Phosphorus content in wastewater can be reduced by recovering a portion of the phosphorous as a crystalline product called struvite. Struvite is relatively easy to dry and handle and shows potential as a slow-release fertilizer. Struvite is the common name for magnesium ammonium phosphate hexahydrate (MgNH₄PO₄·6(H₂O)). Pure struvite contains 9.9 percent Mg, 5.7 percent N, and 12.6 percent P, which as a fertilizer would be 5.7-29-0 for N-P₂O₅-K₂O plus Mg.

Struvite can help animal production facilities remove excess phosphorus (P) from liquid waste systems. Many farmers are already aware that struvite can naturally form and clog pumps and pipes when recycling lagoon liquid. Struvite accumulation is also a common problem in pumping systems for anaerobic treatment portions of municipal waste treatment systems. Although components designed to promote struvite formation and collection have been previously used to remove phosphorus from municipal waste treatment systems, the idea of promoting struvite formation and collection is a relatively new concept for livestock wastewater treatment and nutrient management.

High levels of phosphorus applied to land in excess of crop needs increases the potential that phosphorus will run off into water, depleting oxygen and causing algae blooms, a major environmental concern. When animal waste is applied to meet nitrogen requirements, often more phosphorus than crops can uptake is also applied. Fields that receive animal wastes often have a high P level in soil-test samples, sometimes containing enough P to meet crop needs for several years. In some cases, there is enough P for the next 20 or more years. If farms continue to apply P in excess of crop needs, and if regulations regarding phosphorus are applied to farms, it is possible that fields could be limited by regulations to receiving P at crop uptake rates or no manure P at all.

Continuous-Flow Struvite Crystallizer

Concentrated animal feeding operations with lagoons or digesters can use the continuous-flow struvite crystallizer to remove phosphorus from wastewater and capture it as a struvite.

Figure 1. Struvite crystallizer used for 1.4 gal/min. flow rate of covered digester liquid. A) Add chemicals for Mg and pH increase at bottom of crystallizer cone or in inflow line; B) Waste-water inflow; C) Struvite crystals in bottom of cone.
digestion and biogas collection for energy production (Westerman et al., 2008). Covered lagoons, covered earthen digesters, and other types of anaerobic digesters on farms are being encouraged by renewable energy incentives, carbon credits, and greenhouse gas (GHG) credits. The liquid in a covered digester has higher total ammoniacal nitrogen (TAN) and dissolved carbon dioxide concentrations than liquid in an open lagoon because the cover reduces gaseous losses. The pH of the liquid in the covered digester is also lower than typically found in an open lagoon.

Results with covered digester liquid were similar to those with lagoon liquid. Results for 30-minute field tests (Figure 3) indicated that more than 70 percent of P could be removed by increasing the pH and adding Mg. To control costs, however, fewer chemicals can be added, if a lower reduction in P is adequate. Raising the pH from 7.3 to 7.8 and increasing the Mg from 40 mg/L to 80 mg/L resulted in an average of 55 percent removal of total phosphorus in about 40 two-hour tests conducted over 13 months.

**Fertilizer Performance of Struvite**

Struvite’s effectiveness as a fertilizer has been tested at NC State University and other places. At NC State, struvite N release was calculated for three different particle sizes (< 2 mm, 2-3 mm, and 4-8 mm) by measuring N uptake in ryegrass grown in a greenhouse in two soils (Nelson, 2000). Struvite particle size affected N release in the first 3 to 6 weeks after planting, when the smaller particle sizes released more N than the coarser particles did. After 6 to 9 weeks, the N release was similar for all particle sizes. Struvite released less N during the first 3 to 6 weeks and more N during the last 9 weeks than did ammonium phosphate. The struvite pattern was typical of a controlled release fertilizer, in which nutrient release accelerates as growing plants deplete the soil. In England, struvite and other phosphate products were tested by growing potted ryegrass in two types of soils (Johnston and Richards, 2004). Dry-matter yields and P removal were similar between stru-
vite and monocalcium phosphate, which is considered to be 100 percent available for potential plant uptake.

