ECONOMICS OF AMMONIA RECOVERY ON DELMARVA BROILER PRODUCTION: A COMPARATIVE PROCESS ANALYSIS

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ABSTRACT

Two major challenges faced by poultry producers are the increasing cost for poultry house heating and the environmental impact from ammonia emissions. This study emphasizes an initial overview of the economics of a green technology evaluated for the capture and recovery of volatilized ammonia in a research poultry house unit on the Delmarva Peninsula. The objective is to provide growers, producers, and other stakeholders with information about its potential economic benefits of the systems evaluated. Two treatments, one with a gas semi-permeable membrane system and one without membrane system, were installed in separate poultry housing unit rooms of 36 m^2 each, which were stocked with 400 chicks each. The gas-permeable membrane system room reduced ambient ammonia concentrations in the room by 38% compared to the no membrane system room. The reduced NH_3 in the poultry house air was associated with decreased bird mortality by almost 47%. Comparative analysis of a gas-permeable membrane technology reveals that a tubular membrane system (TMS) performs better than a flat membrane system (FMS). The TMS had the greatest mean NH_4^+ recovery (4,077 mg/L) compared to the FMS (504 mg/L), representing an 8-fold increase. The overall efficiency of the tubular membrane system is associated with 6.8% reduced costs compared to those for the flat membrane system as determined for the physical configurations used in this study and for economic benefits to poultry growers by reducing bird mortality, improving worker health and environment, utilizing recovered NH_3 in fertilizer production, and also improving poultry quality.

Keywords: *Ammonia Recovery; Gas-permeable Membrane; Ammonia Emission; Control; Treatment;*

INTRODUCTION

Poultry production in regions with seasonally cool temperatures requires supplemental heating to sustain chicks during their vulnerable early stage of growth. Expenses for supplemental heat can be substantial for remote locations that use propane. Also, producers must deal with environmental impacts from ammonia emissions, which in estuarine regions like the Delmarva Peninsula, can contribute to eutrophication. Here, we compare economics based on the efficacy of ammonia capture and removal from air in a research broiler production house in the Delmarva region.

Noxious gases, e.g., ammonia, amines, and degraded organic matter, are generated in animal facilities as a result of animal metabolism and animal waste decomposition (Gürdil, 1998). Ammonia ($NH_{3)}$ is a colorless gas with a very sharp odor, detectable by humans exposed to as few as 5 parts per million (ppm) in air. Gaseous ammonia or anhydrous ("without water") ammonia can be compressed to become a liquid under pressure. It dissolves in water easily, maintaining its ionic form (NH_4^+), known as ammonium. Ammonia, once volatilized, can be quickly converted into ammonium salt through reaction with nitric or sulfuric acid where it can be used for various economic purposes.

According to the National Research Council (NRC), the primary air pollutant of concern on a global, national, and regional scale is ammonia because of its atmospheric deposition and haze impacts. The major global sources of ammonia emission are domestic animal's excreta and fertilizers and about 60% of it comes from anthropogenic sources, i.e., human activities (Asman, 1998; Bouwman et al., 1997). Agriculture represents the largest source of ammonia emissions (Fig 1, USEPA 2004). Recent analysis of emissions data for USA (Paulot et al., 2014) using high-resolution data with interpretation of a new agricultural emissions inventory (MASAGE_NH3), shows 79% of total ammonia emissions are from agricultural activities. This is lower than that reported earlier by USEPA (Fig. 1).

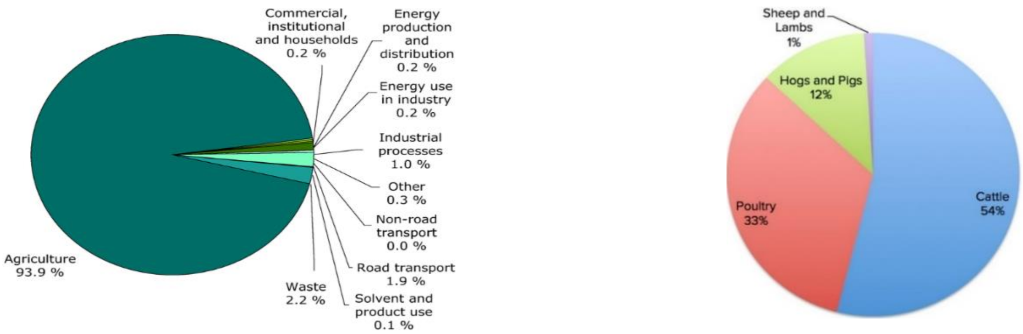
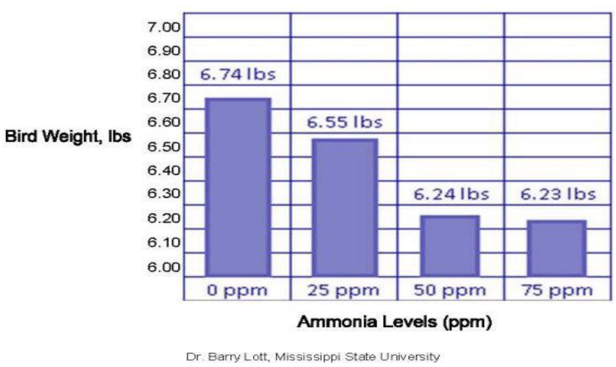


