Module for Phosphorus Separation and Recycling from Liquid Manures

ASA Symposium: Opportunities and Limitations of Phosphorus Removal and Reuse From Manures, Oct. 24, Cincinnati, Ohio

Matias Vanotti - USDA-ARS, Florence, South Carolina
Ariel Szogi - USDA-ARS, Florence, South Carolina
Patrick Hunt - USDA-ARS, Florence, South Carolina
Maria Cruz Garcia – ITACyL Agriculture Institute, Valladolid, Spain
Patricia Millner - USDA-ARS, Beltsville, Maryland
Philip Bauer - USDA-ARS, Florence, South Carolina

Presentation outline: recovery of phosphorus from swine wastewater through calcium phosphate precipitation

• Basic process configuration (discovery) 1997
• Case 1: On-farm testing (pilot scale) 2000
• Case 2: P module as key component of a complete manure treatment system (full-scale)
• Case 3: Cost reduction by simultaneous separation of P and manure solids (full-scale)
• Case 4: Current licensing/commercialization by industry

Phosphorus Removal Process
Buffer Systems in Animal Manure

Carbonates
Ammoniacal Nitrogen

Urea Hydrolysis
CO(NH$_2$)$_2$ + 2H$_2$O $\rightarrow$ 2NH$_4^+$ + CO$_3^{2-}$

High Amount of Lime [Ca(OH)$_2$] Required to Precipitate P

Phosphorus Precipitation (swine wastewater)

- After removal of natural buffers, the addition of Ca(OH)$_2$ (or Mg) rapidly increases the pH, which promotes precipitation of phosphate with small amounts of chemical added.


Phosphorus Removal - Basic Process Configuration
Elimination of Buffer System with Biological N Treatment

Nitrification bacteria naturally produce the acid that destroys the carbonate, which eliminates a huge interference for Ca-P precipitation.
Phosphorus recovery from swine wastewater using Calcium Hydroxide

Case Example 1

1. Phosphorus extraction from digested swine lagoon effluents (pilot study).

Recovery of P from the liquid manure after anaerobic digestion

P recovery from lagoon swine wastewater
Field prototype – Duplin Co., NC, 2000

Precipitation of calcium phosphate with P-module prototype

Rapid precipitate formation (15 min mixing)
Recovered Phosphates:

Phosphorus (and NH₄) treatment: process results

<table>
<thead>
<tr>
<th></th>
<th>INFLUENT (mg/L)</th>
<th>EFFLUENT (mg/L)</th>
<th>EFFICIENCY (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.7</td>
<td>10.5</td>
<td></td>
</tr>
<tr>
<td>Total N</td>
<td>320</td>
<td>299</td>
<td>6</td>
</tr>
<tr>
<td>NH₄-N</td>
<td>278</td>
<td>5</td>
<td>98</td>
</tr>
<tr>
<td>Total P</td>
<td>71.9</td>
<td>1.6</td>
<td>98</td>
</tr>
</tbody>
</table>

Case example 2

P recovery module as key component of a complete manure treatment system (full-scale)

Treatment goals

Meet Environmentally Superior Technology (EST) Standards for New or Expanding Swine Operations in NC

- Substantially eliminate:
  1. ammonia emissions
  2. odor emissions
  3. pathogens
  4. nutrient (N & P) surplus
  5. heavy metal contamination
Soluble phosphorus separation and bagging of the calcium phosphate

Application of lime using pH controller, rapid mixing, and settling of the phosphorus precipitate

Performance of total system during 5 pig production cycles

Removal of soluble phosphorus by treatment system

Dewatering and bagging of calcium phosphate

Dewatering and bagging of calcium phosphate

Recovered P from sludge = 99.5%

Polymer used to retain P precipitate in filter bags
Anionic PAM, 5-10 ppm

Recovered Phosphates

99% plant available (standard citrate test)

Fertilizer Manufacture
Production of fertilizer pellets at IFDC, Alabama

1. Recovered P from module
2. Crushed
3. Compacted
4. Sieved
5. Final Product: Granulated fertilizer

Material was successfully pelletized just by compaction (no additives needed, only moisture)

Agronomic Effectiveness of Phosphates Recovered from Swine Wastewater

Green-house testing at ARS Florence, SC

- Rye-grass yields similar to commercial P fertilizer (TSP)
- Larger size pellets (2-4 mm) = slow release P fertilizer


Pathogen reduction by system

The high process pH of phosphorus treatment disinfects the effluent

<table>
<thead>
<tr>
<th>Treatment point</th>
<th>Enterococci #cfu/mL</th>
<th>Salmonellae #cfu/mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Manure</td>
<td>952,000</td>
<td>23,200</td>
</tr>
<tr>
<td>Solids Separation</td>
<td>159,000</td>
<td>7,210</td>
</tr>
<tr>
<td>Nitrification/</td>
<td>41</td>
<td>310</td>
</tr>
<tr>
<td>denitrification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phosphorus Treatment</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Case example 3

Cost reduction by simultaneous separation of P and manure solids (full-scale)
**Lower Cost, Second Generation Technology Demonstration**

**NC Attorney General – Smithfield Foods Environmental Enhancement Program**

2007-2009

---

**Simultaneous separation of two contrasting sludges using PAM**

\[
y = 1.2483x + 30.235 \\
R^2 = 0.9722
\]

---

**SECOND GENERATION WITH SIMULTANEOUS SOLID-LIQUID SEPARATION OF SWINE MANURE AND PHOSPHORUS PRECIPITATE**

Vanotti et al. (2010), U.S. Patent 7,674,379

---

**Phosphorus recovery after natural buffer removal**

Small P reactor (~ 0.3 m$^3$ for 5400 pigs) 9 m$^2$ settling tank

Application of lime to pH 9.5 and settling of calcium phosphate

---

**2nd Generation System (replacement of lagoons with environmentally superior technology)**

**Full-scale treatment, 5,400 pigs, Tyndall Farm, North Carolina**

Vanotti et al. (2009), Bioresource Technology 100: 5406-5416

---

**Garcia et al. (2007)**

Trans. ASABE 50:2205-2215

---

**Vanotti et al. (2009), 2009, Bioresource Technology 100: 5406-5416**
Phosphorus Separation Module

Solid-liquid separation of manure and phosphorus solids with flocculation
- Flocculation with cationic PAM
- Dewatering with rotary press
- Capture of P, organic N, Cu & Zn

Model: Centralized Plant for Processing of Separated Manure Solids
- Generation of Value Added Products through Composting

Centralized Solids Processing Facility (Composting)
- Conserved the separated N and P
- Manure transformed into Class A compost
- Processed into plant growth media

Nutrient Stabilization & Recovery
Solids Processing Facility
- Material Weight: 55.5%
- Material Volume: 28.4
- Total Carbon: 56.6%
- Total Nitrogen: 97
- Total Phosphorus: 101.2

Production of high-value plant growth media and organic fertilizers from composted manure solids (Terra Blue Inc.)

Commercialization phase - 2012
Terra Blue Inc., Clinton, NC
P Module in NC farm (20,000 pigs)
SUMMARY

- Soluble phosphorus is selectively precipitated using lime after carbonate and ammonia buffers are reduced with biological N removal.

- The precipitate is calcium phosphate (~ 24% P₂O₅).

- The precipitate can be reused as plant fertilizer (99% plant available), alone or mixed with manure solids.

- The high pH also disinfects the effluent.