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## Recovery of ammonia from poultry litter using flat gas permeable membranes

M.J. Rothrock Jr.<sup>1</sup>, A.A. Szögi\*, M.B. Vanotti

USDA-ARS Coastal Plains Soil, Water, and Plant Research Center, 2611 W. Lucas St., Florence, SC 29501, USA

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### ABSTRACT

The use of flat gas-permeable membranes was investigated as components of a new process to capture and recover ammonia (NH<sub>3</sub>) in poultry houses. This process includes the passage of gaseous NH<sub>3</sub> through a microporous hydrophobic membrane, capture with a circulating dilute acid on the other side of the membrane, and production of a concentrated ammonium (NH<sub>4</sub>) salt. Bench- and pilot-scale prototype systems using flat expanded polytetrafluoroethylene (ePTFE) membranes and a sulfuric acid solution consistently reduced headspace NH<sub>3</sub> concentrations from 70% to 97% and recovered 88% to 100% of the NH<sub>3</sub> volatilized from poultry litter. The potential benefits of this technology include cleaner air inside poultry houses, reduced ventilation costs, and a concentrated liquid ammonium salt that can be used as a plant nutrient solution.

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### 1. Introduction

Volatilization of NH<sub>3</sub> gas from manure is one of the largest environmental concerns associated with confined poultry production. Excessive NH<sub>3</sub> accumulation in poultry housing air can adversely affect the health of both workers and birds (Kiryuchuk et al., 2006; Rylander and Carvalheiro, 2006). Several studies have shown the detrimental effect of high levels of NH<sub>3</sub> on bird performance (Dawkins et al., 2004; Ritz et al., 2004; Yahav, 2004). Increased ventilation can lower the NH<sub>3</sub> in poultry houses to safe levels, but energy costs during winter months represent a significant expense to the growers (Xin et al., 1996). Since NH<sub>3</sub> cannot be effectively contained within the house structure, NH<sub>3</sub> emissions may contribute to air pollution, atmospheric deposition, and health concerns for nearby residents (Wing and Wolf, 2000; Wheeler et al., 2006). Due to the high cost of commercial NH<sub>3</sub> fertilizers in today's marketplace, the conservation and recovery of nitrogen (N) are an important agricultural issue. Thus, there is major interest among producers and the public in implementing best control technologies that will abate NH<sub>3</sub> emissions from confined poultry operations by capturing and recovering N.

Technologies used by the poultry industry for NH<sub>3</sub> abatement can be classified into four broad categories based on their mode of action. The first and most widely used technology is simply increasing ventilation to keep NH<sub>3</sub> levels down inside the poultry houses (Xin et al., 1996). The second technology prevents the re-

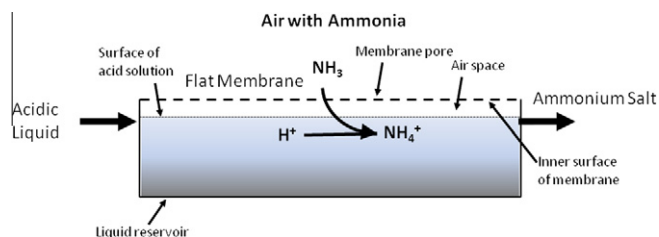
lease of NH<sub>3</sub> into the environment by treating the exhaust air from the house ventilation system using scrubbing or filtration techniques. These techniques remove NH<sub>3</sub> from livestock houses by forcing the house air through an NH<sub>3</sub> trap, such as an acidic solution (scrubbers), or through a porous filter with nitrifying biofilms that oxidize NH<sub>3</sub> to nitrate – biotrickling or organic filters (Melse and Ogink, 2005; Pagans et al., 2005). The third technology uses dedicated ventilation systems independent of the house ventilation system to selectively pull and treat the air near the litter surface, where NH<sub>3</sub> levels are more concentrated (Lahav et al., 2008). The fourth approach involves directly mixing chemical amendments into the poultry litter to prevent NH<sub>3</sub> volatilization, without additional ventilation. These amendments act by either inhibiting microbial transformation of organic N into NH<sub>3</sub> or by conversion of volatile NH<sub>3</sub> into non-volatile NH<sub>4</sub> via acidification. Chemical amendments such as alum [Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>·14 H<sub>2</sub>O], sodium bisulfite (NaHSO<sub>4</sub>), and acidified clays have been widely used to control or reduce NH<sub>3</sub> release from poultry litter and manure (Moore et al., 1995; Rothrock et al., 2008, 2010a). Using these amendments, N is conserved un-volatilized in the poultry litter but NH<sub>3</sub> is not recovered as a separate product as with the scrubbing methods. Recovery of NH<sub>3</sub> is a desirable feature because it can be exported off the farm, solving problems of N surpluses in concentrated poultry production regions.

