiler birds with new bedding. The broilers were fed for 52 – 59 days to reach a market body weight of approximately 3.85 kg (8.5 lb). Prior to the experiment, the same used litter was placed into the two partitions. Before each flock, the brooding chamber (90 m^2 area) of each partition received 45.4 kg (100 lb) sodium bisulfate. During the grow-out from April 2 to May 28, 2013, variable rates (122, 183, 244, 305, and 366 g/m^2 or 25, 37.5 ,50, 62.5, and 75 $lb/1000ft^2$) of sodium bisulfate (PLT ™)

was applied weekly to the east partition at the ages of 21, 28, 35, 42, and 49-d. Production performance data for birds from each partition, including feed and water consumption, body weight, and feed efficiency, were collected. At the end of each flock, litter samples were taken from each partition for nutrient and chemical analysis. One June 3, the caked litter in both partitions was removed and collected from partition for the storage study. Four 0.12-m^3 trashcans were filled with litter from each partition for a total of eight cans. Lids with holes drilled in them were placed on the trashcans to allow for air exchange and prohibit disturbance by pests. The eight cans were paired together and stored at ambient temperature in a litter storage at the University of Delaware Research and Education Center for 10 months.

Figure 25 Poultry litter samplers used for this study

Litter samples (2.5 cm in diameter and the depth of the litter in the can) were collected with a core litter sample (Fig. 1) from three cans for each kind of litter bi-monthly after the initial setup. First and last sample dates were June of 2013 and April of 2014. One temperature probe (TMC-6 HD, Onset Comp.) was inserted into each litter can at the center to measure and record the core temperature with 4-channel data logger (U12-006, Onset Comp.). Ambient temperature and relative humidity of the storage were measured and recorded by a data logger (U23 Pro Temp/RH, Onset Comp.). The recording interval was set to 5 min. Litter samples were sent to a commercial lab (Midwest Laboratories, Inc.) for nutrient and chemical property analysis. During the 10-mo storage period, the core temperatures of litter were below 40 ^{o}C.

Analyses of variance were conducted using General Linear Model in JMP (JMP 11, SAS Institute). Tukey method was used for paired comparisons.

4.3 Results

4.3.1 Effect of Litter Amendment on Ammonia Emissions from Broiler House

Daily NH_3 emission rate (ER) and cumulative emissions over the 8-wk grow-out period for the control and variable rate treatment were summarized and shown in Figures 26 and 27. The NH_3 ERs of the birds with sodium bisulfate were significantly lower than the control after sodium bisulfate was applied. The daily NH_3 ER was reduced dramatically right after sodium bisulfate application and then increased till the following application. Birds with sodium bisulfate had significant lower daily NH_3 ERs and cumulative emissions after 30-d of age. The dynamic reduction rate of daily NH_3 ERs fluctuated in the range of 21.3 and 73 % depending on the dissipation of the applied sodium bisulfate after 21-d of age. The reduction rate of cumulative NH_3 emissions with sodium bisulfate rate was 46% for the 8-wk growout.

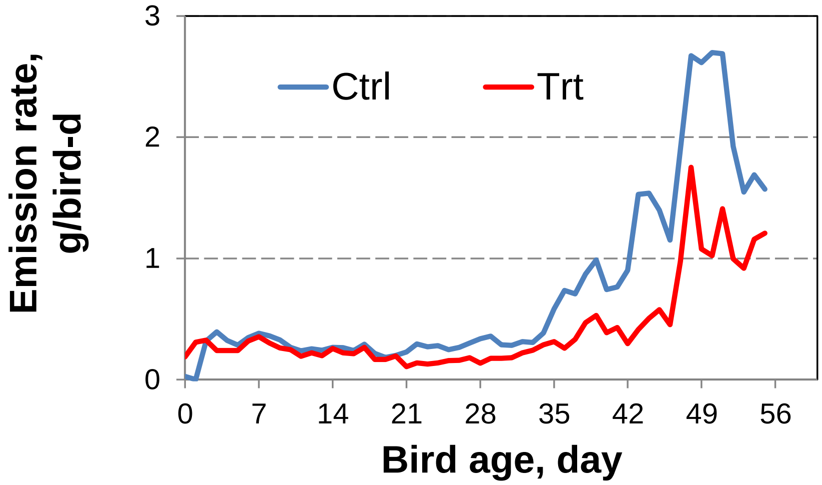

Figure 26 Daily ammonia emission rates of broilers in two partitions without (Ctrl) and with sodium bisulfate treatment.