Struvite’s value depends on market development of a slow-release specialty magnesium and phosphorus fertilizer. Struvite is well suited for fertilizing turf grass not only because of the P it provides, but also because of the Mg, the central element in chlorophyll that promotes a strong green color. Struvite may be the only high-magnesium compound that is slow-dissolving without special treatment. Ostara Nutrient Recovery Technologies, Inc. (Vancouver, B.C.) has used a crystallizer to produce struvite from municipal wastewater and is promoting the product as Crystal Green™ fertilizer for turf and specialty agriculture markets. Multiform Harvest Inc. (Seattle, WA) is further developing the NC State crystallizer for removing and recovering P from wastewater in agricultural, industrial (such as potato-processing wastewater), and municipal systems, and is developing a market for the product. At this point, it is difficult to assign a dollar value to struvite. What a fertilizer company may pay at the farm for raw product will depend on the costs for transportation, drying (if not dried on the farm), storage, and further processing to create a blended product.

Management Considerations

Chemicals must be added to the lagoon or digester liquid to obtain high degrees of P removal in struvite. Anhydrous ammonia or sodium hydroxide (NaOH) work well to adjust pH, but both chemicals should be used with caution. Some nitrogen is added to the wastewater when ammonia is used, making the wastewater more valuable as fertilizer. If a farm does not want to add any nitrogen, however, and prefers to handle a liquid solution rather than have a compressed cylinder of ammonia for the system operation, sodium hydroxide is a good alternative. Adding NaOH may be easier to automate compared to the anhydrous ammonia, but the cost of ammonia is likely less than NaOH.

Magnesium chloride hexahydrate (MgCl₂·6(H₂O)) works well for adding Mg to the lagoon liquid or digester liquid. Effluent from the crystallizer typically contains more Mg than the influent to the crystallizer because 100 percent of the added Mg is not used for struvite formation. For example, when 40 mg/L of Mg was added to digester liquid that already contained 40 mg/L of Mg, the effluent typically had about 50 mg/L of Mg. In this case, NaOH was used to raise pH by 0.5 unit, and total P was reduced by 55 percent (approximately from 70 mg/L to 30 mg/L).

Reliable pumps are needed to maintain consistent flow rates of the lagoon or digester liquid to the crystallizer and the chemicals added for raising pH and Mg. When peristaltic pumps are used, the tubing or hose can wear down, which can change the flow rate or result in hose failure. For pumping wastewater influent, an industrial hose pump made of durable material worked well with dairy lagoon liquid or digester liquid in tests conducted in Washington. A diaphragm metering pump for adding chemicals is an alternative to peristaltic pumps.

Struvite seed crystals must be initially added to the crystallizer to create a bed that will grow as more struvite is formed. Often, struvite can be obtained from pipes in lagoon liquid recycle systems in large aggregated chunks. Break up the chunks and screen particles to help develop the initial bed. In tests with covered digester liquid, the initial bed particle size distributions by weight were typically about 25 percent 0.3-0.4 mm (40-50 mesh screen), 25 percent 0.4-0.6 mm (30-40 mesh screen), and 50 percent 0.6 to 1.2 mm (16-20 mesh screen). As the particles grew and the bed weight increased by about 80 percent, the smallest sizes usually decreased by about 80 percent, and the two larger sizes usu-
ally increased by about 100 percent. However, only about 5 percent of harvested particles were greater than 1.2 mm. Struvite must be removed from the crystallizer periodically. Due to the cone shape of the crystallizer, the highest velocity is at the bottom (smaller cross-sectional area). Thus, the largest, heaviest particles tend to be at the bottom of the cone. If the flow is stopped and the struvite bed is allowed to settle, the larger particles can be collected from the bottom. One way to collect them is with a plunger on a rod that sits in the crystallizer and floats upward with flow, but settles to the bottom and seals the cone when there is no flow. A release valve can be opened at the bottom of the cone and the plunger lifted to allow some product to flow out.

