Recovery of ammonia nitrogen in livestock and industrial wastes using gas permeable membranes

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Abstract – New waste management methods are needed that can protect the environment and allow manure management to switch back to a recycling view of manure handling. We investigated the use of gas-permeable membranes as components of new processes to capture and recover the ammonia in the liquid manures or in the air of poultry houses and other livestock installations. The basic process includes the passage of gaseous ammonia contained in the contaminated air or liquid through a microporous hydrophobic membrane and capture and concentration with circulating diluted acid or water on the other side of the membrane. The membranes can be assembled in modules or manifolds and can be tubular or flat. For liquid manure applications, the membrane manifolds are submerged in the liquid and the ammonia is removed from the liquid matrix in barn pits or storage tanks before it goes into the air. The concept was successfully tested using concentrated swine and dairy manure effluents containing 140 to 1400 mg/L ammonia-N. For the removal of ammonia in air, the technology captured and recovered 96% of the ammonia lost from poultry litter. The membrane manifolds can be placed close to the poultry litter surface (above or below), thus reducing the exposure of the birds to ammonia. The results obtained show that the use of gas-permeable membrane technology could be an effective approach to recover ammonia from livestock wastewater and from the air in poultry barns and other livestock operations. The final products are (1) reduced environmental emissions from livestock facilities, (2) cleaner air inside the poultry and swine houses with benefits to bird/animal health, and (3) concentrated liquid nitrogen that can be re-used in agriculture as a valued fertilizer.

Key-words – Nutrient recovery, swine manure, poultry litter, ammonia emissions control.

Introduction
New waste management methods are needed that can protect the environment and allow manure management to switch back to a recycling view of manure handling (Martinez et al., 2009). One of the largest environmental concerns associated with livestock and poultry production is the loss of ammonia (NH₃) gas from the manure (Aneja et al., 2001, Paerl, 1997). The Research Triangle Institute International (RTI, 2003) estimated the monetized economic benefits to North Carolina households of changes in environmental quality resulting from the generalized adoption of alternative waste technologies (2,300 swine operations). Results indicated that adoption of technologies that provides a 50% reduction of NH₃ emissions account for an estimated benefit of $190 million/year in avoided human health impacts (RTI, 2003). Similarly, volatilization of NH₃ inside poultry barns often results in an excessive accumulation of NH₃ in air, which can negatively affect the health of both workers and birds (Ritz et al., 2004). Although increased ventilation can lower the NH₃ in poultry houses to safe levels, it is expensive due to energy costs during winter months (Moore et al., 1995). Conservation and recovery of nitrogen (N) is also important in animal agriculture because of the high cost of commercial NH₃ fertilizers. Thus, there is major interest from producers and the public on implementing best control technologies that would abate NH₃ emissions from confined livestock and poultry operations by capturing and recovering N. In this work we investigated the use of gas-permeable membranes as components of new processes to capture and recover ammonia from liquid manures as well as from the air in poultry houses and other livestock installations.

Materials and Methods
The basic process includes the passage of gaseous NH₃ through a microporous hydrophobic membrane and capture and concentration with circulating diluted acid on the
other side of the membrane and production of a concentrated ammonium salt (Figure 1). The membranes can be assembled in modules or manifolds. They were used to remove \( \text{NH}_3 \) of manure origin from both liquid (Vanotti and Szogi, 2011) and air (Rothrock et al., 2010). The enclosure consisted of a 2-L, polyethylene terephthalate (PET) plastic jar. The acid tank (Fig. 1) consisted of a 500-mL glass flask containing 300 mL 1N H\(_2\)SO\(_4\). A peristaltic Manostat pump (Cole-Parmer, Vernon Hills, IL, USA) was used to continuously circulate the acid through the tubular membranes inside the chamber and back into the acid tank using flow rates of 70-80 mL day\(^{-1}\). Gas-permeable tubing made of expanded polytetrafluoroethylene (ePTFE) was used in the interior of the chamber for \( \text{NH}_3 \) capture. The length of the tubing used in all experiments was 66 cm with inner diameter 5.25 mm and wall thickness 1.00 mm. For liquid manure applications, the membrane manifolds were submerged in the manure liquid (1.8 L) and the ammonia was removed from the liquid matrix before it went into the air (Figure 2). The concept was successfully tested in ten batches using liquid swine manure containing about 1500 mg/L NH\(_4\)-N. The same acidic solution was used in the consecutive batches. Concentrated acid was added to the acidic solution as needed when pH increased from <1 to about 2. For air applications, the membrane modules are placed exposed to the air close to the manure sources such as poultry litter, composting pile, or the atmosphere above the liquid surface in manure tanks and pits. We tested \( \text{NH}_3 \) capture coming from solid poultry litter manures (Figure 3).

