

FPPC - Final report for solid liquid separation and nutrient removal from dairy manure using comparisons from anaerobic digestion, a screw press separator, a two-stage solid-liquid separator, electrocoagulation and settling ponds

**Utah State University - Conly L Hansen, PI
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ABSTRACT.

Manure from a 1000 cow dairy near Ogden Utah, was treated first through anaerobic digestion in an Induced Blanket Reactor (IBR) to stabilize the waste, after which the effluent passed through several treatment methods to determine the effectiveness of each system in removing solids and/or nutrients from the anaerobically treated waste stream. Systems studied included anaerobic digestion, mechanical liquid-solid separators, (both a screw press separator and a two-stage dewaterer), Electrocoagulation, and natural settling of solids and nutrients. Natural settling was used after some of the treatments to determine its value in removing nutrients in combination with each treatment system. Nitrogen and phosphorus levels in the manure were measured after each stage of treatment to determine the efficacy of the particular treatment system in concentrating and removing these nutrients from the waste stream.

Anaerobic stabilization removed an average 40% and 46% of the TS and VS respectively, and increased the settleability of the manure significantly. Any P difference before and after anaerobic digestion was due to P storage in the anaerobic digester. Solids in the raw influent manure did not settle. Concentration of nutrients through natural sedimentation was only possible with manure that had been anaerobically stabilized and even better if also passed through the two-stage dewaterer before settling. Raw or treated manure had to be relatively dilute (2-3%) to settle probably due to hindered (> type II) settling. Following anaerobic digestion, the screw press only removed 6% of the remaining TS (3% of the original TS level). The screw press would only remove those solids that would settle. The screw press was not effective at removing nutrients from the waste stream.

The two-stage dewaterer was able to remove 38% of the TS in the anaerobically stabilized waste, resulting in a total TS removal of 66% (TS in the waste before entering the lagoon were reduced from 52 g/L to 18 g/L). The two-stage dewaterer was unable to remove nitrogen from the liquid waste, but was able to remove 25% of the phosphorus.

Electrocoagulation (EC) treatment resulted in 85% and 94% removal of the TS and VS respectively from anaerobically treated manure. EC was also effective in removing nitrogen and phosphorus; removing 74% and 93% respectively but expensive to operate. The cost of operation for our unit was near \$16 per thousand gallons of anaerobic effluent. The manufacturer claimed he could reduce these costs dramatically with a different type of electronic system. The more efficient system was never supplied to us.

KEYWORDS. *Manure, Anaerobic Digestion, Electrocoagulation, Screw Press, Solids removal, solid-liquid separation.*

INTRODUCTION AND BACKGROUND

Modern farming practices have changed significantly to allow farms to stay in business in a competitive market. The density of animal units on a farm has drastically increased as farms have cut costs and increased productivity.

In the United States, there are approximately 238,000 farms where animals are kept and raised in confinement. This type of farm is called an animal feeding operation (AFO). These farms produce more than 500 million tons of animal manure per year. These large, high animal density farms are called concentrated animal feeding operations (CAFOs) (EPA 2003).

With the increase in the number of animals on farms, agricultural waste streams have become larger. Historically farming has operated under a no discharge concept. Municipalities do not accept waste from farms, and farms are not allowed to discharge to surface waters. Therefore, all of the manure produced on a farm can stay on site and be land applied. If land application in the raw form is not possible the manure needs to be treated by some processes in order to reduce the volume and/or separate the solids to provide additional opportunities for uses and applications of the manure components. Removal and/or concentration of the nutrients from the manure also add value to the product for value added applications in other locations. Waste management must be utilized and the amount of land needed for nutrient utilization increases as the number of animals increase. Even if farms are not expanding, land requirements for nutrient utilization may increase due to the type of crop being planted, potential for nutrient loss (non-point source pollution) and limits for phosphorus and nitrogen application (Fulhage 1997). What is considered proper manure management is changing quickly and radically. With the increase in regulations over these waste streams, it is becoming increasingly important for manure management strategies to be effectively implemented in order to control nutrient fate, odor, pathogens, and oxygen demand of the waste.