Figure 1. Ammonia Emission Sources (USEPA, 2004)

Ammonia is an abundant gas in poultry houses. Without sufficient ventilation, it increases the mortality rate for broilers raised on a litter bedding system. The odor of ammonia can be detected at concentrations > 5 mg/L (ppm, parts per million) (Verberk, 1977). The ammonia concentration in poultry houses are optimal at 25 ppm or less to help fight off respiratory disease challenges and prevent weight loss (Gospodinov, 2016). Ammonia is an eye and respiratory irritant, leads to chronic stress which contributes to infectious disease and complicates treatment (Gospodinov, 2016; Kristensen and Wathes, 2000). Chronic and even acute exposure to excess concentrations of ammonia directly influences animal growth and development, (Fig. 2) especially for very young chicks. In poultry houses, ammonia adversely affects the bird's performance, i.e., growth rate, feed intake efficiency, quality of carcass as well as susceptibility to combat disease challenge (Carlie, 1984). According to Gospodinov (2016), even exposing poultry to ammonia concentrations as low as 20 ppm for a long time period can affect their health. A study by Miles et al. (2004) indicated that when ammonia levels in broiler houses increased from 25 ppm to 50 ppm, body weight of 7 weeks old broilers was reduced by 226 g.



20,000 birds, Annual revenue loss = $19,920 per house due to bird mortality

Figure 2. Ammonia Effect on Poultry Industry (adapted from Pacific Sentry, LLC; https://pacificsentry.com/applications/cafos/)

PROJECT JUSTIFICATION

The poultry industry in general faces two major challenges: (a) Increasing cost of heating; and (b) Impacts of ammonia emissions in and from poultry houses. Regulatory agencies have great concern about numerous negative impacts of ammonia on animals, humans, and the environment. These impacts on humans, are illustrated in Table 1. Environmental impacts involve air and water pollution, eutrophication and soil acidification, as well as numerous adverse respiratory health impairments in chickens and other animals.

Nonlethal Effects of Ammonia on Humans

Concentration (ppm)	Exposure Time (min)	Effect	Reference
50	10	Moderate irritation (NOS)	MacEwen et al. 1970
110	120	Irritation: eyes, nose, throat, chest	Verberk 1977
140	30	Irritation: eyes, nose, throat, chest; urge to cough	Verberk 1977
140	120	Nuisance irritation: eyes, throat; urge to cough	Verberk 1977
143	5	Irritation: eyes, mouth, nose, throat, chest	Ind. Bio-Test Lab. 1973
571	One breath	Threshold for glottis closure in young males	Erskine et al. 1993

Table 1. Ammonia Effect on Human and Environment. Adapted from NIOSH, 1974.

Continuous research endeavors are in place to develop processes and technologies to reduce ammonia emission in the environment as well as in animal facilities such as poultry houses. Capturing, recovering and reusing recovered ammonia in litter or soil could provide valuable plant nutrients. Solutions to these challenges can be achieved through integrated approaches that incorporate enhanced sustainability by decreasing off-farm inputs, preferably substituting internally generated inputs on-farm with technologies such as heat and ammonia capture or a recovery system. Moreover, the economy of producing value-added products such as compost with high nitrogen fertilizer value, rebalanced nitrogen-phosphorus ratio, and reduction of air emission through internalizing resource flows within the production process would strengthen sustainability of poultry operations. Although the significance of ammonia emissions and its impact led researchers to explore and develop different abatement technologies for various sources (Ullman et al., 2004), there are limited studies on the use of gas-permeable membrane systems to control ammonia concentration in broiler houses. The focus of this study was to investigate the performance of two gas-permeable membrane systems in reducing ammonia concentration in broiler houses on the Delmarva Peninsula.

