CONTROLLING POULTRY HOUSE AMMONIA EMMISSIONS USING GAS PERMEABLE MEMBRANE SYSTEMS

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ABSTRACT: *An experiment was conducted to investigate the use of gas-permeable membrane systems to capture and recover ammonia from poultry houses. The objectives of the experiment were: 1) to evaluate the performance of two gas-permeable membrane ammonia-capturing system models and 2) to assess ammonia emission impact on birds' mortality, and to investigate the relationship between birds age and ammonia emission in rooms equipped with and without these systems. The systems were developed and placed inside a 6.0 m X 6.0 m room in a research poultry house. The systems were started by preparing 5N sulfuric acid in an acid tank and a pH 1 solution in a concentration tank. Acids were added to the concentration tank manually to achieve a pH of 2.0, and then the pH pump controller and the membrane circulation modules were used to bring the pH back to 1. After NH_3 gas passed through the membrane and was in contact with the acidic solution, ammonium (NH_4^+) salt was formed, which was retained and concentrated in the acidic solution. The experiment consisted of two treatments namely: 1) Control (room without membrane systems (RWOMS), and 2) treatment (room with both membrane systems (RWMS). Each room contained 400 birds. The results demonstrated a significant ($p<0.05$) difference of air ammonia concentration between rooms and from poultry litter. Among the membrane systems, tubular membrane system had the greatest mean NH_4^+ recovery compared to the flat membrane system. The difference was highly significant ($p<0.01$). Birds' mortality rate was decreased by ~46.6% in room with the installed systems indicating that reduced ammonia resulted in improved bird survival. The findings of this study indicate that the membrane systems can be an effect method of reducing ammonia concentration in poultry houses with an added advantage of retaining ammonium salt has plant food.*

KEYWORDS: Ammonia, Sulfuric Acid, Poultry Manure, Gas-Permeable Membrane, Ammonium

INTRODUCTION

Ammonia is very important atmospheric species due to its impact on the environment. Major impacts associated with air ammonia include eutrophication, soil acidification, and aerosol formation. Gospodinov (2016), explained that exposing poultry to ammonia for a longer period of time at concentrations as low as 20 mg/L can negatively affect their health. Ammonia levels above 25mg/L in the poultry house can cause damage to the bird's respiratory organs and allow infectious pathogens to develop and establish, affecting bird's growth and performance. Miles et al., 2004 investigated the detrimental effect of ammonia exposure in broiler house. Results indicated that when ammonia level in the broiler house increased from 25 to 50 mg/L, broiler body weight at 7 weeks of age reduced by 226g. The quality of air in broiler houses is directly related to birds' ability to respond to respiratory disease and meet their genetic growth

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potential. Studies have shown that birds become highly susceptible to Newcastle Disease virus when they are exposed to ammonia during brooding period (Anderson, 1964) and have more difficulty in clearing *E. coli* from the respiratory system (Nagaraja, 1983). Ammonia emissions are the result of complex physical and chemical processes (Freney et al., 1983; Harper, 2009) with the emission rate related to several factors: NH_4^+ concentration of the source, temperature, pH, and the effectiveness of turbulent transport of the NH_3 away from the source, moisture content, and population of microorganism. Of the manure characteristics, the most important is manure pH, with higher losses of NH_3 occurring at pH's above 7.0. The most commonly used chemicals to control NH_3 emissions from manure are dry acids, such as alum (Moore et al., 2011). High levels of ammonia in the broiler litter can cause stunted growth, high mortality, and a reduction in antibodies such that there is lower immunity after vaccination (Colon et al., 2010). Studies have also shown that high levels of gaseous NH_3 within layer and broiler operations reduce egg production, feed efficiency, and growth (Charles and Payne, 1966; Reece et al., 1980; Drummon et al., 1980; Donham et al., 1982; Carlile, 1984). Anderson et al. (1964) reported that poultry can display a variety of disorders when exposed to ammonia for extended periods to levels as low as 20 ppm. According to Agency for Toxic Substances and Disease Registry (ATSDR)**,** inhalation of lower concentrations of ammonia can cause coughing, and nose and throat irritation (ATSDR, 2004**)**. Poultry litter is usually considered to be a major source of odors associated with emissions from poultry production housing facilities (Pillai et al., 2012). Gas-permeable membranes (GPM) including expanded polytetrafluoroethylene (ePTFE) have been used for removing ammonia (NH_3) from a total ammoniacal nitrogen (TAN) source and capturing it in an acidic solution (Mukhtar et al., 2011; Rothrock et al., 2010; Samani Majd and Mukhtar, 2013). The applications of the use of the synthetic membranes started in 1981 with different configurations, such as, flat sheet, hollow fiber, tubular, and spiral-wound cylinders (Blet et al., 1989). Selection of a membrane depends on its specific application, cost, and accessibility, as well as its resistance to fouling and aging. The performance of a membrane in terms of NH_3 mass capture is directly related to the availability of NH_3 in the TAN source (Ahn et al., 2011; Rothrock et al., 2010).