The Environmental Protection Agency (EPA) regulates waste streams under the Clean Water Act. Under the Clean Water Act, Congress charged the EPA with guarding the quality of the nation's water. In order to accomplish this goal each concentrated animal feeding operation (CAFO) must plan and begin to execute a comprehensive nutrient management plan (CNMP) (EPA 2003). In order to comply with EPA standards, research needs to be done on the efficacy of different treatment methods on animal manures. The ideal treatment method would be inexpensive, easy to operate, handle the waste in an environmentally friendly manner, and maximize the reuse and recovery of nutrients, energy, and organic matter (Van Horn et al., 1994).

Treatment of animal waste has been investigated, and many wastewater unit operations have been utilized to deal with the solids and nutrients present in the waste stream. Not many have been feasible for use on farms due to the amount of operator experience required, and the monetary cost of treating the waste.

Description of the IBR:

The Induced Blanket Reactor (IBR) anaerobic digester is a new type of anaerobic digester that was developed at Utah State University. The IBR is somewhat similar to an Upflow Anaerobic Sludge Blanket (UASB) reactor developed in the Netherlands. Major differences

include the addition of an anti-plugging device at the top of the reactor and a much slower upward flow of liquid.

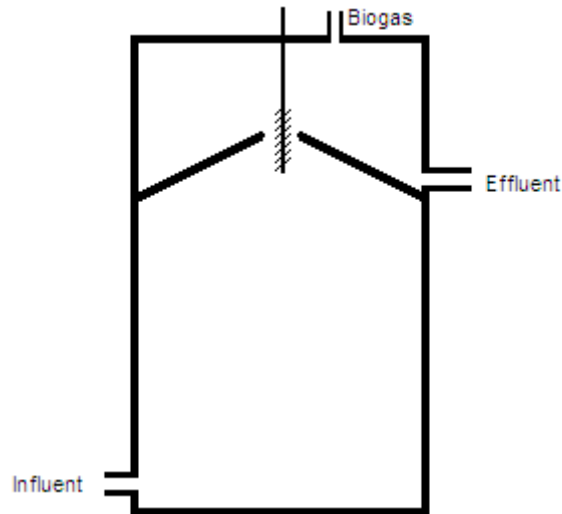


Figure 1. Diagram of an IBR anaerobic digester (not to scale). Influent waste is pumped into the bottom of the digester and flows through a bacterial sludge blanket as it is forced to the top of the reactor, flowing through a hole in the center of a septum and out the effluent line. Biogas escapes through a pipe in the top of the tank.

The IBR generally operates at a 4-6 day hydraulic retention time (HRT). The IBR invention controls the formation of a sludge blanket within the digester and the sludge blanket leads to high treatment rates. High treatment rates reduce capital cost and make it easier to build large systems because the vessels needed to contain the waste are smaller.

To treat waste at a high rate, anaerobic digesters (AD) must have some means of retaining the slow growing anaerobic bacteria. The principle of operation of the IBR is to capture solids in an enclosed vessel, thus creating an enriched environment for the bacteria. The IBR system includes a septum near the top of the tank. As methanogenic bacteria metabolize the waste, gas bubbles form which make the bacteria float. The bacteria and attached solids float to the top and hit the septum which separates the gas from the bacteria. The bacteria and uneaten solids sink, thus they are retained and the cycle starts over again. The gas escapes through a hole in the septum. The invention causes a sludge blanket or bed to form in the lower portion of the bioreactor vessel. Under the right circumstances, this sludge bed becomes mostly living bacteria. This means that wastewater can be treated much faster and more efficiently in this anaerobic bioreactor compared to others. The IBR speeds up anaerobic treatment of animal waste by 2-10 times over commonly used AD methods.

Temperature of the vessel is kept $\geq 100^{\circ}\text{F}$ in order to maintain a high rate of metabolic activity. Manure pumped into the IBR usually has solids content between 6 and 8%. The digester will perform with influent solids less than one percent but the cost to heat the extra water does not make it practical.

In order to treat all of the manure produced at the Blaine Wade farm, the system used three tanks each approximately 32 ft high and 13 ft in diameter. The tanks operate in parallel with one of the tanks being fed raw manure at all times. The biogas from this IBR digester was

used to run a generator that produced about 100 kW of electricity continuously. The electricity was fed into the local power grid. Heat produced by the generator was used to heat the influent manure before it entered the tanks. The hydraulic retention time of the IBR at the Wade dairy was typically five days. The organic loading rate was about 5 kg/m³-d.