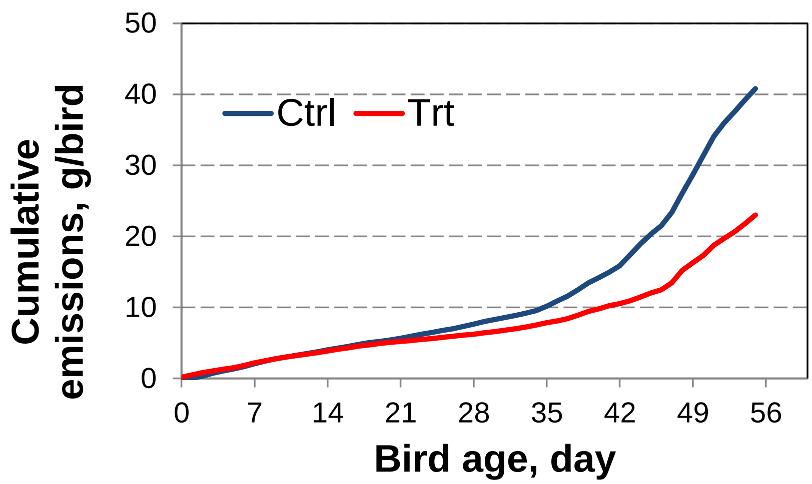

Figure 27 Cumulative ammonia emissions of broilers in two partitions without (Ctrl) and with sodium bisulfate treatment

4.3.1.1 Litter Properties and Nutrient Composition during Storage

At the beginning, the treated litter had higher Org-N, TKN, and N/P_2O_5 ratio than the untreated litter while the NH_3-N and P levels were similar in both litter (Figure 28). The pHs of treated litter were lower than the control throughout the 10-mo period (Figure 29). The manure properties indicate that sodium bisulfate application during the growout led to less pH, greater Org-N and TKN contents in the litter. Litter amendment reduces nitrogen loss as NH_3 and increase the Org-N in litter by lowering litter pH during broiler growout. During the 10-mo storage period, NH_3-N of treated litter varied from 1.75 to 1.5 %, which was slightly higher than the control, while Org-N levels were similar in both types of litter. The The Org-Ns in both litter dropped to 3.3% while the TKNs were 4.7and 5% in the control and treated litter after 10-mo. In general, P_2O_5 in control litter was higher than in treated, which was presumably due to the normal variation of litter moisture content. P_2O_5 of the control litter at 4 and 6- mo were significantly higher than that in treated litter ($P<0.05$). The N/P_2O_5 ratios of both litter continuously decreased over the 10-mo period due to N-loss to atmosphere as NH_3 and other forms of gases (Figure 30). The treated litter consistently had 15% higher N/P_2O_5 than the control litter.