MATERIALS AND MEHODS

Broiler House Description and Experimental Plan

This experiment was conducted and repeated over a 3-year period (2014 to 2016) at the University of Maryland Eastern Shore poultry experimental and teaching house # 11989. The experimental poultry house consisted of eighteen rooms measuring 6m x 6m each. Twelve of these rooms were renovated in 2009 and contained the 'state of the art' equipment for monitoring and evaluating air emissions, and environmental conditions. The rooms had solid sidewalls with an insulated drop ceiling with cemented floor. Two automatic feeder lines spanning the length of the room; one automatic nipple waterer line, on the side of the feeder line; infrared propane heater (brooders) hanging from the center of the ceiling. The experiment was performed in two of the rooms; room 1 (control) and room 10 (treatment) in the poultry house. The distance between these two rooms was about 1m apart. Rooms featured cross-ventilation with exhaust fans. The ventilation systems were thermostatically controlled (fans come on automatically based on the temperature of the room). The recovery manifolds for tubular membrane system were placed inside the experimental rooms hanging from the roof and 30.5cm above the litter. The ammonia concentrator tanks were outside the rooms in an enclosed cabinet. For flat membrane system, the manifold was supported by two metal frames

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about 30.5cm above the floor. These membranes have been trialed in biomedical sciences and textile and shoe industries. They have been used in membrane oxygenators to imitate the function of the lungs in cardiopulmonary bypass, to add oxygen to, and to remove carbon dioxide from the blood (Gaylor, 1988).

With these concepts in mind, a field study was conducted to investigate the development of gaspermeable membrane modules as components of new processes to capture and recover ammonia from poultry litter. The gas-permeable membrane technology has been used to recover NH_3 from swine manure (García-Gonzalez and Vanotti, 2015). This concept of using the gas-permeable membrane technology includes the passage of NH_3 through microporous, hydrophobic, gas-permeable membranes and its capture in a recirculated acidic solution accompanying production of a concentrated NH_4^+ salt. Once NH_3 gas passes through the membrane and is in contact with the acidic solution, it reacts with free protons (H^+) to form non-volatile ammonium (NH_4^+) salt, which is retained and concentrated in the acidic solution (Rothrock, Szögi and Vanotti, 2010).

Two treatments were utilized, with 4 replications per treatment. One room was used as control room (room without membrane system) and other room for treatment room (room with membrane systems).

System Description and Experimental Procedure

The ammonia capture and recovery setup consisted of two NH_3 treatment cabinets (flat membrane system and tubular membrane system .The cabinet for both systems consisted of a concentration tank (60L) and acid tank (20L). The acid tank contained 5N H_2SO_4 (135.85ml H_2SO_4 in 1000ml deionized water), pH controlling system (Etatron DLXB pH/ORP Pump control system Cole-Parmer,Vernon Hills, IL, USA), including a pH controller, acid pump, pH probe, Masterflex L/S Precision Pump System, 65mm correlated PTFE Flowmeter valved, glass, 013-88 (Cole-Parmer,Vernon Hills, IL, USA). The ammonia removal system used a specialized gas-permeable membrane that was placed in protective modules in the poultry house close to the poultry litter from which the ammonia was emitted. The pump manifold continuously pumps liquid from concentration tank to the manifold inside the poultry room. The flow rate (60mL/min) was controlled by manifold pump and pump tubing (Masterflex C-Flex tubing (50A), I/P26). The pH value of the recipient solution was controlled at 0.8 and 1.2 by using an acid dosing and pH controlling device. The reservoir of acidic solution containing the captured ammonium was also monitored for pH. An ePTFE membrane (Phillips Scientific, Inc., Rock Hill, S.C.) was used in this study for the systems. The thickness of the flat gaspermeable membrane was 0.044 mm, width 160mm and a bubble point of 21 kPa with 3048mm in length. (FL1001, Phillip Scientific, Rock Hill, SC). Four lines of tubular membranes were used in this study. The length was 2743.2 mm with outer diameter of 10.25 mm and wall thickness of 0.75 mm. The systems were started by preparing 5N H_2SO_4 in an acid tank and a pH 1 solution in a concentration tank. Acids were then added to the concentration tank manually to achieve a pH of 2, and the pH pump controller and the membrane circulation manifolds were used to bring the pH back to 1. The acidic solution (5N H_2SO_4) contained in the acid tank was continuously re-circulated using a peristaltic Manostat pump (Cole-Parmer,Vernon Hills, IL, USA) into the poultry room containing the poultry litter. Once inside the room, the acid was contained and recirculated through a plastic reservoir covered by the flat, gas-permeable membrane sheet, and tubular membrane allowing for the passage of NH_3 gas emitted by the litter and subsequent recovery and concentration of the N as NH_4 salt.