The largest agricultural revenue generator for Maryland is broiler production. In 2016, about 35% of all farm income in Maryland came from broiler production which ranked eighth nationally in the number of meat chickens and tenth in pounds of meat chicken produced (Rhodes et al., 2016). Most of the poultry plants located on Delmarva Peninsula are regulated under Clean Water Act as Concentrated Animal Feed Operations (CAFOs). In addition to concerns about the effects CAFOs may have on humans and the environment, there may be significant effects on property values as well (Hribar & Schultz, 2013). In order to limit the adverse effects posed by CAFOs and the ammonia they emit, additional regulations have been imposed (Reed, 2017). Such regulations are of major concern to most producers and they are looking for various sustainable approaches to reduce the negative impacts of their production activities on the environment. This project was designed to address some of these issues affecting the poultry industry on Delmarva Peninsula.

Our study reports on an initial overview of economic factors associated with research-scale results from study of ammonia capture/recovery using Flat and Tubular gas-permeable systems.

METHOD AND PROCEDURE

The experiment was designed and conducted over a 3-year period (2014-2016) at the University of Maryland Eastern Shore (UMES) using poultry experimental and teaching house # 11989. Two rooms with cemented area of 6m X 6m each were selected: one without the membrane system (control, MS^-) on North side of the poultry house, and the other with the membrane system (treatment; MS^+), on the South side was the treatment room. The depth of bedding material was 7.9cm (3.6 in) for the control room and 8.1cm (3.2 in) for the treatment room. Temperature sensors were installed in both rooms. Each 36 m^2 room was supplied with 400 chicks (at a density of 1ft^2/bird); birds were grown to ~3.1 kg. The two treatments were utilized with 4 replications per treatment. Estimated parameters include litter moisture content, litter pH, NH_4^+ (ammonium in acid solution), NH_3 (ammonia in air), bacteria, birds' mortality, etc.

Gas-permeable membranes were used to capture and remove ammonia (NH_3) from a total ammoniacal nitrogen (TAN) source with capture in acidic solution of H_2SO_4 (Mukhtar et al., 2011; Rothrock et al., 2010; Samani Majd & Mukhtar, 2013). Performance of the gas-permeable membrane system in NH_3 removal is directly related to availability of NH_3 concentration in the TAN source (Rothrock et al., 2010; Vanotti & Szogi, 2010). The two membrane systems (Flat and Tubular) thus far tested in laboratory settings were used in this research poultry house setting (Buabeng, 2017) to investigate their performance in capturing and recovering ammonia from a situation and condition that reflects that, which is typical of broiler house production in the Delmarva region. Statistical analyses were performed using Stata v.15 Statistical Software. Both gas-permeable membrane systems were installed in the same room for consistent environment and comparison of performance under identical room conditions. The two systems are shown diagrammatically for general understanding in Figures 3 and 4.

On a weekly basis, litter samples were collected and analyzed for moisture content, pH, and NH_4^+. Rooms and ambient temperature, feed intake, body weight, feed conversion ratio, bird mortality, and litter accumulation were also analyzed. Feed intake was calculated as kg/bird = Feed consumption in a replication/No. of live birds in a replication (Ghazi et al., 2012) and the feed conversion ratio was derived from dividing the dry matter of feed consumed by weekly body weight gain (Kumar et al., 2009).