Description of the screw press:

A screw press is a machine that uses a large screw to pull a waste stream containing solids along a horizontal screen tube. Movement of the solids is impeded by a weighted plate at the end of the tube. The pressure of this plate on the solid plug forces liquid out of the solids and through the holes in the sides of the screen tube and then along the effluent pipe. The screw will then push the remaining solids past the plate where they fall out onto a collection pad below. Excess manure must be pumped into the screw press at all times to ensure that the screw can bite into the liquid and continue pushing the solid plug past the pressure plate.

The screw press used in this experiment was a FAN Press Screw Separator (Westfalia, Germany). The solids content of the IBR effluent was between 3 and 4%. The FAN Separator was able to remove about 50% of the effluent solids. Solids removed from the waste stream by the screw press were used as bedding for the animals.

Description of the two-stage dewaterer:

The Houle two-stage dewaterer (Drummondville QC, Canada) incorporates ideas from several different liquid-solid separators on the market. The waste stream is pulled through a vertical screen tube by a screw. Gravity causes the liquid portion to run through the screen, while solids are retained and pushed up to the top of the open tube. The screen tube vibrates to keep solids from plugging the holes in the screen. After the solids are pushed out the top by the action of the screw, the solids slide down an incline to a set of rollers that press additional liquid out of the solids. The lower roller has holes in it so that the liquid can escape from the solids as they pass through the press. The solids then fall onto a collection pad below and are used as bedding for the dairy cows. The final solids content coming from the two-stage dewaterer was about 2%.

Description of the Electrocoagulation process

Electrocoagulation (EC) is an electrochemical process through which solids are removed from suspension in a liquid by passing an electric current between an anode and a cathode through the waste stream. The corrosion of the sacrificial anode gives the precursors that are classically used in chemical coagulation to begin the coagulation process in the wastewater being treated (Eckenfelder and Cecil, 1972). EC has been a known method for treating wastewater for a long time. The first patent for this process was awarded in 1909 (Vik et al., 1984). However, it has never entered the mainstream of unit operations used in treatment of water and wastewater.

EC treatment has been successfully applied to many types of wastewaters including paper pulp mill waste, metal plating, domestic sewage, slaughter houses, canning factories, and swine manure (Eckenfelder and Cecil, 1972, Laridi, et al., 2005).

EC has three separate phenomena involved in its operation specifically electrochemistry, coagulation, and flocculation (Mollah et al. 2004). One major difference between EC and classical chemical addition is the point at which the dosing of the metal ions occurs. In chemical

coagulation the coagulant is introduced externally and mixed into the wastewater. With EC the metal cations are introduced as the wastewater flows past and mixing is not required.

Small-scale delocalized treatment of waste performed by individual farms is the way that manure has always been handled, and as such demands different approaches to treatment than large-scale centralized wastewater treatment performed by municipalities. Treatment of manure on-site at the farm where it is produced is the type of application where EC can be effectively applied. The relatively small scale of farm treatment operations compared to water and wastewater treatment facilities where the volume of water treated is measured in millions of gallons per day make some of the drawbacks to EC less important.

An advantage of EC in manure treatment is the ability of this unit operation to remove a variety of pollutants. Another advantage of EC over chemical (metal salts and polymers) addition is that there are minimal salts being added into the waste stream. Many farms are concerned with the amount of salts that are being applied to the soil. The small footprint of an EC unit and no need for a supply of dosing chemicals make EC a potentially attractive option in a farm setting.

Design of EC systems varies greatly and no particular design has been able to obtain dominance (Holt et. al. 2005). For this reason it is very difficult to correlate performance of different units. Electrolytic oxidation of the anode and passivation of the cathode are drawbacks to EC making maintenance of these systems necessary (Vik et al., 1999). EC systems work well at relatively low solids content. The unit worked best when the effluent stream coming from the two-stage dewaterer was diluted reducing solids to $\leq 1\%$.

Description of the settling columns:

Manure was taken between each unit operation and placed into a settling column seven feet high and twelve inches in diameter. Samples were taken from the column at various times (shown in the Figures in the results section) from 0 to 24 hours at depths 0, 1, 3, 5, and 6 ft (One foot of headspace was left in the top of the column to allow for mixing at time, $t = 0$). Manure samples were tested for both nitrogen and phosphorus to determine if nutrients could be concentrated using natural settling at any location in the treatment process.