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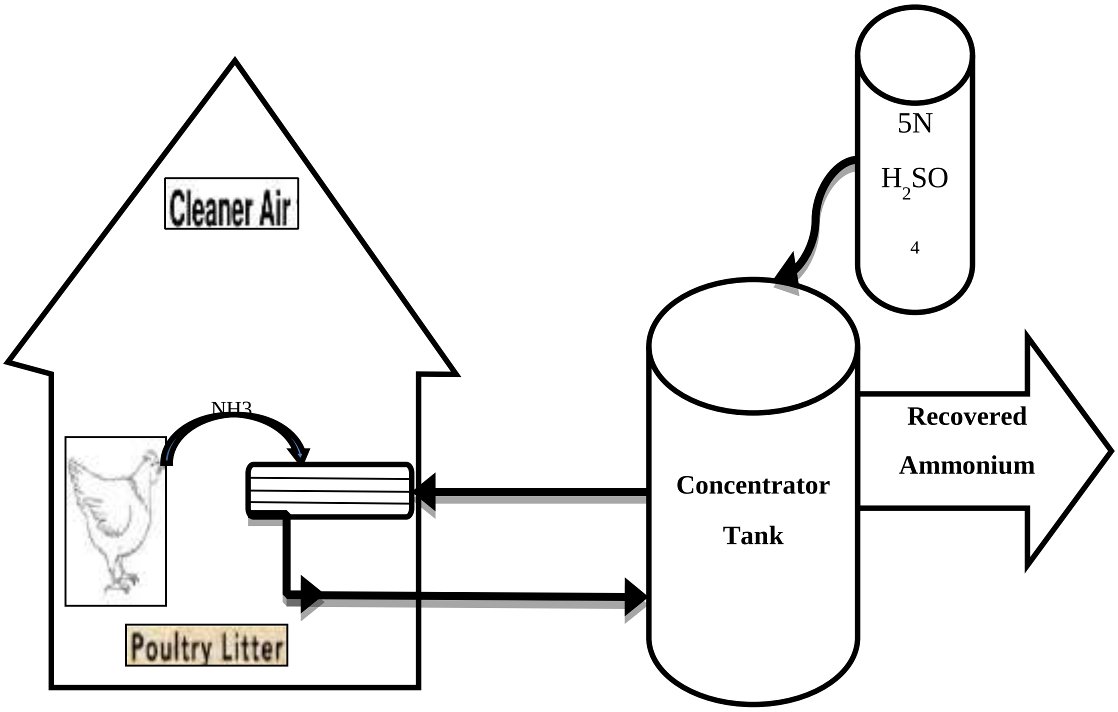

Figure 1. Process diagram of gas-permeable membrane manifold system for ammonia capture and recovery from poultry litter.

