Alternative Management of Liquid Swine Manure: Separation of solids and nutrients into value-added products

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USDA-ARS Coastal Plains Research Center
Florence, South Carolina
CONFINED SWINE PRODUCTION

- Industrial production of swine generates large amounts of waste
- Most farms use anaerobic lagoon and sprayfield technology
- Nitrogen and phosphorus exceed crop area available for disposal
- Also problems of odor and ammonia emissions
Phosphorus budget for Duplin Co, NC

- There is enough pastureland to apply 370,000 lb of P/year without building soil P
- vs. 16,934,000 lb of recoverable manure P available for application each year
- When crop uptake and pastureland are combined, there is a current annual excess of 15,647,000 lb of P due to animal production
- Thus, P needs to be removed from the farm and transported to other areas

Data from Charles Lander, NRCS National Nutrient Specialist
Nutrients in swine manure in North Carolina

- 162 million lb of Nitrogen
- 54 million lb of Phosphorus

- Can provide all fertilizer needs for North Carolina’s six largest agricultural counties

- Transport in liquid form is not feasible
BENEFITS OF SOLIDS-LIQUID SEPARATION

• Removes odor generation compounds and organic nutrients

• Allows movement of N and P to nutrient deficient areas

• Opens new alternatives for swine waste management:
  - Economic aeration treatment of liquid – ammonia removal
  - Extraction of soluble phosphates
  - Processing of solids for value-added products
  - Concentration strategies for biogas production

- Full-Scale demonstration of Environmental Superior Technologies to replace current hog lagoon-sprayfield system

- Competitive funding process

- Environmental performance standards (II.C.1.5):
  - Eliminate discharge to surface and groundwater
  - Eliminate ammonia emissions
  - Eliminate odor emissions beyond farm boundaries
  - Eliminate pathogens
  - Eliminate nutrient contamination of soil and water.
Project: Treatment system for elimination of lagoons, reduced environmental impact and improved water quality

- Super Soil Systems USA (NC): Production of soilless growth media from solids

- Selco M.C. (Spain): Solids separation module

- Hitachi Plant Engineering and Construction Co. (Japan): Biological ammonia removal

- Mitsui & Co (Chicago): Marketing of environmentally friendly pork meat and solids by-products

- USDA-ARS Florence and NCSU Animal Waste Mgmt Program: Scientific and engineering support.
Smithfield Project: Environmental Superior Technology
Solids separation and wastewater treatment at Duplin Co.
Smithfield Project: Centralized plant to stabilize manure solids & market value added products
Super Soil Systems USA, Clinton, NC
VALUE-ADDED PRODUCTS: Soilless Media
### Economic Analysis

**Processing of Solids into Soilless Media**

**Smithfield Project: Finishing operation with 4360 pigs in NC**

1,302 ton manure/year; 60% moist. 
compost use cotton gin trash & bark 
media: 50% compost/50% enhancing materials

<table>
<thead>
<tr>
<th></th>
<th>Annual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composting equipment and site preparation</td>
<td>$12,135</td>
</tr>
<tr>
<td>Blending &amp; bagging equipment/bldg</td>
<td>$4,253</td>
</tr>
<tr>
<td>Rental value of land (0.8 ac)</td>
<td>$51</td>
</tr>
<tr>
<td>Operational and media materials</td>
<td>$115,971</td>
</tr>
<tr>
<td>Sale of soilless media 4795 cu yrd @ $45/cu yrd</td>
<td>$215,792</td>
</tr>
</tbody>
</table>

**Earnings per finished pig** $6.83
System without lagoon

- Processing of separated solids (generation of income)
- Treatment of liquid fraction
- High-efficiency separation required
CAN SOLIDS IN LIQUID SWINE MANURE BE SEPARATED?