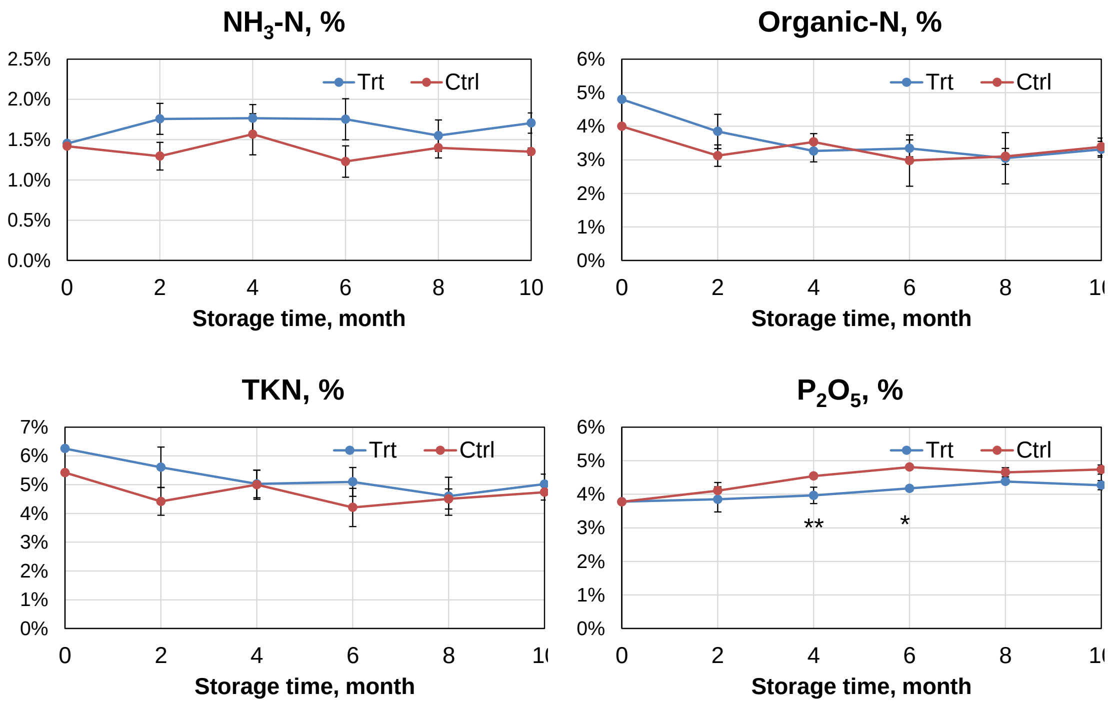

Figure 28 Nutrient properties of stored litter during a 10-mo period

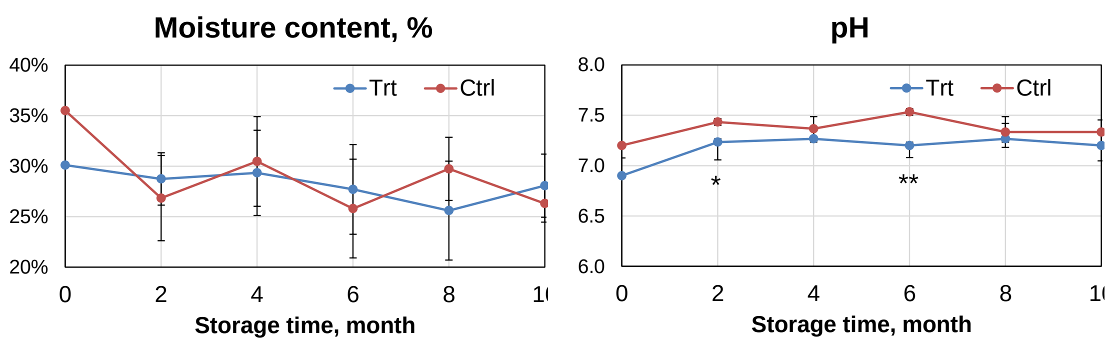

Figure 29 Moisture content and pH of stored litter during a 10-mo period.

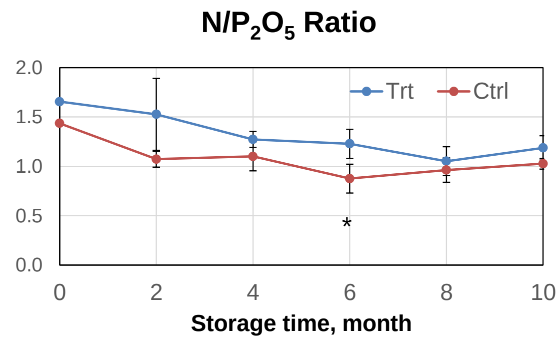

Figure 30 Nitrogen and P_2O_5 ratio of stored litter during a 10-mo period.

4.4 Conclusions

A study was conducted that aimed to evaluate the impact of frequent litter amendment application on NH_3 emission from a broiler operation and nutrient composition and properties changes of stored litter during a 10-mo storage period. The following conclusions and observations were made.

(1) Frequent application of sodium bisulfate led to significant reduction in NH_3 emissions from broilers.

(2) Litter pH level of the litter was lower in the treated litter. Organic and total nitrogen contents in the treated litter were higher while less nitrogen was emitted as NH_3.

(3) The N/P_2O_5 ratios of both litter continuously decreased over the 10-mo period. The treated litter consistently had 15% higher N/P_2O_5 than the control litter.

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Chapter 5

GREENHOUSE GAS EMISSIONS OF CORN FIELD WITH BROILER LITTER TREATED BY AMMONIA CONTROL TECHNOLOGY

5.1 Introduction

Delmarva is one of the most geographically concentrated poultry industries in the USA, producing ~600 million broiler chickens per year. The poultry litters (PL; manure and bedding) generated are valuable fertilizers, which can increase yields, and therefore overall nutrient use efficiency, compared to inorganic fertilizer alone. In recent years, concerns have also grown about the adverse human health and environmental impacts of carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3) and nitrous oxide (N_2O) emissions from poultry production facilities and PL applied to cropland.