The struvite product that is collected from the bottom of the crystallizer can contain particles of various sizes. The collected struvite can be dried and screened to retain only the larger particles, and the smaller particles returned to the struvite crystallizer. About 90 percent of the particles harvested in tests with covered digester liquid were in the range of 0.4 to 1.2 mm.

The struvite product is usually relatively easy to dry and results in a product that looks like sand (Figure 2). To produce particle sizes as large as possible, keep handling and wearing of particles during drying to a minimum. Spreading out the product and blowing air across it resulted in drying within 24 hours for struvite harvested in pilot tests. Struvite is thermally unstable in air at temperatures above 120°F (about 50°C). It can lose part or all of its ammonia and water molecules depending on the time and temperature of the heat treatment, ultimately forming magnesium hydrogen phosphate.

A typical farm might produce only about 50 to 100 lb/day of struvite. Regions that have many farms could form a cooperative or other type of organization to collect and market struvite.

A struvite crystallizer can be easily added to farms with lagoons or digesters. Handling the treated liquid is an issue for farms with single lagoons. If the treated liquid is discharged back into a single lagoon, phosphorus released from the lagoon sludge could result in little change in P levels in the liquid above the sludge. This has not yet been tested. Another possibility with single lagoons is to install a partition (hanging curtain) to separate treated liquid from untreated liquid. If the farm has two lagoons in series, the crystallizer could be installed to treat liquid from the first lagoon and discharge into the second one. Although there have been no farm tests using treated liquid to flush barns, it is likely that treated liquid would help keep struvite from clogging pumps and pipes in recycle systems.

Average farm workers have the expertise needed for managing a struvite system most of the time. The main requirements are harvesting struvite (probably every one or two days); handling, drying, and storing struvite; mixing chemical solutions; and checking flow rates. If periodic pH measurement or measurement of P in influent and effluent is needed, a technical expert could visit the site once per week, and a farm worker could maintain the routine daily operations.

**Design and Installation**

The struvite cone-shaped fluidized bed crystallizer is patented by N. C. State University and is licensed to Multiform Harvest, Inc. Persons interested in design and installation of these systems should contact Keith Bowers at Multiform Harvest, Inc. (keithbowers@yahoo.com) for further information. Mr. Bowers has experience with scale-up of the struvite crystallizer on swine, dairy, food processing, and municipal waste-water systems.

**Cost of Struvite System**

An example of projected costs for a 1,000-sow farrow-to-finish operation with a lagoon is shown in Table 1. The reduction in TP used for this example is 60 percent (about – 40 mg/L). The estimated $87,000 capital cost is amortized over an assumed 7-year lifetime at 6 percent APR, resulting in an annual capital cost of $15,585, and the annual operating cost is $24,464. Subtracting the estimated value of the struvite at $0.15/lb (based on an estimate of what a fertilizer company might pay for raw product at the farm), the net cost is $0.0066/lb of live hog marketed. The value of the struvite will vary depending on fertilizer costs, niche markets for the struvite such as turfgrass fertilization, and also possible use as a feed ingredient. Fertilizer costs can be variable as reported by Huang et al. (2009). This analysis excludes any cost for drying and storage of product. It also excludes any cost for treated water storage, which would probably not have to be added on farms with a covered digester. These farms will likely already have a storage unit for the overflow from the digester, and the crystallizer could be positioned to take liquid from the digester and discharge treated liquid to the storage pond. The largest net costs of the system are for amortization (depreciation and interest on capital invested) (43 percent), labor and management (25 percent), chemicals (17 percent), and electricity (13 percent). Economies of scale are expected for this system. Capital cost and labor costs may change at a fraction of the rate of change in animal capacity treated. The struvite system could be scaled up by increasing the size of the crystallizer or by using multiple units. It may also be possible to obtain cost sharing of this system as a nutrient management technology at some point.
Table 1. Cost analysis example for struvite crystallizer for 1,000-sow farrow-to-finish operation.