SAMPLING AND ANALYTICAL METHODS

The arrangement of the manure treatment system was such that manure from a short-term holding tank was pumped into the IBR system for anaerobic digestion, after which the stabilized manure passed through either of the two mechanical liquid-solid separators, the screw press or the two-stage dewaterer, for further solids removal, then into the EC unit, and finally into a settling basin where coagulated solids were allowed to separate from the manure by sedimentation.

The two-stage dewaterer and screw press were not installed at the same time. Manure solids characteristics changed slightly from the sampling time of the screw press to about 9 months later when the two-stage dewaterer was installed in the spring. Solids and nutrient removal characteristics are given for both unit processes within the rest of the system (holding tank and IBR) that did not change. The EC unit was leased during the time the screw press was in service; the two-stage dewaterer was a relatively recent addition to the farm.

Samples of manure were taken between each of these unit operations and analyzed for solids content, and also for settling characteristics. According to Chescheir et al. (1985), and Chaistain, et al. (2001), most of the nitrogen and phosphorus in manure is associated with the solids portion of the manure. For this reason manure samples were loaded into a settling column and allowed to settle for 24 h in order to try concentrating these nutrients into the lower part of the manure, to determine to what extent inexpensive natural settling could be used for removal of nutrients. Samples from this column were taken at various times including time = 0 and t = 24 h from depths of 0, 1, 3, 5, and 6 ft. Samples were stored in a freezer at -18° C until analyses could be performed.

Manure was collected from a total of four locations in the waste treatment system. These include raw manure, anaerobically stabilized manure, stabilized manure that had passed through the screw press, stabilized manure that had passed through the two-stage dewaterer, and finally stabilized manure that had passed through mechanical separation and then through electrocoagulation. A volume of 40 gallons of manure of each type was collected. The manure was collected in 5 gallon buckets and taken to Utah State University for experimentation and analyses. A small part of the samples were sent to the Utah State University Analytical laboratory to verify N and P concentrations and to determine other nutrient concentrations by inductively coupled plasma (ICP) mass spectrometry analysis.

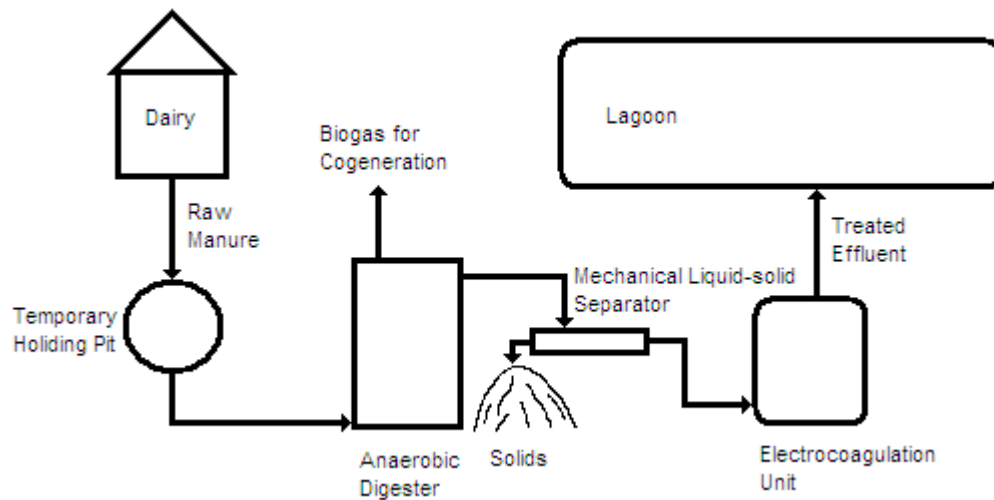


Figure 2. Diagram of the waste treatment system (not to scale). Waste flows from the dairy to a temporary holding pit from which it is pumped into the anaerobic digester. Gas from the digester is used to produce electricity and hot water. The stabilized manure goes to the screw press or the two-stage dewaterer for mechanical liquid-solid separation. The liquid portion was then treated by the planned EC unit for further treatment, and finally to a lagoon for long-term storage.