Since poultry litter contain both organic and inorganic N and C resource, it provide the essential substrates required for the microbial production of CO_2, CH_4, NH_3 and N_2O. CO_2 produced from the respiration of microorganism in soil. Soil respiration rate with manure application may 1.6 times larger than CO_2 release from none treatment soil and N_2O flux from manure treatments was 25 times larger than that from mineral fertilizers (Jones et al., 2004). Thornton et al. (1998) applied composted poultry litter and fresh poultry litter and urea as fertilizer in Bermuda grass field and measured the N_2O emission at 1.64 kg N ha^{-1}, 3.87 kg N ha^{-1} and 2.96 kg N ha^{-1}, respectively. Yagi et al. (1990) applied different kinds of fertilizer into paddy fields and observed a 1.8-3.5 times increase on CH_4 emission with organic matters than inorganic fertilizer. Few works did on the NH_3 emission after poultry litter application on the field.

New technologies have been introduced to help combining PL and inorganic fertilizers in high yielding corn production with minimal environmental impact in Delmarva. Ammonia control technologies (ACT) that use innovative methods to mitigate NH3 loss from poultry houses, thus increasing the N value of PL and reducing air and water quality concerns. Conserving NH3 in poultry houses has other benefits as well including resource conservation (the original source of the NH3 in PL was the fertilizer N used to grow the feed, which was produced using natural gas, a finite resource) and producing PL with higher N:P ratios which will more closely match crop uptake and thus be less likely to lead to P accumulations in soils. And a new fertilizer application method, called “subsurfer”, was used to inject solid PL under soil surface, which both reduces N loss via NH_3 volatilization and the potential for P losses in surface runoff. Moreover, the subsurfer offers the unique opportunity to use nitrapyrin in combination with PL. Nitrapyrin can conserve ammonia in soil, reducing nitrification and denitrification, resulting in overall higher N use efficiency by maintaining plant available N in the root zone.

In this study, ACT poultry litter, normal poultry litter and urea nitrogen were applied in a corn field as fertilizer. Greenhouse gas (CO_2, CH_4, and N_2O) fluxes were measured using a static chamber to decide new poultry litter treatment and application technology can reduce the gas emission rate and decrease the environmental impacts.

5.2 Methods and Materials

5.2.1 Site and corn description

The experimental site is at the experimental farm of University of Delaware in Georgetown, Delaware, United States. This site is an irrigated corn field. The corn was planted in May, 2014 and harvested in September, 2014. The distance between each row was 30 in.

5.2.2 Poultry litter (PL) preparation

Two kinds of poultry litter, ammonia control technology poultry litter (ACT-PL) and normal poultry litter, were used as the fertilizer in this study. The ACT technology in this study included the use of permanently installed in-house spinners that applied sodium bisulfate weekly to control NH_3 emission during broiler grow-out.

An environmentally-controlled experimental house at the University of Delaware Carvel Research and Education Center (UDCREC; Georgetown, DE) was used for this project. The environmental house measuring 114 ft x 37 ft was east-west orientated and divided into two partitions, 57 ft x 37 ft each. The two partitions were symmetrical and shared the same end wall and control room. East partition was equipped a little amendment delivery system, which consisted of two overhead applicators with variable speed motors. The two partitions were managed separately, but had the same setup, bird genetics, and production stage. Each partition had an initial placement of approximately 2,400 straight-run broiler birds with new bedding. The broilers were fed for 52 – 59 days to reach a market body weight of approximately 8.5 lb. Prior to the experiment, the same used litter was placed into the two partitions. Before each flock, the brooding chamber (90 m^2 area) of each partition received 100 lb sodium bisulfate. During the grow-out from October 17, 2012 to

March 18, 2013, 150 lb/1000ft^2 of sodium bisulfate (PLT ^{TM}) was applied to the east partition at the age of 21. Two flocks of broilers with 8 week grow-out were raised in two separate rooms (2400 bird/room), one with ACT and the other as control. Eight tons of ACT litter and control litter from the two rooms was stored separately and used for laboratory field application.

5.2.3 Static chamber setup

The gas emission was measured using USDA recommended static chamber. The chamber mainly included two parts, the anchor and chamber. The anchor was made using the middle part of a 5-gallon plastic bucket. The upper diameter of the anchor was 6.4 in., which is slightly smaller than the chamber. The anchor was 6 in. tall, and had some saw teeth for easily installation. All anchors were permanent installed into the sampling points one week before the measurement. The over ground part of the anchor was 1in to avoid any micro environment perturbations.