This study describes a novel NH<sub>3</sub> removal approach using gas-permeable flat membranes placed inside the poultry house near the NH<sub>3</sub> source that combines some of the advantages and benefits of the technologies mentioned above. This new technology recovers N in a concentrated, purified form using the concept of integrated membrane separation and gas absorption also shared by hollow fiber membrane contactor techniques (Pabby and Sastre,

\* Corresponding author. Tel.: +1 843 669 5203; fax: +1 843 669 5970.

E-mail address: [ariel.szogi@ars.usda.gov](mailto:ariel.szogi@ars.usda.gov) (A.A. Szögi).

<sup>1</sup> Permanent address: USDA-ARS Poultry Processing & Swine Physiology Research Unit, 950 College Station Rd., Athens, GA 30605, USA.



**Fig. 1.** Schematic diagram of  $\text{NH}_3$  capture using flat, hydrophobic, gas-permeable membranes. The  $\text{NH}_3$  gas permeates through hydrophobic membrane walls with micron-sized pores, where it combines with the free protons ( $\text{H}^+$ ) in the acid solution to form non-volatile ammonium ions ( $\text{NH}_4^+$ ).

2013). This concept includes the passage of gaseous  $\text{NH}_3$  through microporous, hydrophobic, gas-permeable membranes and its capture in a circulated acidic solution with concomitant production of a concentrated  $\text{NH}_4$  salt. Once  $\text{NH}_3$  gas passes through the membrane and is in contact with the acidic solution, it reacts with free protons ( $\text{H}^+$ ) to form non-volatile ammonium ( $\text{NH}_4^+$ ) salt, which is retained and concentrated in the acidic solution (Fig. 1).

Hydrophobic gas-permeable membranes are made of different materials such as polypropylene (Shindo et al., 1981), polyethylene-polyurethane composites (Lee and Rittmann, 2000), and polytetrafluoroethylene (Blet et al., 1989). As a device that accomplishes mass transfer in gas-liquid systems, membrane contactor modules using a bundle of microporous tubular membranes have been studied in separation processes for gas stripping and absorption (Mansourizadeh and Ismail, 2009; Yang and Cussler, 1986). In these modules, gas flow or air movement accelerates the mass transfer between the gas and liquid phases. In fact, increased  $\text{NH}_3$  gas flow in membrane contactors accelerates  $\text{NH}_3$  removal rate (Klaassen et al., 2008). However, in a previous study, we found that tubular gas-permeable membranes made of expanded polytetrafluoroethylene (ePTFE) were effective for removing gaseous  $\text{NH}_3$  from enclosures containing poultry litter in absence of air movement/ventilation (Rothrock et al., 2010b) and that they could be equally effective placed above or below the litter surface.

Tubular membrane performance can be affected by changes in the pressure of the liquid. Increasing pressure in the liquid side can lead to membrane pore wetting and drastically reduce gas absorption performance in long-term operation (Mansourizadeh and Ismail, 2009). As shown in Fig. 1, our design using flat membranes configured for removing  $\text{NH}_3$  from poultry litter could be an advantage to tubular membranes because the liquid absorbent is not in direct contact with the membrane. The objective of this study was to test the feasibility of using flat ePTFE, gas-permeable membrane as a new approach to remove and recover  $\text{NH}_3$  from poultry litter. To achieve this, flat ePTFE membrane manifolds were developed and installed in bench- and pilot-scale chambers using a circulated acidic solution to evaluate their ability to recover and concentrate N from poultry litter under normal and enhanced  $\text{NH}_3$  volatilization conditions. Results from this study and Rothrock et al. (2010b) have been used in the filing of a U.S. Patent on the process (Szögi et al., 2011).