- Solids in swine manure mostly in fine particles
- Fine solids clog sand filter beds
- Screen and presses only remove 10-15% of total suspended solids and organic nutrients
- Higher separation efficiencies possible with chemical treatment
## SEPARATION EFFICIENCIES WITH SCREEN (1/32”)

<table>
<thead>
<tr>
<th></th>
<th>TRIAL 1</th>
<th>TRIAL 2</th>
<th>TRIAL 3</th>
<th>TRIAL 4</th>
<th>TRIAL 5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS (%)</td>
<td>13</td>
<td>16</td>
<td>19</td>
<td>10</td>
<td>19</td>
<td>15.4</td>
</tr>
<tr>
<td>COD (%)</td>
<td>10</td>
<td>3</td>
<td>13</td>
<td>1</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>ORGANIC N (%)</td>
<td>13</td>
<td>8</td>
<td>14</td>
<td>18</td>
<td>13</td>
<td>13.2</td>
</tr>
<tr>
<td>ORGANIC P (%)</td>
<td>7</td>
<td>5</td>
<td>14</td>
<td>13</td>
<td>14</td>
<td>10.6</td>
</tr>
</tbody>
</table>
POLYACRYLAMIDE POLYMER (PAM)

- Water soluble polymer, high molecular weight
- Applications: municipal, food processing, soil erosion, animal waste
- Absorb and bridge colloidal suspended particles into flocs
- Effective at low dosage

PAM Flocculation
POLYACRYLAMIDE POLYMER (PAM)

- More than 50 formulations available
- Cationic, Anionic, neutral
- Best for animal waste are cationic PAMs with low charge density
SOLIDS REMOVAL FROM FLUSHED SWINE MANURE USING PAM

TSS, g/L

POLYMER RATE, mg/L

INITIAL CONCENTRATION
SCREEN
PAM + SCREEN
Polymer usage rate: best results with higher strength wastewater

![Graph showing the relationship between total solids in flush (g/L) and polymer usage rate (lb polymer/ton dry solids separated or g polymer/100 g dry solids separated). The graph indicates a decrease in polymer usage as the total solids increase.]
Chemical Cost

Based on

- Polymer usage rate = 0.9%
- Solids removal = 97%
- Polymer cost = $1.80/lb
- Manure production = 5.05 lb dry/1000 lb /day
- Feeder to finish operation, 4400 head

- Chemical cost = $1.38 / finished pig
PAM treatment also removes nutrients from liquid manure

ORGANIC N or P REMOVED (%)

SUSPENDED SOLIDS REMOVED (%)

Phosphorus

Nitrogen
After flocculation with PAM, solids and liquid are separated and dewatered using:

- Filter presses – Ecoliz system
- Sand Filter beds – Deskins system
- Rotating screens – Selco system
- Belt filters – Bio/Resource system
Ecoliz Filter Press System in Brittany, France

1. Manure.
2. Anti-odor treatment and preparation for flocculation.
3. Flocculation.
4. Filtration.
5. Final processing and storage of the liquid filtrate in pool.
6. Indoor pre-drying and storage of the solid cake for external recycling.

Livestock farming:
- Irrigation.
- Possible feedback to the installation.
Ecoliz Filter Press System in Brittany, France

Compression and filter chamber

Solid cake

Indoor storage of separated manure
Deskins sand filter drying beds: Construction of pilot unit at NCSU Animal Waste Center
Deskins system:

In-line polymer injection for flushed swine manure and pouring into sand filter bed
Deskins system

3 hours

3 days
## PAM solids separation: 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>Suspended Solids</td>
<td>7,410</td>
<td>135</td>
<td>98</td>
</tr>
<tr>
<td>Volatile Solids</td>
<td>6,110</td>
<td>107</td>
<td>98</td>
</tr>
<tr>
<td>COD</td>
<td>11,800</td>
<td>1,330</td>
<td>89</td>
</tr>
<tr>
<td>TKN</td>
<td>674</td>
<td>259</td>
<td>62</td>
</tr>
<tr>
<td>Organic N</td>
<td>443</td>
<td>41</td>
<td>91</td>
</tr>
<tr>
<td>TP</td>
<td>196</td>
<td>67</td>
<td>66</td>
</tr>
<tr>
<td>Organic P</td>
<td>162</td>
<td>12</td>
<td>93</td>
</tr>
</tbody>
</table>
SELCO Ecopurin Module in Modena, Italy:

PAM flocculation and separation with rotating screen
SELCO solids separation module: Rotating screen
SELCO system in Italy
## Economic Analysis
### PAM Liquid-solids separation

**Smithfield Project: Finishing operation with 4360 pigs in NC**
- Solids removal = 97%
- Wastewater = 33,000 gal/day
- Interest rate = 8%

<table>
<thead>
<tr>
<th>Component</th>
<th>Annual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selco separation module</td>
<td>$16,356</td>
</tr>
<tr>
<td>Building + homogenization tank</td>
<td>$3,055</td>
</tr>
<tr>
<td>Polymer cost (9376 lb)</td>
<td>$16,878</td>
</tr>
<tr>
<td>Energy costs (168 Kwh/d)</td>
<td>$3,152</td>
</tr>
</tbody>
</table>