The chamber was cut from the bottom of the 5-gallon bucket. The chamber had a diameter of 10.5 in. and height of 6 in. Two holes were made at the center and edge of its top, respectively. Air sample was taken from the central hole and sent back from the edge hole after real-time

measurement. The edge hole connected with a 5.5in long tubing inside the chamber to send the air back to the bottom of the chamber. Weather-strip tape was applied inside the chamber at bottom part to increase airtightness between anchor and chamber. Outside of the chamber was covered by aluminum tape to decrease the temperature perturbations due to the solar radiation (Figure 31).

Figure 31 Static flux chamber used for the study

5.2.4 Experiment design

There were two repeated experiments in this study. Each replicate had a control plot and three treated plots (the high treatment shown in Figure 1 was not included in this study). The three main treatments were ACT litter injected with nitrapyrin, normal litter surface applied, and Urea-nitrogen (UAN) surface applied. Before the experiment, these four plots randomly distributed into each replicate. The control plot had six rows of corn and each treatment plot had thirty rows of corn. The plot map is shown in Figure 32.

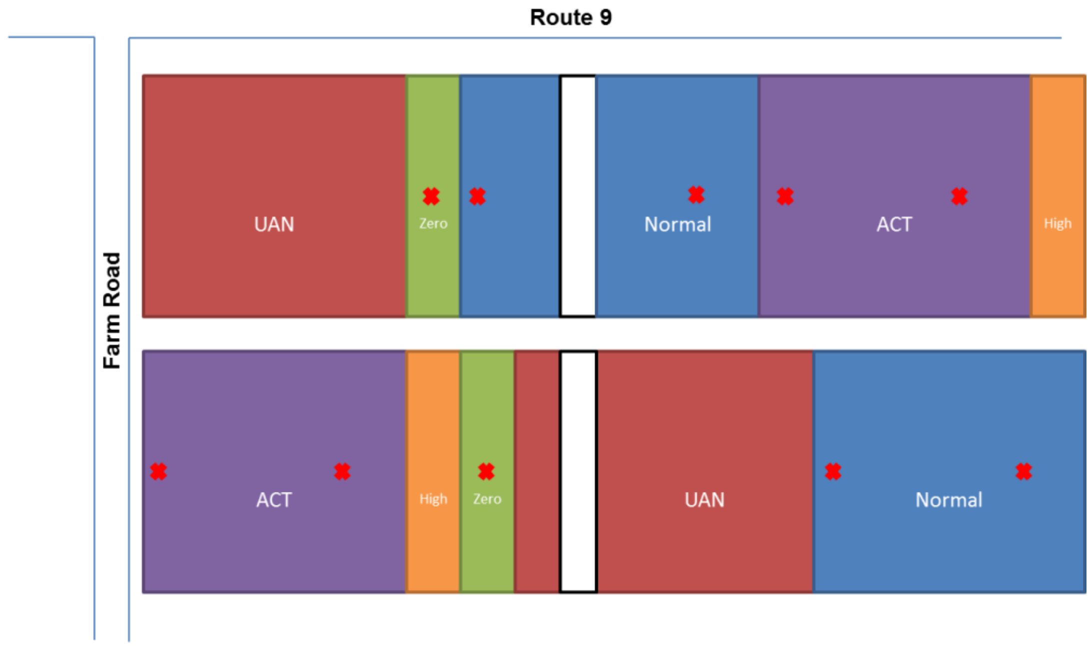

Figure 32 Plot and sampling map. (X: sampling points)

Each plot was applied with PL 14 days before planting at a rate equivalent to 50% of the total estimated plant available nitrogen (PAN) requirement based on yield goal. Six side-dress N rates were nested in each of these plots. Each side-tress occupied five rows corn and included 0, 50, 75, and 125% of the remaining N prescribed based on yield goal, respectively. In addition, there was also a sensor-based variable rate N side-dress treatment based on the GreenSeeker active optical sensor. The overall treatment setup is shown in Table 9.

Five sampling pints were selected in each replicate which located in control plot, ACT-PL plot with 0% and 125% side-dress, normal PL with 0% and 125% side-dress. The surface greenhouse gas fluxes were measured in a 15min period using static chamber. Change in greenhouse gas concentration inside the chambers was analyzed in situ with a 1412 Infrared Photoacoustic Gas Monitoring System (Innova Air Tech

Instruments, Ballerup, Denmark). Soil temperature and moisture content at each sampling point were measured using a moisture probe and temperature probe.