**Results and Discussion**

**Treatment of liquid** – The idea of using gas permeable membranes to remove \( \text{NH}_3 \) from liquid manure was successful. The concept was tested using concentrated swine manure effluents containing 140 to 1400 mg/L NH\(_4\)-N (Vanotti and Szogi, 2011). The use of gas-permeable membranes to remove \( \text{NH}_3 \) from liquid manure was effective, and the rate of N recovery by the gas-permeable membrane system was higher with higher NH\(_3\) concentration in the manure. While ammonia gas passed readily through the membrane pores, the soluble COD compounds did not pass. The rate of \( \text{NH}_3 \) recovery was also increased with increased pH of the wastewater. With a pH of 8.3, the rate of N recovery was about 1.2% per hour. This rate was increased 10 times (to 13% per hour) at pH of 10. For liquid manure containing 1,400 mg/L NH\(_4\)-N, with the membrane manifold installed, in 9 days the total NH\(_4\)-N concentration decreased about 50%, from 1,290 mg/L to 663 mg/L. As a result, the NH\(_3\) fraction in the liquid, which is linked to NH\(_3\) emissions (Szogi et al., 2006), decreased 95%, from 114.2 to 5.4 mg/L. By using the same stripping solution in 10 consecutive batches treating raw swine manure, the recovered N was concentrated in a clear solution containing 53,000 mg/L NH\(_4\)-N.

**Treatment of air** - The concept of using gas permeable membranes to remove \( \text{NH}_3 \) from air in livestock facilities was also successful. During a 21-day test, the NH\(_4\)-N content in the litter decreased 58% by volatilization, from 1,369 mg/kg (± 9) to 792 (±7). In terms of recovery efficiency, 82% of the NH\(_4\)-N was recovered during the first week of the experiment, and 100% was recovered by the end of the third week (Rothrock et al., 2010). It was found that the \( \text{NH}_3 \) volatilized from the litter can move down and below the litter layer and be effectively recovered with the membranes. This provides flexibility in future membrane treatment system design. For example, membrane manifolds may be placed below the bedding, or under caged production, thus reducing exposure of birds to \( \text{NH}_3 \). The results also showed that aboveground placement of membrane manifolds is equally effective at recovering NH\(_4\)-N from the litter, and these manifolds could be placed in grids near the surface or along waterer/feeder lines, or even placed on the building walls. Considering the \( \text{NH}_3 \) is captured inside the houses, this technology help reduce ventilation and energy needs to lower \( \text{NH}_3 \) levels in poultry houses. The recovery can also be accelerated to a few days using hydrated lime. Thus, producers choosing to disinfect the poultry manure using lime could benefit from this membrane system by simultaneously recovering the \( \text{NH}_3 \) that is rapidly released upon lime application.

**Conclusions**
The results obtained in this study show that the use of gas-permeable membrane technology could be an effective approach to recover NH₃ from livestock wastewater and from the air in poultry litter and other livestock operations. The final products are (1) reduced environmental emissions from livestock facilities, (2) cleaner air inside the poultry and swine houses with benefits to bird/animal health, and (3) concentrated liquid nitrogen that can be re-used in agriculture as a valued fertilizer.

References

Figure 1 - Cross-sectional diagram of ammonia capture using hydrophobic gas-permeable membrane. Ammonia gas (NH₃) in the liquid manure permeates through hydrophobic membrane walls with micron-sized pores, where it combines with the free protons (H⁺) in the acid solution to form non-volatile ammonium ions (NH₄⁺). In another configuration, the same membrane is exposed to air instead of liquid.

Figure 3. Field prototype tested at USDA-ARS in Florence, SC, USA of a new system to recover ammonia from poultry litter using flat, hydrophobic gas-permeable membrane.