INTRODUCTION

Finishing pigs produce, at an average 150-pound bodyweight, about one pound of total manure solids per day, within the total manure volume of about 1.2 gallons per day (9.5 lb). Approximately 80 percent of the total solids are volatile solids and can be broken down further in a digester, anaerobic lagoon or similar treatment unit. In a pit under a building, finishing pig manure may have a concentration of about 50 lb/1000 gallons total N, 33 lb/1000 gallons ammonium-N, 42 lb/1000 gallons total P, and 30 lb/1000 gallons K (MWPS 2000). Very substantial differences in concentration among pits are found, however.

There are several valid reasons to try to separate the liquid and solid fractions of manure. Unfortunately, the most effective separation methods are expensive and actually add material to the manure. Therefore, the selection of a liquid-solid separation system must address the overall goals of the production facility and practical cost constraints.¹

Here are some of the more common reasons for utilizing liquid-solid separation of swine manure. Reduce loading rates on liquid-based treatment systems. Breakdown of the volatile solids is also responsible for much of the manure odor. Much of the phosphorus in the manure -- 96% -- is in the solids fraction (Rice et al. 2003), and of that solids fraction, the phosphorus predominates in particle sizes too small to capture in mechanical screens. Soluble phosphorus can be precipitated from the liquid stream through further processing, but at this time the particulate phosphorus is of more interest to the engineering community addressing phosphorus extraction. Nitrogen is split about half-and-half between liquids (the ammonium fraction) and solids (the complex organic fraction). Potassium is largely soluble and is distributed fairly evenly throughout liquid and solids. Partition phosphorus to move it off-site. As producers and regulators become more conscious of phosphorus imbalances on cropland and attendant buildup of P in soils, the amount of cropland available to any given farm for land application of manure is reduced. Removing a large fraction of the phosphorus from manure into a solids stream that can be economically transported is therefore very attractive to many farms. Improve handling characteristics of the liquid. Lagoon recycle flush systems with solids

¹ The reader is referred to the thorough discussion of liquid-solid separation techniques and performance of systems that is found in MWPS (2001).
separation can supply the lower-solids-content liquid to irrigation systems that use small
diameter, plug-prone nozzles. *Lengen interval between sludge cleanout of liquid
treatment systems.* Inconvenient and expensive de-sludging operations can be postponed
by using settling tanks or other simple separation techniques. *Produce a targeted-market
product; for example, composting solids.* For many production facilities composting
warrants consideration. *Create another farm enterprise using the separated stream.*
Vermiculture (earthworm production) using composted manure solids is a way to
generate additional farm income from an otherwise low-value material.

**Characteristics of separation equipment**

Cost and complexity have removed most industrial separation equipment from
consideration for the livestock production market. Municipal waste treatment plants,
food processing waste plants, and many other applications have the resources needed to
install, operate and maintain elaborate liquid-solid separation systems, some of which
could be otherwise suited for livestock manure. At the same time, many people in the
non-agricultural public have the mistaken belief that municipal waste treatment processes
are, money considerations aside, all automatically adaptable to livestock manure
treatment. Manure is orders of magnitude more concentrated than municipal sewage,
however, and therefore most sewage treatment installations would fail miserably at
treating raw undiluted manure.

Some university studies have successfully piloted and improved upon an Asian based
system for keeping urine and feces separate after excretion. The rationale is that, if
particulate phosphorus removal is one of the main drivers for using liquid-solid
separation, why mix the phosphorus-rich feces stream with the nitrogen- and potassium-
rich urine in the first place? A Michigan State University study found that a sloping-pit-
floor approach, which allows the urine and wastewater to drain away from feces and the
solids to be periodically scraped to a receiving channel, could capture 90-97 percent of
the phosphorus produced in the solids fraction (Tengman and Person 1995). North
Carolina State University’s sloping-belt system under slotted floors (Fig. 1) performed
similarly (Rice et al. 2003). This separation performance is about as good as can be
attained with the best chemical-augmented separation technology that starts with a mixed
manure stream. Odors from the buildings that use such manure-urine segregation
construction are greatly reduced as well, since anaerobic decomposition of the manure
does not have a chance to become established.