In order to establish the natural settling characteristics of manure, a seven-foot settling column with a diameter of twelve inches was filled with manure taken from the different treatment locations described above. Each column was loaded with manure and mixed with an eight-foot auger to simulate a time zero for settling to begin. Samples were analyzed for total solids (TS), volatile solids (VS), suspended solids (SS), and suspended volatile solids (SVS). This information was used to establish how the settling characteristics of the waste stream were

changing due to the different waste treatment systems. Samples from this column were taken at heights of 0, 1, 3, 5, and 6 ft and at 0, 0.5, 1, 2, 4, 8, 12, and 24 hours. Samples were stored in a freezer at -18 °C from the time of collection until testing.

Initially, digested manure from the IBR anaerobic digester was collected and sent to GlobalSep Corporation, Richland Washington for treatment in an electrocoagulation unit in order to test the feasibility of such treatment on this high strength waste stream. Later anaerobic digester effluent was treated on-site using an electrocoagulation unit leased from Gold Coast Stabilization, Inc. (Ventura, CA).

Measurements of TS, VS, SS, and SVS were performed using standard methods (APHA, 1992). Nitrogen as total Kjeldahl nitrogen (TKN) was determined using the macro-Kjeldahl method (APHA, 1992). Total phosphorus (TP) analyses were performed using the molybdovanadate method (Method 8114) on a DR/890 colorimeter (HACH Company, Loveland, CO). Samples were also sent to the Utah State University Analytical Laboratory for inductively-coupled plasma spectrophotometer (ICP) analysis.

Data was statistically analyzed using a linear model, randomized two-factorial design within each treatment. Each treatment had two replicates. Treatments were compared using a single factorial design. Analysis of variance (ANOVA) was performed on the data. Comparisons of means were made using the Ryan-Einot-Gabriel-Welsch (REGWQ) method. The REGWQ comparison uses a 0.05 significance level. Data was analyzed using SAS (SAS, Cary, N.C.) software version 9.1 on Windows. For the sake of brevity, not all statistical results are included in this report. All data that is reported below has been verified statistically to $P \leq 0.1$.

RESULTS AND DISCUSSION

Solids results

Tables 1 and 2 show measured solids concentration of manure at each stage of treatment with accompanying percentages of solids removal, Table 1 is for the original waste treatment utilizing a screw press. Electrocoagulation treatment is also listed. Table 2 shows solids removal after the screw press had been replaced with the Houle (QC, Canada) two-stage dewater.

Table 1. Solids levels of manure at each stage of treatment with accompanying percentages of solids removal for the original waste treatment utilizing a screw press. Electrocoagulation treatments are also listed.

| | Raw Manure | Digested Manure | Amount Removed | Screw Press | Amount Removed | Total Amount Removed | EC 1 | Amount Removed | Total Amount Removed | EC 2 | Amount Removed | Total Amount Removed |
|-----|------------|-----------------|----------------|-------------|----------------|----------------------|-------|----------------|----------------------|-------|----------------|----------------------|
| | (g/L) | (g/L) | (%) | (g/L) | (%) | (%) | (g/L) | (%) | (%) | (g/L) | (%) | (%) |
| TS | 68.51 | 44.23 | 35 | 41.64 | 6 | 39 | 8.89 | 79 | 87 | 6.22 | 85 | 91 |
| VS | 53.08 | 29.81 | 44 | 26.33 | 12 | 50 | 2.78 | 89 | 95 | 1.53 | 94 | 97 |
| SS | 59.63 | 38.08 | 36 | 31.84 | 16 | 47 | 2.04 | 94 | 97 | 1.62 | 95 | 97 |
| SVS | 48.37 | 28.16 | 42 | 22.15 | 21 | 54 | 1.24 | 94 | 97 | 0.71 | 97 | 99 |

Table 2. Solids levels of manure at each stage of treatment with accompanying percentages of solids removal for the new waste treatment utilizing a two-stage dewaterer.

| | Raw Manure (g/L) | Digested Manure (g/L) | Amount Removed (%) | Two-stage Dewaterer (g/L) | Amount Removed (%) | Total Removed (%) |
|------------|-------------------------|------------------------------|---------------------------|----------------------------------|---------------------------|--------------------------|
| TS | 51.86 | 28.87 | 44 | 17.81 | 38 | 66 |
| VS | 41.05 | 21.33 | 48 | 11.50 | 46 | 72 |
| SS | 42.05 | 24.06 | 43 | 10.91 | 55 | 74 |
| SVS | 34.67 | 19.53 | 44 | 8.18 | 58 | 76 |