Table 9 Treatments setup

Main Plot #	Sub-plot #	Pre-plant treatment	Side-dress
1	1	ACT-PL injected w/Nitrapyrin	0-N
	2		50% Yield Goal Rate
	3		75% Yield Goal Rate
	4		100% Yield Goal Rate
	5		125% Yield Goal Rate
	6		Sensor-based
2	7	Normal PL surface applied	0-N
	8		50% Yield Goal Rate
	9		75% Yield Goal Rate
	10		100% Yield Goal Rate
	11		125% Yield Goal Rate
	12		Sensor-based
3	13	UAN surface applied	0-N
	14		50% Yield Goal Rate
	15		75% Yield Goal Rate
	16		100% Yield Goal Rate
	17		125% Yield Goal Rate
	18		Sensor-based
4	19	0 N Control	0-N

5.2.5 Data analysis

During the measurement, gas concentrations in the chamber were determined every 50s over 15 minutes, for a total of 19 values including time zero. Before a measurement the INNOVA took the ambient air sample until the reading became steady. For the linear increasing data (R^2>0.80), the slope φ (concentration vs. time) of the linear regression line was used to calculate the emission rate using the following equation.

$$ER = \emptyset \times 10^{-6} \times \frac{T_{std}}{T} \times \frac{w_m}{V_m} \times \frac{V}{S} \times t_d \quad (8)$$

Where,

ER = Gas emission rate from the field surface, g d^{-1} m^{-2}

φ = slope of linear regression line, ppm_v min^{-1}

T_{std} = standard temperature, 273.15K

T = absolute temperature of soil surface, K

w_m = molar weight of the gas, g $mole^{-1}$

V_m = molar volume of gas at STP, 0.022414 m^3 $mole^{-1}$

t_d = minutes in one day, 1440 min d^{-1}

For the nonlinear increased data, three specific data point (0, 7.5 and 15min) were selected to determine the emission rate. The following equation (Eq. 2) modified based on Hutchinson et al. (1981) was used:

$$ER = \frac{(C_1 - C_0)^2}{t' \times (2 \times C_1 - C_2 - C_0) \times \ln[(C_1 - C_0)/(C_2 - C_1)]} \times 10^{-6} \times \frac{T_{std}}{T} \times \frac{w_m}{V_m} \times \frac{V}{S} \times t_d \quad (9)$$

Where,

ER = Gas emission rate from the field surface, g d^{-1} m^{-2}

C_0, C_1, C_2 = gas concentration at 0, 7.5, 15 min, ppm_v

t' = interval between sampling points, 7.5 min

T_{std} = standard temperature, 273.15K

T = absolute temperature of soil surface, K

w_m = molar weight of the gas, g $mole^{-1}$

V_m = molar volume of gas at STP, 0.022414 m^3 $mole^{-1}$

t_d = minutes in one day, 1440 min d^{-1}

All data were analyzed by repeated measures analysis of variance (ANOVA) using a Paleontological Statistics Software Package (PAST) (Hammer et al. 2001).

5.3 Results and Discussion

CO_2 emission from soil resulted from the respiration of microorganism could vary from 0 to 56 g m^{-2} d^{-1} depending on soil type and time of year (Glinski & Stepniewski, 1985). CO_2 emission rate change during the experiment shows in Figure 2. The P-value of repeated measures ANOVA for different treatments was 0.584, which indicated no significant difference between any of two treatments. The soil temperature and water content change during the test period shows in figure 33 and figure 4. Since the test conducted between 8:00 to 14:00 in the same day, the soil temperature (P=0.085) and water content (P=0.475) did not change. The result shows neither litter treatment nor application rate had significant influence on CO_2 emission from the corn fields. The mean CO_2 emission rate was 15.4 g m^{-2} d^{-1}.