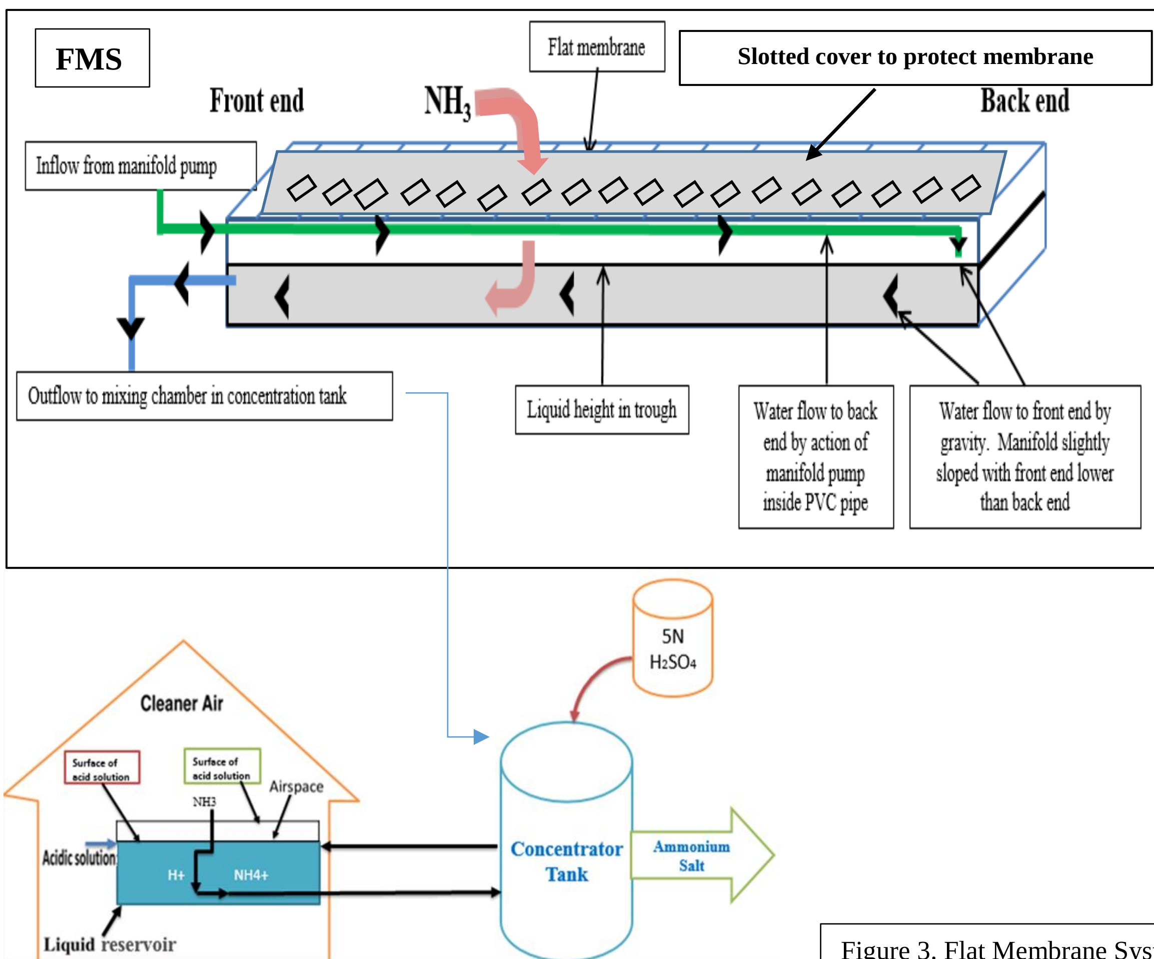


Figure 3. Flat Membrane System (FMS)