The lower initial levels of solids presented in Table 2 is due to the time of year that samples were taken. The screw press was evaluated in the fall after a relatively dry period. The two-stage dewaterer was evaluated in the spring while snow and rain contributed to runoff at the farm. The two unit processes: screw press and two-stage dewaterer were not installed at the same time. The anaerobic digester was performing better in the spring, removing 44% and 48% of the TS and VS respectively perhaps because the bacteria were more acclimated by then. The two-stage dewaterer was able to remove 38% of the TS in the anaerobically stabilized waste, resulting in a total TS removal of 66%. The TS in the waste before entering the lagoon was reduced from 52 g/L to 18 g/L.

Figures 3-6 report data for the column settling experiments. Manure was taken between each unit operation and placed into a settling column and samples were taken from the column at various intervals from 0 to 24 hours and at depths 0, 1, 3, 5, and 6 ft.

Raw manure did not settle over a 24 hour period (Figure 3), solids concentration at all levels in the column remained effectively the same over the course of the experiment. Anaerobically digested manure (Figure 4) settled over 24 hours. The screw press had poor performance, removing only an additional 3% of the total solids following anaerobic digestion. It appears that the solids that were removed by the screw press were the solids that will settle out of the manure, as the settling performance of this waste was very similar (Figure 5) to anaerobically digested waste. Both the anaerobically digested manure and the manure from the screw press following anaerobic digestion were at about 40 mg/L (Figure 5). The remaining solids could not be concentrated further by the screw press or by reasonable settling times. Observations included that the farmer had trouble maintaining the plug in the screw press and the screen was often at least partially plugged.

The two-stage dewaterer performed well, and removed enough of the solids from the manure that remaining solids were better able to settle out of the waste stream (Figure 6). The effective retention times for settling could be as short as 5 hours compared to days or no separation at all.

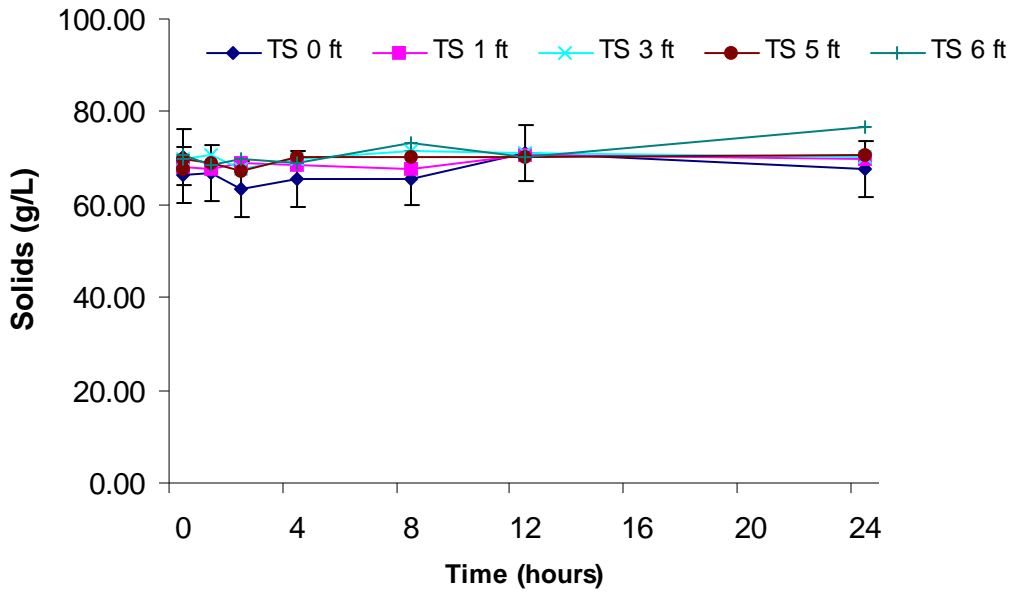


Figure 3 TS levels of influent (raw) manure during the 24 hr settling test at each height. This indicates that solids in raw manure did not settle.