Assumptions
a. Estimate assumes a 1,000 sow farrow-to-finish operation (about 10,000 animals total population at an average weight of 140 pounds).
b. Annual production is 20,000 market hogs weighing an average of 275 pounds.
c. Estimate produced using experience from building and operating a unit sized to 2,000 animals (200 sows) at that operation.
d. Capital investment is amortized over 7 years to obtain annual amount.
e. Assume 1.5 hours of labor per day and one hour of management per week to: 1.) remove product, 2.) monitor the system and make minor repairs, 3.) make up magnesium solution, and 4.) change ammonia cylinders.

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Quantity</th>
<th>Unit Price or Rate</th>
<th>Annual Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Costs (annual amortization @ 6 percent APR over 7 years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment, materials</td>
<td>$</td>
<td>$44,000</td>
<td>17.91 percent</td>
<td>$7,882</td>
</tr>
<tr>
<td>Installation, construction</td>
<td>$</td>
<td>$43,000</td>
<td>17.91 percent</td>
<td>$7,703</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$</td>
<td>$87,000</td>
<td>17.91 percent</td>
<td>$15,585</td>
</tr>
<tr>
<td>Operating Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg Brine delivered (+40 ppm to wastewater)</td>
<td>lb of Mg</td>
<td>2919</td>
<td>$0.25</td>
<td>$730</td>
</tr>
<tr>
<td>Sodium Hydroxide (50 percent solution)</td>
<td>Gal.</td>
<td>4424</td>
<td>$1.274</td>
<td>$5,637</td>
</tr>
<tr>
<td>delivered (specific gravity is 1.53)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(adding 0.505 gal/1000 gal. wastewater)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity (10 hp average)</td>
<td>KwH.</td>
<td>66,671</td>
<td>$0.07</td>
<td>$4,667</td>
</tr>
<tr>
<td>Labor</td>
<td>Hours</td>
<td>540</td>
<td>$12.00</td>
<td>$6,480</td>
</tr>
<tr>
<td>Management</td>
<td>Hours</td>
<td>52</td>
<td>$50.00</td>
<td>$2,600</td>
</tr>
<tr>
<td>Maintenance at 5 percent of Capital Cost</td>
<td>$</td>
<td>87,000</td>
<td>5 percent</td>
<td>$4,350</td>
</tr>
<tr>
<td>Subtotal</td>
<td></td>
<td></td>
<td></td>
<td>$24,464</td>
</tr>
<tr>
<td>Total Costs</td>
<td></td>
<td></td>
<td></td>
<td>$40,049</td>
</tr>
<tr>
<td>Revenue</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Struvite (64 lb per day) (40 ppm TP removal; 24,000 gal./d flow)</td>
<td>lb</td>
<td>23,384</td>
<td>$0.15</td>
<td>$3,508</td>
</tr>
<tr>
<td>Total Net Cost</td>
<td></td>
<td></td>
<td></td>
<td>$36,541</td>
</tr>
</tbody>
</table>

Notes
a. Excludes cost for treated water storage
b. Equates to $0.0066 net cost per lb live hog marketed ($36,541/(20,000 x 275))
c. Equates to $0.01 net cost per animal per day ($36,541/(10,000 x 365))
d. Substituting Ammonia at 133 ppm for sodium hydroxide (NaOH) could reduce costs of pH adjustment by $335 per year if ammonia price is $0.45/lb, but the need to avoid adding nitrogen to the wastewater may cause farmers to prefer NaOH.
References


The use of trade or brand names or vendors in this publication does not imply endorsement of products or vendors mentioned or criticism of similar products or vendors not mentioned.

Prepared by:

Philip W. Westerman, Professor, Department of Biological and Agricultural Engineering
Kelly D. Zering, Associate Professor and Extension Specialist, Department of Agricultural and Resource Economics
Diana Rashash, Area Specialized Agent, Cooperative Extension Service

Distributed in furtherance of the acts of Congress of May 8 and June 30, 1914. North Carolina State University and North Carolina A&T State University commit themselves to positive action to secure equal opportunity regardless of race, color, creed, national origin, religion, sex, age, veteran status or disability. In addition, the two Universities welcome all persons without regard to sexual orientation. North Carolina State University, North Carolina A&T State University, U.S. Department of Agriculture, and local governments cooperating.