**Methods to increase solids removal effectiveness and throughput**

To improve the percentage of total solids removed from the mixed manure stream, there
are a few basic techniques.

*Separate as soon as possible.* The fresher the manure, the easier it is to separate. (Zhu et
al. 2000).

*Keep particles as large and heavy as possible.* By mixing fluids that contain charged
particles into the liquid, the smaller manure solids particles tend to agglomerate and
become large enough to settle out, squeezing the trapped water out of the mass as they go through the process.

*For gravity settling:* decrease turbulence; increase gravity (centrifuge); add flocculant, precipitant, or coagulant; increase detention time; compact the solids.

*For mechanical screening:* decrease mesh size to increase throughput; vibrate the screen to keep larger particles from blinding the screen openings; add flocculant, precipitant, or coagulant.

Factors that increase throughput usually work in opposition to obtaining better separation efficiency. For example:

*Settling:* increase settling tank size or number of tanks; centrifuge; reduce detention time; removal solids continually and recycle liquid.

*Screening:* increase number and/or area of screens; increase mesh size; screw press, belt press, centrifuge, vibrate.

**Gravity liquid-solid separation**

The simplest method for liquid-solid separation is gravity settling in a tank or other vessel. Compared to mechanical separators without chemical augmentation, gravity
settling can usually attain better solids removal efficiency (MWPS 2001). The drawback to most gravity systems is that the solids must be removed batchwise and the solids fraction is much wetter than solids coming from most mechanical separators.

The attraction of gravity settling systems is even greater with the possibility of continuously removing solids from the settling tank. Experience and studies (e.g. Zhu et al. 2000) have shown that settled solids on the tank bottom tend to become re-suspended, at least partly due to anaerobic digestion and gas release. Therefore, removing solids regularly and often from the gravity settling system can increase solids removal efficiency.

Objectives

The objective of this study was to use a laboratory scale settling tank to determine the optimum settling tank bottom angle (angle of repose of solids), optimum retention time, and optimum solids percentage of the incoming manure stream. A system for continuously removing solids by way of an auger and pump was explored.

Approach

A series of experiments was conducted with a laboratory-scale settling tank. A tank was built simulating a section of a settling tank; liquid swine manure was circulated through the tank, using peristaltic pumps, with a solids-enriched stream being drawn from the tank bottom and a more liquid stream overflowing the top (Fig. 2). A cross-auger was installed in the lowest corner of the tank, to help direct the settled solids into the removal port of the tank.

Two measurement parameters were set for the experiments. One, the solids separation quality, was a measure of the greatest solids content expected from a quiescent settling at the bottom of the tank. The other, sedimentation efficiency, was a measure of the effectiveness of the tank in separating the slurry into mostly-liquid and mostly-solid streams. Retention times were picked to represent a typical range of operating conditions for field applications. Samples of the influent, effluent and solids streams were collected and analyzed for solids content, TKN, total phosphorus, and potassium.

RESULTS

The optimum slope of the tank bottom (that is, the solids angle of repose) was shown to be about 35 degrees from horizontal (Table 1 and Figs. 3 and 4). The amount of solids leaving the tank in the
overflow effluent could be reduced by almost half, using gravity and the continuous solids removal, with no further treatment. The retention time of 30 minutes was optimal for the tank configuration tested.

Table 1. Optimum parameters for settling tank construction and operation.