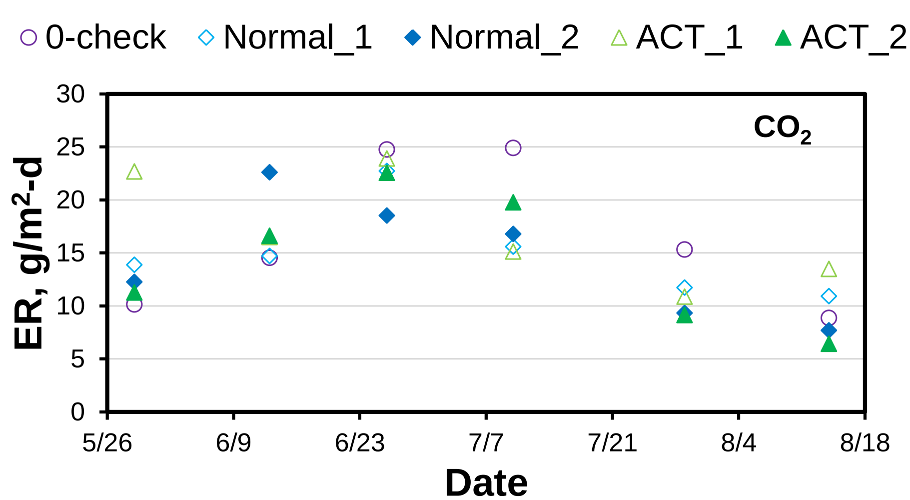

Figure 33 CO_2 emission rates during experiment period

Due to the low emission rate and higher detection limits (0.03 ppm on N_2O and 5 ppm on CH_4) of INNOVA, only limited numbers of emission rates were collected for N_2O and CH_4. Figures 34 and 35 show emission rates of N_2O and CH_4 from corn fields. There were large variations among different treatment and no clear correlation between emission rate and litter type or litter application rate was found. The average emission rate of N_2O and CH_4 were 1.22 and 0.08 mg m^{-2} d^{-1}. Gaseous emissions were converted to CO_2 equivalents (Mg CO_2 equivalents ha^{-1} yr^{-1}) using global warming potential of 310 and 21 for N_2O and CH_4 respectively (IPCC, 2001). Annual flux (Mg CO_2 equivalents ha^{-1} yr^{-1}) totaled 57.6 for corn field in Delaware.

