Advanced Manure Treatment

Part 3: Nitrogen recovery technologies

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Many of the phosphorus recovery technologies also recover nitrogen (N) to some degree, especially for the N associated with the suspended solids. Nitrogen recovery technologies are most successful and cost-effective when paired with the recovery of solids (phosphorus and some N).

However, a significant portion of the N (approximately 50%) is in the liquid phase and would require a removal process if a lower nitrogen liquid was desired to limit the land application area needed. These removal processes can be further subdivided into chemical or biological in nature.

Biological N removal processes

With the addition of air (or oxygen) nitrifying aerobic bacteria oxidize the ammonium (NH_4^+) to nitrite (NO_2^-) then to nitrate (NO_3^-). Then in the absence of oxygen denitrifying anaerobic bacteria convert nitrate to N_2 gas. Typical steps include: NO_3 to NO_2 to NO to N_2O and then finally to nitrogen gas N_2. N_2 is an inert gas making up 78% of our atmosphere and is benign. Generally, there would be a power requirement to aerate the liquid to initiate the process. There is the potential for nitrous oxide (N_2O), a potent greenhouse gas, to escape in these processes if the reaction does not go to completion.

Conventional nitrification–denitrification (NDN)

NDN is a two-step process carried out in separate reaction vessels. In the first step, after aeration, nitrification occurs. During step 2, with no air added, denitrification occurs. This second step has a significant requirement for carbon to combine with the oxygen. Unfortunately, this makes this process unsuitable for use with anaerobic digestate since much of the biologically available carbon has already been removed.

Simultaneous nitrification–denitrification (SND)

SND is very similar to NDN except that the reactions happen simultaneously in the same vessel. This requires very strict control of the dissolved oxygen in the system. Because only part of the total biomass is participating in the nitrification or denitrification reactions conversions of ammonium and nitrate are relatively slow.

Shortcut biological N removal (SBNR)

In SBNR, ammonium is oxidized to nitrite, as usual, but not further to nitrate. Instead nitrite is reduced to N_2 gas by denitrifying bacteria utilizing an electron donor.

Anaerobic ammonium oxidation (Anammox)

Typically used for wastewaters with high ammonia concentrations, Anammox follows the $NH_3 \rightarrow NO_2 \rightarrow N_{2(gas)}$ pathway, but the organisms involved use only CO_2 as their carbon source for growth. Because the bacteria do not require an organic carbon source Anammox can work well with effluent from an anaerobic digester. CO_2 needs to be dissolved into the reaction container.

Vermifiltration

A passive aerobic bioreactor consisting of layers of wood shavings, composting earthworms, castings, and other porous materials through which liquid manure is trickled. The liquid manure has a very short hydraulic retention time. Although the role of the worms in the NDN process is still unclear, the system has very low operating and energy costs, and can significantly reduce total N. One commercial scale system[1] has seen performance efficiencies of 86% of N, 84% of P, and 94% of total suspended solids removed. The resulting waste stream can be spread via an irrigation system rather than trucks, and only requires 300 acres (down from 4,000) to satisfy the farm's nutrient management plan. Unfortunately, the filtration system itself requires a large footprint at about an acre per 100,000 gallons of daily effluent. It also has not been evaluated in temperatures below 15°F, and it produces almost 150 g of N_2O per day on this 5,000-cow dairy.

Ammonia stripping (chemical process)

This process is based on the fact that a rise in pH and/or temperature results in a shift in the ammonium (NH_4^+) ion toward $NH_{3(gas)}$. This facilitates its removal and/or collection as an aqueous solution or ammonium salt fertilizer. It is especially advantageous for anaerobic digestate since the effluent is typically high in ammonia, at least somewhat alkaline, and waste heat from the combined heat and power (CHP) generation can provide the needed thermal energy. This process has the potential for recovery of the N as a concentrated fertilizer.

Table 1. Nitrogen removal/recovery technologies relative costs and efficiencies.

Technology	Capital Cost / Cow	Annual Operating Cost / Cow	Solids Reduction	Nitrogen Reduction	Phosphorus Reduction	Product Yield	Product Revenue	Avoided Costs
Nitrification - Dentrification	$$$	$$$	N/A	88%	67%	0	0	$
Vermifiltration	$$$	$$	96%	86%	84%	0.4 yd^3 castings/ cow/year 1.3 lbs. worms/ cow/year	$	$$
Ammonia Stripping	$$$$	$$$	N/A	72% - 85%	0%	0.5 ton/cow/ year	$	$

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[1] Using Worms to Manage Dairy Manure, *Manure Manager*, September 29, 2018, https://www.manuremanager.com/using-worms-to-manage-dairy-manure-30640/, accessed 27 July 2020.