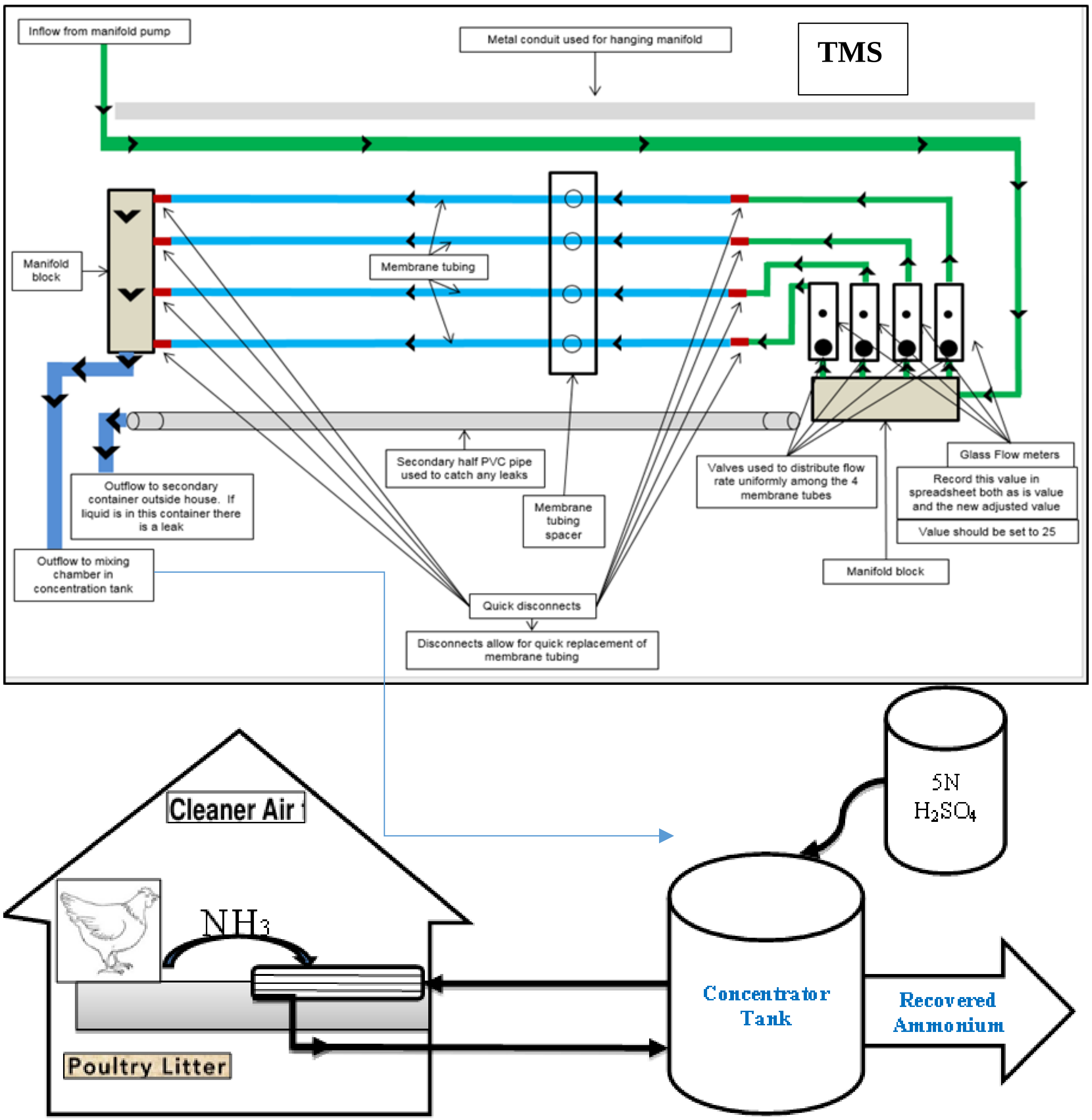


Figure 4. Tubular Membrane System (TMS) for this research project

RESULTS AND DISCUSSION

Production performances between rooms with (MS^+) and without the membrane systems (MS^-) (Table 2) show an overall improvement in terms of mortality rate, body weight, and feed conversion ratio (FCR). There were no significant differences in feed intake and body weight between the rooms ($p < 0.05$). Mortality rate was significantly reduced (by almost 47%) in MS^+. There was a significant difference in ammonia concentration between MS^+ (42.1 mg/L ± 36.7) and MS^- (68.3 mg/L ± 51.9) as shown in Table 2 with $t = -7.6$, $p \leq .001$. Ammonia concentration was reduced by almost 38.3% in the treatment room (Table 3). A corresponding reduction of 37% in ammonium (NH_4^+) extracted from poultry litter was measured in the room with membrane systems (Table 4). The results indicate that the membrane systems work in a field condition setting and would be an efficient option in controlling ammonia emissions in a broiler house.

Treatments	Capacity (Birds) Initial	Bird/m^2	Feed Intake (g) Mean ± SD	Live body weight (g)/bird Mean ± SD	FCR (g)	Mortality, %
MS$^+$	400	0.093	2370.4 ± 1650	2909.8 ± 73.8	1.67	8.7
MS$^-$	400	0.093	2355.9 ± 1634	2918.9 ± 227.7	1.68	16.3

Table 2. Production performance for rooms with (MS$^+$) and without (MS$^-$) membrane systems (mean values of four replications, i.e., separate flocks).

Variable	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]
MS$^+$ (NH_3)	42.1	7.6	36.7	26.2 57.9
MS$^-$ (NH_3)	68.3	10.8	51.9	45.8 90.8
difference	-26.2	3.4	16.6	-33.4 -19.0

Table 3. Ammonia Concentrations (mg/L) in air for treatment rooms with (MS$^+$) and without (MS$^-$) Membrane System (mean values of four replications, i.e., separate flocks).

Variable	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]
MS$^+$ (NH_4^+)	905.3	216.5	750.1	428.6 1381.9
MS$^-$ (NH_4^+)	1436.1	370.2	1282.4	621.3 2251.0
difference	-530.8	210.9	730.7	-995.1 -66.5

Table 4. Ammonium (NH_4^+) concentrations (mg/L) in poultry litter in treatment rooms with (MS$^+$) and without (MS$^-$) Membrane System (mean values of four replications, i.e., separate flocks).