**Cost per finished pig**

$3.23
Nutrient flow

The solids separation process capture nearly all the organic nutrients:

- 65 % of total N in fresh manure
- 85 % of total P in fresh manure

After separation, the liquid contains:

- 35 % of initial N, mostly ammonia
- 15 % of initial P, mostly phosphate
Nitrifying pellets:

Nitrifying bacteria is protected inside polymer pellets permeable to ammonia and oxygen.

Wastewater is treated in a nitrification tank equipped with a screen to retain the pellets and an aeration system for fluidization.
Japanese pellet technology effectively treats nitrogen in animal and other high-strength wastewater

By Matias B. Vanotti, Patrick G. Hunt, J. Mark Rice, and Frank J. Humenik

In Japan, municipal wastewater treatment plants use state-of-the-art technology — immobilized microorganisms to nitrify treatment on-demand. Immobilization of microorganisms from municipal wastewater treatment plants (WWTPs) is increasingly used in animal and other wastewater industries. Immobilized microorganisms can be used to remove nitrogen from wastewater at rates comparable to those found in Japan in municipal wastewater systems — rates that are three times higher than those achieved by conventional activated sludge treatment systems. In addition, the pellet technology is quick and relatively inexpensive.

Nitrifying Pellet Technology

The immobilization process provides an environment in which nitrifying microorganisms can perform optimally. Nitrifiers are entrapped in 1- to 3-mm pellets made of polymers that are permeable to the ammonia, oxygen, and carbon dioxide that the microorganisms need to thrive (see Figure 1, p. 31).

The pellets, typically made of polyethylene glycol and polyvinyl alcohol, are functional for more than 10 years. Wastewater is treated in a nitrification tank equipped with a self-priming aeration system and a wedge-wire screen that retains the pellets, which comprise 2% to 15% of the reactor volume. According to Vanotti and Hunt (2000), immobilization technology also can
# HIGH-AMMONIA NITRIFIERS

Batch treatment, influent ammonia 340 to 2600 ppm-N

<table>
<thead>
<tr>
<th>Initial Ammonia Concentration (mg N/L)</th>
<th>Ammonia Removal Rate (mg N/L-reactor/day)</th>
<th>Final Nitrate Concentration (mg N/L)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>344</td>
<td>991</td>
<td>348</td>
<td>100</td>
</tr>
<tr>
<td>860</td>
<td>924</td>
<td>855</td>
<td>99</td>
</tr>
<tr>
<td>1570</td>
<td>917</td>
<td>1525</td>
<td>97</td>
</tr>
<tr>
<td>2608</td>
<td>1013</td>
<td>2569</td>
<td>99</td>
</tr>
</tbody>
</table>
Biogreen system after solids-liquid separation using nitrifying pellets and denitrification for total N removal

Nitrified liquor recycle

Ammonia
(NH₃ + O₂ = NO₃)

Nitrate
(NO₃ + Manure C = N₂)

Nitrogen gas
(N₂)

Sludge recycle

Clean water

Clarifier

BOD

Nitrification

Denitrification

Ammonia

Pellets increase nitrifying bacteria concentration in tanks and ammonia treatment efficiency.
## Ammonia Treatment: Biogreen Process Results

<table>
<thead>
<tr>
<th></th>
<th>INFLUENT (mg/L)</th>
<th>EFFLUENT (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.7</td>
<td>7.9</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>1,378</td>
<td>653</td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>135</td>
<td>110</td>
</tr>
<tr>
<td>TKN</td>
<td>259</td>
<td>19</td>
</tr>
<tr>
<td>Ammonia</td>
<td>231</td>
<td>1</td>
</tr>
<tr>
<td>Nitrate</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>
TREATMENT PERFORMANCE
SOLIDS SEPARATION +
NITRIFICATION/DENITRIFICATION

N CONCENTRATION (mg/L)

- TOTAL NITROGEN IN FLUSHED MANURE
- AFTER PAM SOLIDS SEPARATION
- AFTER BIOLOGICAL NUTRIENT REMOVAL
## Economic Analysis
### Biological Ammonia Removal Treatment