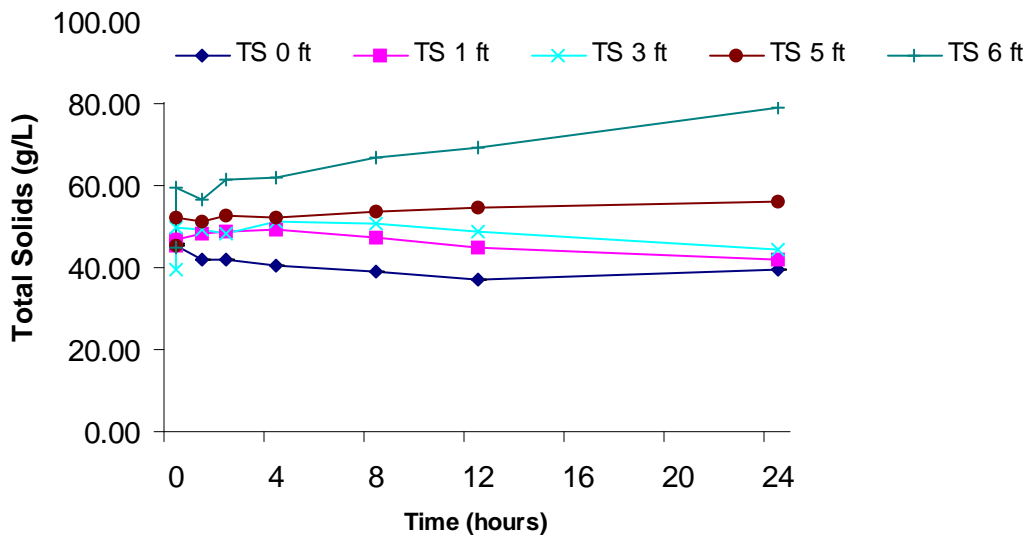


Figure 4. TS of manure after anaerobic stabilization and its settling characteristics over 24 hours. Note that TS on the surface (0 ft) decreased significantly while the bottom (6 ft) increases due to settling.

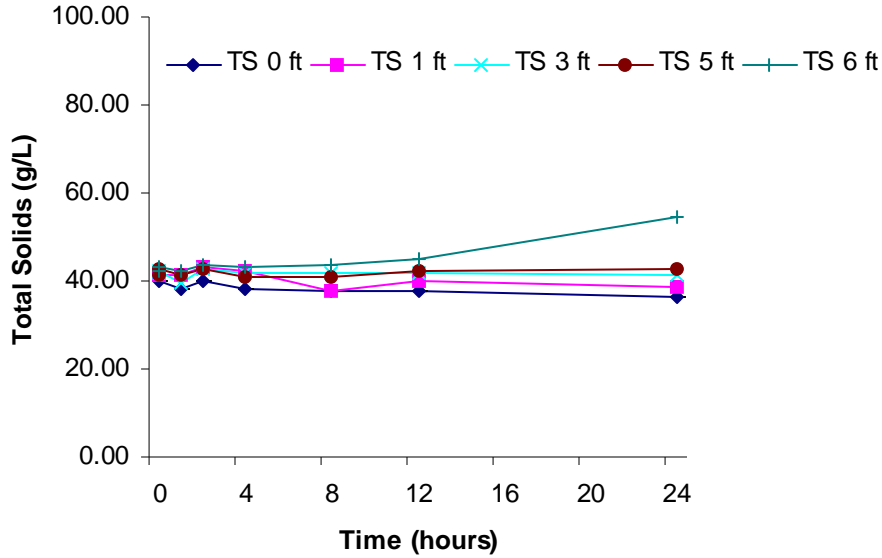


Figure 5. TS levels of manure after both anaerobic digestion and passing through a screw press separator over 24 hours of settling. Note that the screw press apparently removed solids that would have settled.