Statistical Analysis

On daily basis, liquid samples were collected and analyzed for pH using VWR SympHony Meter, SB90M5. For NH_4^+, samples were filtered through 0.45µm filter and the supernatant diluted and analyzed for NH_4^+ by flow injection using Lachat QuickChem® method 10-107-06-2-A (Lachet Instruments, Milwaukee, WI). NH_3

Dräger Chip Management System (Dräeger Safety, Inc., Pittsburgh, PA). Data were analyzed using concentrations in the in the poultry rooms were measured using

Stata v.15 Statistical Software. A paired t-test was used to determine the significant difference between selected variables**.** The level of significance at $p \leq 0.05$ was considered statistically significant

RESULTS AND DISCUSSION

Broiler production information and bird growth performance

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Four flocks were completed during the duration of the experiment and considered as replications. Each flock operated in-all and all-out mode, placing an average of 400 birds on Day 1 at a density of .09m^2/bird. The birds were fed a standard commercial corn and soybean meal-based diet based on age for starters (0 to 18 days), growers (18 to 33 days) and finishers (33 to 46 days), with 24%, 18% and 20% protein respectively. Descriptive statistics and significance of feed intake, live body weight, feed conversion ratio (FCR), and mortality of broilers up to 42 day of age are summarized in Table 1. The total feed intake capacity of broilers in RWMS and RWOMS were found to be 2370.4 ± 1650, and 2355.9 ± 1634 g respectively. The difference was not significant ($P>0.05$). For live body weight, no significant difference was observed between the rooms ($P < 0.05$), however, a slightly higher live body weight (2918.9 ± 227.7.24g) was seen in the RWOMS than the RWMS (2909.8 ± 73.8g). Feed conversion ratios (FCR) of the two rooms were 1.67 for treatment room and 1.68 for control room. Mortality was significantly ($p \leq 0.01$) reduced in RWMS compared to RWOMS. Mortality in the

RWMS was reduced ~46.6% (Table 1).

These findings agree with Do, Choi, and Niamh, 2005 who reported no significant differences in bird performances between broilers raised on litter treated with chemicals such as alum and aluminum chloride to control ammonia. These results are somewhat consistent with those of Moore et al. (2000), who indicated that the average bird weight for broilers raised on alum treated litter was 1.75 kg vs. 1.66 kg for the controls. According to Quarles and Coven (1979), body weight and feed intake for 8-week-old birds on a control treatment did not show significant difference from those of birds exposed to 50 ppm ammonia. Reece and Lott (1980) reported that birds exposed to 25 to 200 ppm ammonia concentration levels during brooding weighed less at market age than controls. Weight reduction was minimal at 25 ppm, but weight at 50 ppm was reduced by 10% and by 25% at 200 ppm. Mortality increased at levels of 100 ppm ammonia and over, however, feed conversion was not affected (Reece and Lott, 1980; Reece et al., 1980). Studies also have reported that higher ammonia concentration in the broiler house can result in higher bird mortality.

Table 1. Descriptive statistics and significance of feed intake, live body weight, feed conversion ratio (FCR), and mortality of broilers up to 42 days of age

Treatments	Capacity (birds) Initial	Bird/m^2	Feed intake (g) M ± SD	Live body weight (g)/bird M ± SD	FCR (g)	Mortality , %
*RWMS	400	0.093	2370.4 ± 1650^a	2909.8 ± 73.8^a	1.67^a	8.7^a
**RWOMS	400	0.093	2355.9± 1634^a	2918.9 ± 227.7^a	1.68^a	16.3^b

N=76. *RWMS= room with membrane system **RWOMS =room without membrane. ^{ab}Values with no common superscripts differ significantly ($p<0.01$)

Gaseous ammonia captured by gas-permeable membrane systems

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Results compared the differences of ammonia concentration between the treatments (RWMS), and control (RWOMS) rooms (Figure 2). The average ammonia concentration between RWMS and RWOMS showed 42.08 mg/L (±36.7), 68.31 mg/L (±51.94) respectively representing a percentage difference of ~48%. Paired t-test result indicated a significant difference between the two room (t= 7.5652, p≤.001). This findings support a laboratory chamber study conducted by Rothrock et al., 2010, they found out that using flat expanded polytetrafluoroethylene (ePTFE) membranes systems and a sulfuric acid solution could reduce headspace NH_3 concentrations ~ 70% to 97%.