## 2. Materials and methods

### 2.1. Gas-permeable membrane

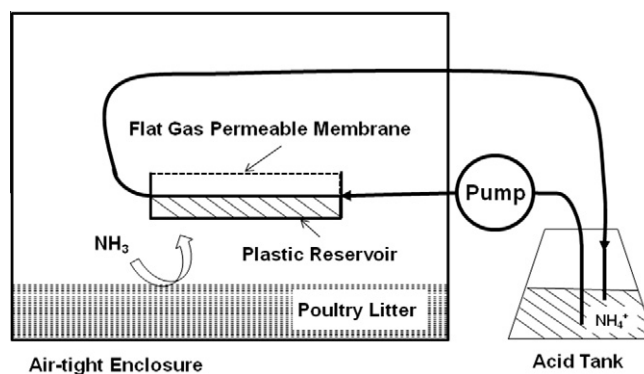
The flat gas-permeable membrane was made of ePTFE with a thickness of 0.044 mm and a bubble point of 21 kPa (FL1001, Philip Scientific, Rock Hill, SC). The ePTFE membrane was supported with a 0.229-mm thick spun-bond polypropylene fabric that faced the acid.

### 2.2. Process configurations

Two laboratory experiments and one pilot-scale prototype experiment were performed to test the feasibility of using flat membranes to capture and recover  $\text{NH}_3$  volatilized from poultry litter. The basic process configuration used in both laboratory and pilot-scale experiments in this study is shown in Fig. 2. An acidic solution (1 N  $\text{H}_2\text{SO}_4$ ) contained in an acid tank was continuously re-circulated using a peristaltic pump into an air-tight enclosure containing the poultry litter. Once inside the enclosure, the acid was contained and circulated through a plastic reservoir covered by the flat, gas-permeable membrane sheet, allowing for the passage of  $\text{NH}_3$  gas emitted by the litter and subsequent recovery and concentration of the N as an  $\text{NH}_4$  salt. For all bench- and pilot-scale experiments,  $\text{NH}_3$  concentrations in the headspace of the chamber were measured using the Dräger Chip Management System (Dräger Safety, Inc., Pittsburgh, PA). The  $\text{NH}_3$  chips were in the measuring range of 100–2000  $\mu\text{g NH}_3 \text{ L}^{-1}$  (20 °C) with an accuracy of  $\pm 10\%$  of the measured values according to the manufacturer. The instrument was further tested under laboratory conditions (21 °C) with a 9% accuracy of the measured values using a 500  $\mu\text{g L}^{-1}$  certified  $\text{NH}_3$  standard (National Specialty Gases, Durham, NC).

### 2.3. Laboratory experiments

Two bench-scale experiments were performed to test the feasibility of using flat ePTFE membranes in conjunction with an acidic solution to capture and recover  $\text{NH}_3$  volatilized from poultry litter under natural and enhanced conditions using lime [ $\text{Ca}(\text{OH})_2$ ] to accelerate  $\text{NH}_3$  volatilization. In both experiments, lime raised the pH of the litter to convert available non-volatile ammonium-N ( $\text{NH}_4\text{-N}$ ) to volatile  $\text{NH}_3\text{-N}$ . The addition of lime was to test how quick  $\text{NH}_3$  could be recovered from the litter but also because lime has been historically used for disinfection and  $\text{NH}_3$  management of poultry litter (Yushok and Bear, 1948; Shah et al., 2012). The bench-scale experiments included two replicates. The acid solution and headspace air were sampled daily. The pH of the acidic solution was monitored using pHDrion Insta-Chek 0–13 litmus paper (Micro Essential Laboratory, Brooklyn, NY). In all experiments, the pH values of the liquid in the acid tank were always below pH 2, which is an indication of a 100%  $\text{NH}_3$  absorption efficiency (Lahav et al., 2008; Rothrock et al., 2010b). Liquid acid samples from the acid tank (0.3 mL) were diluted into 2.7 mL ultrapure water and stored in capped vials at 4 °C until analysis. Final litter samples were taken once the enclosures were opened after the last air/acid sampling; all litter samples were stored at  $-20$  °C until analysis. The experiments were performed in a laboratory at ambient pressure and temperature conditions (23–25 °C).



**Fig. 2.** Schematic diagram of the basic process for  $\text{NH}_3$  recovery.

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