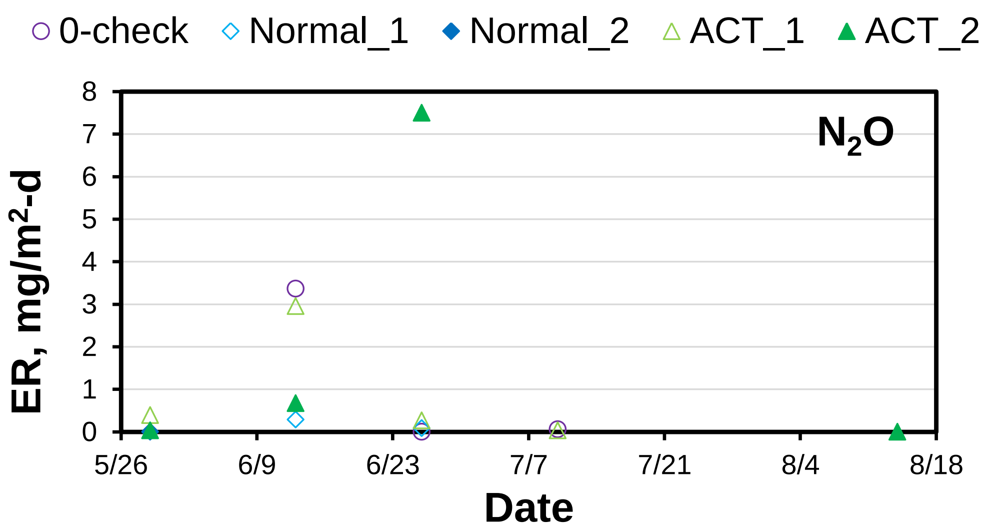

Figure 34 N_2O emission rates during experiment period

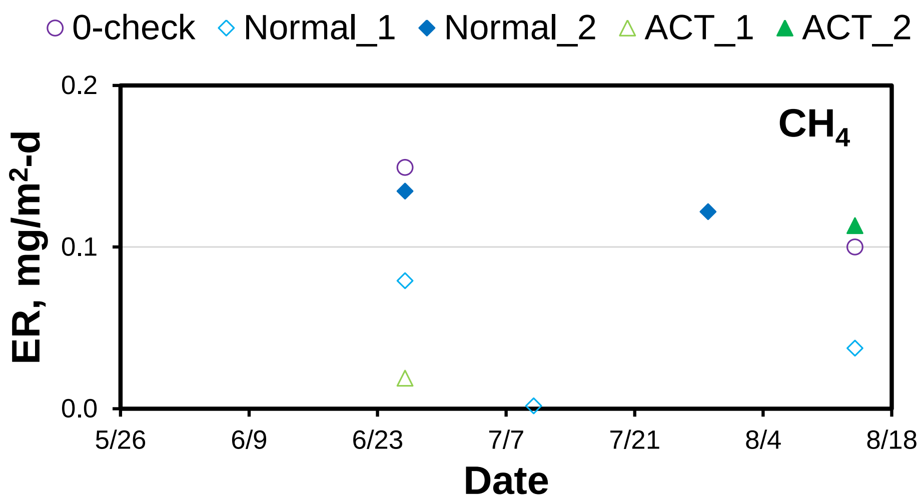

Figure 35 CH_4 emission rates during experiment period

Table 10 Greenhouses gas emissions from literatures

Location	Soil condition	Gas emission rate, mg m^{-2} d^{-1}		Reference
		N_2O	CH_4	
Alabama	Fresh PL in Bermuda grass field	1.73		Harper et al., 2000
Alabama	Urea in Bermuda grass field	1.30		Harper et al., 2000
Alabama	Composted PL in Bermuda grass field	0.86		Harper et al., 2000
Alabama	No fertilizer in Bermuda grass field	<0.43		Harper et al., 2000
Georgia	Field grazed by cattle	10.37		Walker et al., 2002
Finland	Peat soil	3.66	0.36	Nykanen et al., 1995
Netherlands	Drained peat soil	3.83~16.71	-0.08~0.03	Langeveld et al., 1997
This study		1.22	0.08	

5.4 Conclusions

A study was conducted to evaluate the impact of different broiler litter treatment on greenhouse gas emission from core fields in Delaware. The following conclusions and observations were made.

(1) Neither litter treatment nor application rate had significant influence on CO_2 emission from the corn fields. The mean CO_2 emission rate was 15.4 g m^{-2} d^{-1}.

(2) No clear correlation between emission rate and litter type or litter application rate was found. The average emission rate of N_2O and CH_4 were 1.22 and 0.08 mg m^{-2} d^{-1}.

(3) Annual flux greenhouse gas flux was (Mg CO_2 equivalents ha^{-1} yr^{-1}) 57.6 for corn field in Delaware.

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Chapter 6

GENERAL SUMMARY

A two-stage scrubber design was tested in three commercial broiler farms to capture NH_3 from broiler house exhaust air. The scrubber can remove 11.0 to 34.3% NH_3 from the broiler house exhaust air. To achieve a higher removal efficiency, the acid solution should check and replace frequently.

The study also evaluates the effects of acidified PL biochar application on NH_3 emission from broiler litter. It is concluded that PL biochar with 200 lb/1000ft2 of application rate reduced 45.6 % and 20.2 % NH_3 emission from broiler litter at high and low MC (40% vs. 35 %); and increased acidified PL biochar application rate could achieve the similar performance of PLT on NH_3 emission reduction from broiler litter.

Frequent application of sodium bisulfate (PLT) can significant reduction in NH_3 emissions from broilers. Litter pH level of the litter was lower in the treated litter. Organic and total nitrogen contents in the treated litter were higher while less nitrogen was emitted as NH3.

Appendix A

ASABE REPRINT PERMISSION

This thesis includes three published meeting papers (conference meeting of American Society of Agricultural and Biological Engineers) listed as below. The request of include these three papers into this thesis has been granted by Glenn Laing (ASABE Technical Publications Editor). The copy right link for ASABE is https://asabe.org/Copyright.

1. Zhang, C., Li, H., Shober, A., & McGrath, J. (2004). Greenhouse Gas Emissions of Corn Fielded with Broilers Litter Treated by Ammonia Control Technology. In NABEC Papers (p. 1). American Society of Agricultural and Biological Engineers.

2. Zhang, C., Alexis, W. D., Li, H., & Guo, M. (2016). Using Poultry Litter Derived Biochar as Litter Amendment to Control Ammonia Emissions. In 2016 ASABE Annual International Meeting (p. 1). American Society of Agricultural and Biological Engineers.

3. Zhang, C., Lin, C., Li, H., & Collier, S. L. (2004). Impact of Frequent Litter Amendment Application on Nutrient Composition and Properties Changes of Stored Broiler Litter. In NABEC Papers (p. 1). American Society of Agricultural and Biological Engineers.