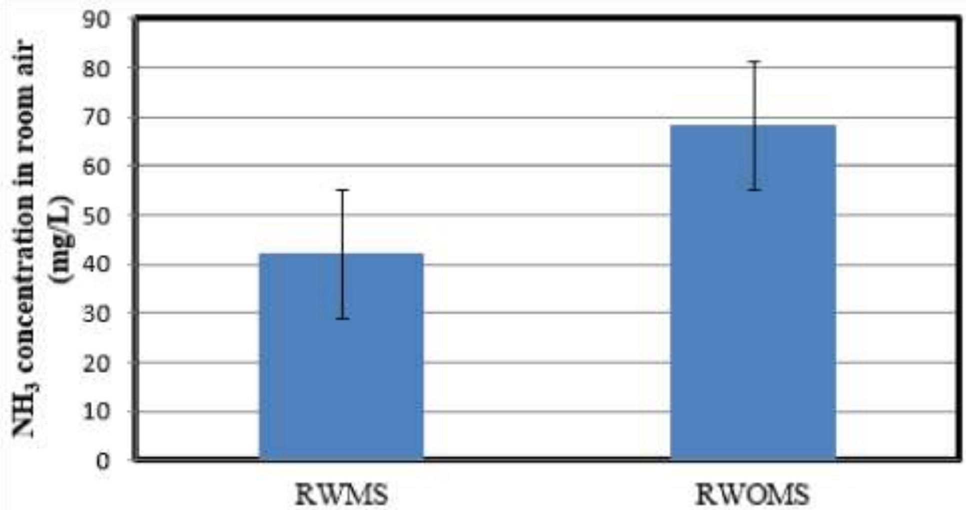

Figure 2. Ammonia concentration in room with membrane system (RWMS) and room without membrane system (RWOMS).Bars represent standard deviation

Comparison of ammonium (NH_4^+) Recovered by Flat and Tubular Membrane Systems

Two gas-permeable membrane systems (flat and tubular membrane) were evaluated to determine their efficiency in recovering ammonium (NH_4^+) from recipient acid solution (Figure 3). Tubular membrane systems had the greatest mean ammonia removal (4077.35mg/L) compared to the flat membrane system (504.55mg/L) representing a ~88% decrease. A paired t-test result showed significant mean difference between tubular membrane systems (M = 4077.35, SD = 1905.859) and flat membrane systems (M = 504.55, SD = 1051.90), t statistics = -13.8347, p<0.001. Tubular system performed more efficiently than the flat system. This finding agrees with a laboratory-scale chamber study conducted by Rothrock, Szogi & Vanotti, 2010. In their study they tested the feasibility of using gas-permeable membranes as a new approach to remove and recover NH_3 from poultry litter. They indicated that during 21 day evaluation, the membrane systems recovered about 96% of the NH_3 lost from poultry litter. Mukhtar et al., 2011, stated that using membrane systems with increasing the recipient solution flow rate from 40 to 280 mL min-1 in the field-scale increased NH_3 recovery ~ 16.5%.

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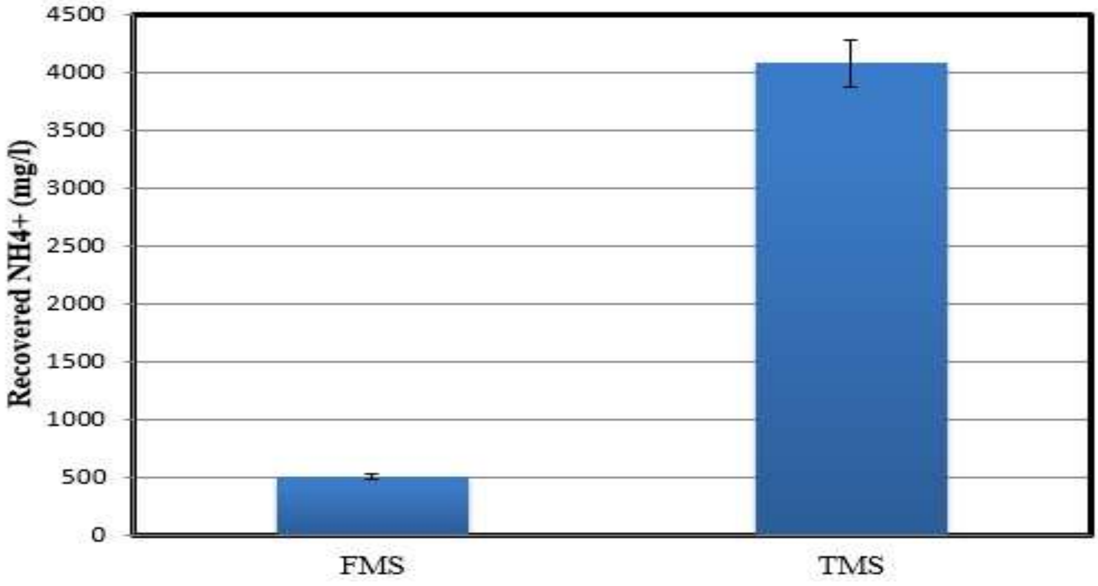