The two gas-permeable membrane systems (flat and tubular) were evaluated to determine their efficiency in recovering ammonium (NH_4^+) in the recipient acid solution. The tubular membrane system (TMS) had the greatest mean NH_4^+ removal/capture, i.e., 4,077.4 mg/L (Table 5) compared to 504.55 mg/L in the flat membrane system (FMS). The mean difference showed a significant recovery of 87.6% in ammonia as ammonium by the TMS with t = - 13.8347, p < 0.001 compared to 12.4% recovery by the FMS (Table 5). This result indicates that the tubular membrane system (TMS) is more efficient in recovering volatilized ammonia than the flat membrane system (FMS).

Variable	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]
FMS (NH_4^+)	504.6	134.7	1051.9	235.1 773.9
TMS (NH_4^+)	4077.4	244.0	1905.8	3589.2 4565.4
difference	-3572.8	258.2	2016.9	-4089.4 -3056.2

Table 5. Comparison of ammonium (NH_4^+) concentrations (mg/L) recovered separately through the Tubular (TMS) and Flat (FMS) membrane systems (mean values of four replications, i.e., separate flocks).

ECONOMIC ANALYSIS

These results show that the gas-permeable membrane technology for ammonia reduction and capture can greatly contribute to reducing production costs, increasing quality of product via healthier chicks and reducing contaminant emissions into the environment. Integrating with other technologies, it may have significant positive and synergistic effects to improve profitability and hence, sustainability of poultry farming here on Delmarva Peninsula and elsewhere.

Reduced mortality ensures more revenue for the producer and other parties in the marketing and supply chain. Ammonia recovery and reduction in poultry houses improves quality of broilers. Recovered ammonia can be used in fertilizer production for cropping systems. Reduction in ammonia eventually reduces environmental pollution, and adverse animal and human health impacts.

The cost-benefit analysis was limited by the availability of real benefit data. However, it has been observed that the membrane systems are highly effective in recovering ammonia from poultry houses which reduces the negative effects on broiler health and quality, workers' health, and the environment. The synergic benefits across the economy may include reduction in overall health care costs for workers, availability of fertilizer nitrogen for crop production and minimized farming costs, which may contribute to sustainability. Comparing the substantial positive impacts that can accrue from capturing volatilized ammonia from poultry houses and reusing the recovered ammonia as fertilizer with the cost of the device/technology may justify its acceptance and applicability. Table 6 shows the separate costs for installation of the two research membrane systems [Flat membrane (FMS) and Tubular membrane (TMS) systems] in a 36 m^2 research poultry housing facility unit using the cost of supplies and materials for each system (actual cost incurred) in this study as reported here.

Item	**Flat System (FMS) (US$)**	**Tubular System (TMS) (US$)**
Fixed Materials and Supplies (pumps, tubing, tank, fittings pH sensor & controller	4,556.25	4,556.25
Specialized Materials for system installation	568.63	217.55
Total Cost	5,124.88	4,773.80

Table 6. Cost Comparison of Flat and Tubular Membrane Systems based on input for this study.

Comparing the cost of installation of the two membrane systems in this study (Table 6), the tubular system cost was 6.8% less than the flat system. Thus, accounting for the overall system costs and efficacy in ammonia capture and recovery, the TMS is especially cost effective with its overall ammonia capture performance superiority and somewhat less cost of installation in this study. While deployment of a tubular membrane system in a full-scale poultry production house is expected to be cost-effective, estimates will need to be customized to each situation and location. Other economic uses of the recovered ammonia also will need to be taken into consideration and valued to realize production cost-benefits to the total production operation (broiler and other by-products). For example, some of the household products contain ammonia such as ammonia cleaning solution, window cleaners, floor waxes and smelling salts. Some manufacturing processes also use ammonia. Hence, the economic impact of ammonia control and recovery in the poultry industry could be remarkable.

CONCLUSION

Gas-permeable membrane systems especially the tubular system (TMS) has multiple benefits as shown in this field-level setting study. The tubular system (TMS) was more efficient in recovering NH_4^+ than the Flat system (FMS). Bird mortality was reduced by nearly 47% ensuring higher revenue for producers. More ammonia captured and recovered by the tubular system can be used for fertilizer production and other applications and products. Producers should be encouraged to apply the membrane system. Further research should be undertaken to estimate economic benefits on human health and the environment.

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