<table>
<thead>
<tr>
<th>Slope of tank floor, deg.</th>
<th>Retention Time, minutes</th>
<th>Initial solids percentage</th>
<th>Total solids sedimentation efficiency, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>60</td>
<td>3</td>
<td>51.7</td>
</tr>
</tbody>
</table>

Optimum parameters for solids separation quality

<table>
<thead>
<tr>
<th>Slope of tank floor, deg.</th>
<th>Retention Time, minutes</th>
<th>Initial solids percentage</th>
<th>Total solids separation quality, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>20</td>
<td>5</td>
<td>22.5</td>
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</tbody>
</table>

Fine settleable solids tend to settle in a very porous “sponge” formation (Fig. 5) making it inefficient to remove those solids directly. The auger removal device was placed in the tank to help compact those solids and improve sedimentation efficiency by dewatering the fine solids matrix. Coarse solids appeared to be made up largely of pieces of undigested cellulose material and ash (Fig. 6), settling into a more compact matrix containing somewhat less water.

Figure 3. 35 deg. slope 20 minute retention time 5% solids, showing solids reposing at same 35 deg. angle as tank bottom.

Figure 4. 15 deg. slope 60 minute retention 3% solids during removal.

Charts of the concentration ratios of the sampled parameters (Figs. 7, 8, and 9) summarize the ability of the gravity tank to remove constituents in the solids stream,
based on the solids content of the incoming manure stream. Note that the actual solids contents of the influent streams, while the experimental parameters were set at 1%, 3% and 5% solids and the “stock manure” was diluted by formula, were actually shown to be closer to 0.8%, 3%, and 8% solids when samples were evaluated in the laboratory. As demonstrated by the charts of concentration ratios, total solids are the easiest to segregate by settling; total nitrogen is next easiest; total phosphorus is next, and potassium is the most difficult to remove by settling.

With 1% solids manure entering the tank, settling was able to concentrate total solids more than 20 times; total Kjeldahl nitrogen more than 5.5 times, and total phosphorus more than 5 times. However, with the highest solids concentration manure (about 8%) entering the tank, phosphorus was concentrated in the solids only 13% to 18%. Retention time in the tank – 60 minutes v. 20 minutes – had little effect. The tank floor slope did not affect phosphorus recovery consistently, with the shallower slopes sometimes giving more phosphorus in the solids stream coming from the bottom of the tank and other times less. With the highest concentration of solids in the influent stream, phosphorus recovery was best with the shallower slope, implying that with a steeper tank bottom slope, the heavier, easily settled solids slid downward and blocked the exit for the smaller, phosphorus-rich solids. That emphasizes the importance of continuous solids removal from the tank, to enhance the capture of fine solids as well as the coarse ones.

**Implications**

Results show the operating ranges to design for, and performance to expect, from a gravity tank with continuous solids removal. Such a component could be incorporated into other systems. For example, the maximum solids separation quality of approximately 20% is optimum for feedstock to a thermochemical conversion process (He et al. 2001). Fine solids remaining suspended in the supernatant from the gravity separation could be more efficiently flocculated (and with less addition of costly chemical, since no chemical would be wasted on the solids that were easily settleable by gravity) and separated in another gravity or mechanical separation apparatus (Fig. 10).
Vanotti et al. (2002) indicated a linear function of PAM (polyacrylamide) addition required to remove the suspended solids, and that about 0.75% is needed for 2.5% TSS manure. At $2.00 per pound of PAM, they estimated a minimum chemical cost of $1.27 per pig to effectively separate solids and nutrients from flushed liquid manure, using a screen separator. Our experiment shows that the addition of a simple gravity separation system as a first stage might substantially reduce the amount of chemical, thus the variable cost of the operation; and 50% reductions of chemical costs if costs are linearly related to total solids in the manure (not necessarily total suspended solids) could be attained.

**Publications**


**Acknowledgement**

Financial support of the Illinois Council on Food and Agricultural Research is gratefully acknowledged.

**REFERENCES**


Figure 7. Concentration ratios for liquid-solid separation experiments using 3% solids manure influent.

Figure 8. Concentration ratios for liquid-solid separation experiments using 1% solids manure influent.
Figure 9. Concentration ratios for liquid-solid separation experiments using 5% solids manure influent

Figure 10. Dual stage liquid-solid separation using gravity settling plus a polymer treatment step.