$^{+}$)

Figure 3. Performance of tubular and flat membrane systems in recovering ammonium (NH_4

Note: N=427. FMS= Flat membrane system, TMS = Tubular membrane system. Means difference was established using t-test analysis at 5% probability. Bars represent standard deviation

Ammonium (NH_4^+) Concentration Levels in Poultry Litter

The systems were evaluated to determine their efficiency in recovering ammonium (NH_4^+) from poultry litter. Paired t-test analysis showed a significant difference between RWMS ($M = 905.33$, $SD = 750.19$) and RWOMS (1436.16, $SD = 1282.48$), t statistics = 2.5163, $p= 0.0287$ (Figure 4).This suggests that the removal of NH_3 from the RWMS using membranes allowed for a change in the equilibrium concentration of ammoniacal-N in the litter. The high removal efficiencies obtained in this RWMS showed that the concept of using NH_3 gas-permeable membranes for poultry litter applications is technically feasible. Comparing the two rooms, NH_4-N content in the litter decreased by 37% in RWMS. Vanotti et al., (2010), investigated the removal and recovery of NH_3 from liquid manures using gas permeable membranes. They reported that with the membrane manifold installed, in 9 days the NH_4-N concentration in the poultry litter decreased ~ 50%, from 1,290 mg/L to 663 and at the end of the 21 day experiment , the NH_4-N content in the litter decreased 58% by volatilization, from 1,369 mg/kg (± 9) to 792 (±7).

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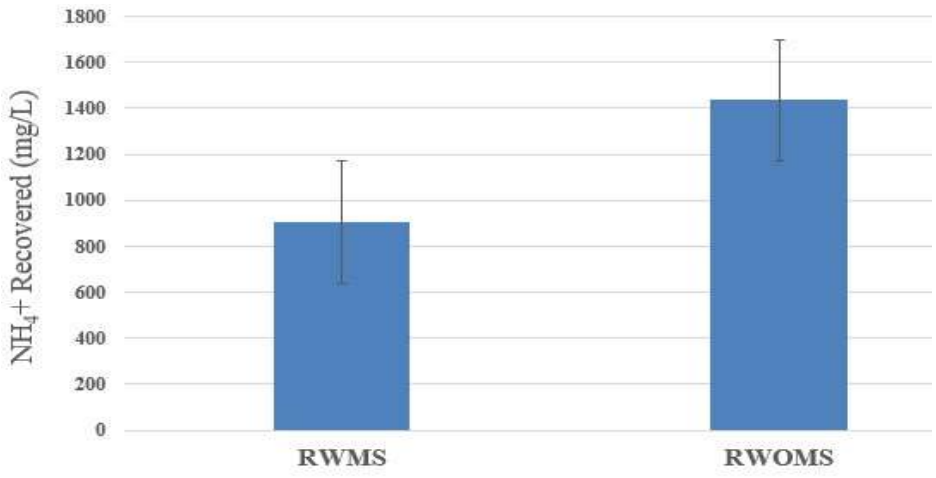

Figure 4. Poultry litter NH_4^+ concentration in associated e-PTFE membrane system. Note: RWMS = room with membrane system, RWOMS =room without membrane system. Means difference was established using t-test analysis at 5% probability. N=84. Bars represent standard deviation.

Birds Mortality

The flocks were inspected daily and mortality recorded. At the end of the grow-out period, the weight of the dead and culled birds were used to calculate percentage of mortality. Mortality percentage was calculated by dividing the number of birds that died in the period by the initial number of birds in the room and multiplying by 100 (Borges et al., 2003). Comparing ammonia concentration level and broiler mortality between RWMS (M=3.08, SD=0.72) and RWOMS (M=6.15, SD=0.55), t=7.3, p=0.0053, results were found to be statistically significant. The mortality rate was decreased by 46.6% in RWMS giving an indication that the reduction in ammonia resulted in reduced mortality as shown in figure 5.