**Smithfield Project:** Finishing operation with 4360 pigs in NC  
Effluent Ammonia < 10 ppm  
Wastewater = 33,000 gal/day  
Water temperature = 10 °C  
interest rate = 8%

<table>
<thead>
<tr>
<th>Annual cost</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor + treated water tanks</td>
<td>$5,726</td>
</tr>
<tr>
<td>Biogreen equipment + nitrifying pellets</td>
<td>$15,298</td>
</tr>
<tr>
<td>Energy costs (395 Kwh/d)</td>
<td>$7,410</td>
</tr>
</tbody>
</table>

**Cost per finished pig:** $2.33
Solids-liquid separation with PAM removes most organic nutrients and COD in liquid swine manure.

Low carbon concentration important consideration for economical aeration and nitrification treatment.

Immobilized technology provides quick and effective treatment of ammonia in animal wastewater.
Phosphorus Extraction and Dewatering/bagging

Phosphorus separation reactor

Soluble P

Calcium phosphate
## Phosphorus Removal: Process Results

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Applied Ca/Influent P</th>
<th>Total P</th>
<th>Effluent N/P</th>
<th>Product grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Molar ratio</td>
<td>mg/L</td>
<td>Conc. ratio</td>
<td>% P2O5</td>
</tr>
<tr>
<td>Influent</td>
<td></td>
<td>71.9</td>
<td>4.45</td>
<td></td>
</tr>
<tr>
<td>Treated Effluent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 1</td>
<td>0.82</td>
<td>25.5</td>
<td>11.9</td>
<td>17.5</td>
</tr>
<tr>
<td>Level 2</td>
<td>1.58</td>
<td>11.1</td>
<td>27.1</td>
<td>17.2</td>
</tr>
<tr>
<td>Level 3</td>
<td>2</td>
<td>3.3</td>
<td>90.6</td>
<td>16.1</td>
</tr>
</tbody>
</table>
N/P ratio of treated effluent can be adjusted for specific needs

<table>
<thead>
<tr>
<th>Added Ca (Ca/P ratio)</th>
<th>Effluent P</th>
<th>N/P ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>53.1</td>
<td>5.6</td>
</tr>
<tr>
<td>0.5</td>
<td>37.6</td>
<td>7.8</td>
</tr>
<tr>
<td>1</td>
<td>21.8</td>
<td>13.7</td>
</tr>
<tr>
<td>2</td>
<td>7.9</td>
<td>38</td>
</tr>
<tr>
<td>3</td>
<td>3.2</td>
<td>93.8</td>
</tr>
</tbody>
</table>

Prescribed use
- Corn uptake needs
- Bermudagrass needs
- Sprayfield remediation
# Economic Analysis

## Phosphorus Extraction Treatment

### Smithfield Project: Finishing operation with 4360 pigs in NC

- **P effluent < 5 ppm**
- **Wastewater = 8,250 gal/day**
- **P$_2$O$_5$ value = $0.25$/lb**
- **interest rate = 8%**

<table>
<thead>
<tr>
<th>Annual cost</th>
<th>Reactor module</th>
<th>Dewatering and bagging equipment</th>
<th>Chemical cost</th>
<th>Dewatering and bagging operating cost</th>
<th>Sale of fertilizer P product 11,800 lb P2O5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,694</td>
<td>$3,341</td>
<td>$472</td>
<td></td>
<td>$1,488</td>
<td>-$2,949</td>
</tr>
</tbody>
</table>

**Cost per finished pig** $0.33
Smithfield Project: Waste treatment system without lagoon
Three modules: PAM solids separation, N removal, P removal.

- Solids-liquid Selco Separation Module
- Biological Nitrogen Removal Module - Hitachi
- Phosphorus Removal Module

Bagged phosphorus product
Manure solids for composting and soilless media products
Treated water (flushing/irrigation)
## Economic Feasibility of Total System

### $ per finished pig

<table>
<thead>
<tr>
<th>WASTEWATER TREATMENT COST</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids Separation</td>
<td>3.23</td>
</tr>
<tr>
<td>Nitrogen Removal</td>
<td>2.33</td>
</tr>
<tr>
<td>Phosphorus Removal</td>
<td>0.33</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5.89</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REVENUES FROM MANURE PRODUCTS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6.83</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OVERALL COST</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>-0.94</strong></td>
</tr>
</tbody>
</table>

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*Finishing operation with 4360 pigs in NC*