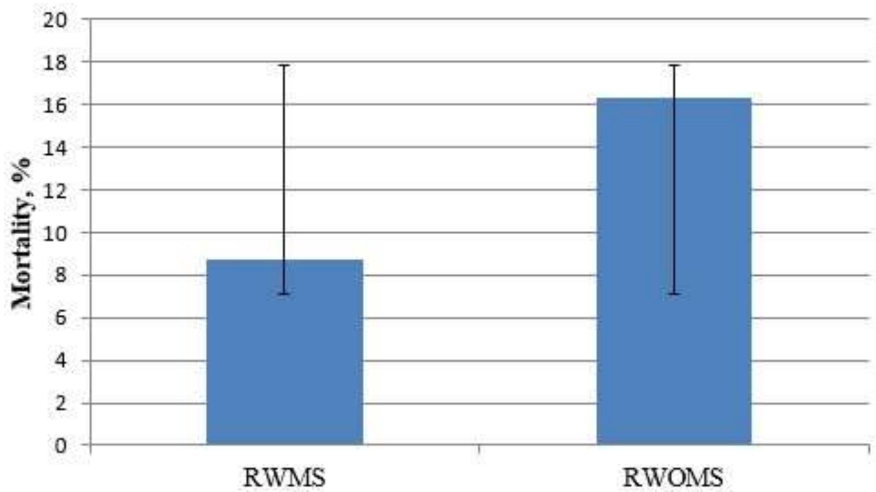

Figure 5. Comparing birds' mortality between room with membrane system (RWMS) and room without membrane system (RWOMS). Bars represent standard deviation

Age of Birds and Ammonia Concentration at day 28

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Several studies have reported that ammonia emissions increase with age of bird (Elwinger and Svensson, 1996). In both rooms of this study, the age of birds showed a significant positive effect on ammonia concentration ($p \leq 0.01$), however, comparing both rooms at day 7, 14, 21, and 28, day 7 and 14 were found not to be significant, however, day 21 and 28 were significant (Table 2). Ammonia concentrations were found to be lowest at day 7 and day 14 in both rooms. Ammonia concentration increased significantly at day 21 and day 28 (Table 2), which could be associated with the increase in animal age. For RWMS, young birds at the age of 7 d, ammonia concentration was 13.58 mg/L. For birds at the age 14 d, 21 d, and 28 d ammonia concentration were 25.71 mg/L, 32.93 mg/L and 53.98 mg/L respectively. In the room RWOMS, at age 7 d ammonia concentration was 21.66 mg/L. For birds at the age 14 d, 21 d, and 28 d ammonia concentration were 41.06 mg/L, 56.23 mg/L and 88.41 mg/L respectively. These findings confirm a study conducted by Knizatova et al., 2010; they reported that ammonia concentrations increase with bird age. They measured 0.0 mg/L and 29.1 mg/L of ammonia indicating an increase as the bird's age. Vučemilo et al. (2007) correlated the increase in ammonia concentration with the increase in animal age. They reported almost seven times higher level of ammonia concentration between the first and the fifth week of age.

Table 2. Paired t-test analyses showing the effect of bird's age on average ammonia concentration (mg/L) observed between RWMS and RWOMS.

Treatments	7 days	14 days	21 days	28 days
[a]RWMS	13.56	25.71	32.93	53.98
[b]RWOMS	21.66	41.06	56.23	88.41
	t = -2.79 p=0.0680	t = -2.88 p= 0.0635	t = -10.33 p= 0.0019	t = -4.25 p=0.0238

Note: [a]RWMS= room with membrane systems, [b]RWOMS= room without membrane systems=t-test analyses. Ammonia concentration was measured using Dräger instrument

CONCLUSION AND RECOMMENDATIONS

Many poultry farmers are looking for ways to reduce the impact of ammonia on their operation. The results of this study has shown that the membrane systems can be an effective method of reducing ammonia concentration in poultry houses with an added advantage of retaining ammonium salt as plant food. As evidenced by the results from this study, the membrane systems also recovered ammonia efficiently from poultry litter. Broiler live performance was not influenced by the membrane systems. The membrane system helped in reducing birds' mortality ~46%. This shows that high levels of ammonia concentration will result in higher birds' mortality which will have impact on profitability of the poultry operation. Broiler mortality represents significant loss in income to growers and integrators alike. Therefore in poultry operations, measures should be put in place to control ammonia concentration in poultry house. The use of ePTFE GPM was successful at reducing the ammonia concentration

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in the poultry room and in litter and capturing it as ammonium sulphate, a valuable fertilizer. This process of ammonia capture and recovery is a low energy process compared to commercial nitrogen production, as the only energy requirement is the pump used in circulating the acid

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