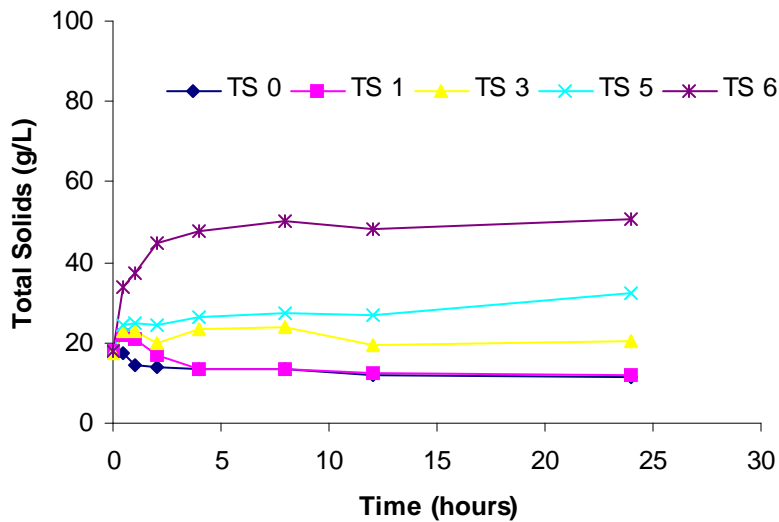


Figure 6. TS levels of manure after anaerobic digestion and liquid-solid separation in a two-stage dewaterer over 24 hours of settling.

Nutrient results

Tables 3a and 3b show that P and N were not removed by simple settling of raw and digested manure. Concentrations of these nutrients were not significantly different from top (depth = 0) to bottom of the column. This observation that only a small amount of nutrient can be removed by removing solids; at least with equipment that can only remove relatively large solid particles leaving colloidal materials, concurs with data and observations made by Gooch et.al (2005). Note that the P concentration of the raw manure and digested manure also did not

change indicating the IBR tank may have stored all the P that it was going to store thus P was exiting at about the same level as it came in. This was also the case for N (Table 3b).

Table 3a. TP levels of untreated and treated manure placed in settling columns. ANOVA analysis showed no significant difference in P from top (depth=0) to bottom of the column.

| Depth (ft) | Raw Manure | | Digested Manure | | Screw Press | |
|------------|------------|-----------|-----------------|-----------|-------------|-----------|
| | P (mg/L) | P (mg/L) | P (mg/L) | P (mg/L) | P (mg/L) | P (mg/L) |
| | Time 0 h | Time 24 h | Time 0 h | Time 24 h | Time 0 h | Time 24 h |
| 0 | 540 | 568 | 550 | 532 | 585 | 548 |
| 1 | 499 | 584 | 543 | 533 | 579 | 551 |
| 3 | 509 | 568 | 557 | 489 | 581 | 570 |
| 5 | 501 | 578 | 549 | 583 | 583 | 575 |
| 6 | 586 | 597 | 556 | 681 | 590 | 623 |

Table 3b. TKN levels of untreated and treated manure placed in settling columns. There was no significant difference in N from top (depth=0) to bottom of the column.

| Depth (ft) | Raw Manure | | Digested Manure | | Screw Press | |
|------------|------------|-----------|-----------------|-----------|-------------|-----------|
| | TKN (%) | TKN (%) | TKN (%) | TKN (%) | TKN (%) | TKN (%) |
| | Time 0 h | Time 24 h | Time 0 h | Time 24 h | Time 0 h | Time 24 h |
| 0 | 0.26 | 0.25 | 0.26 | 0.25 | 0.28 | 0.26 |
| 1 | 0.25 | 0.26 | 0.27 | 0.26 | 0.27 | 0.27 |
| 3 | 0.28 | 0.29 | 0.26 | 0.26 | 0.27 | 0.27 |
| 5 | 0.25 | 0.28 | 0.27 | 0.29 | 0.28 | 0.28 |
| 6 | 0.27 | 0.26 | 0.28 | 0.29 | 0.30 | 0.30 |

Table 4 reports TKN and TP levels at various locations along the waste treatment system measured after the two-stage dewaterer had been installed, which was in the spring. The two-stage dewaterer only reduced nitrogen levels in the liquid waste stream by 11% even though it was quite effective in removing solids (38% - Table 2). It was more effective at removing P (24%). This is most likely due to most of the nitrogen being in a soluble form such as ammonia. The two-stage dewaterer did remove enough solids ($\leq 2\%$ TS remaining) so that the suspended solids remaining in the waste stream would settle (Figure 4). This was likely due to the fact that particles were not unduly hindered (Type I or Type II settling) at the lower solids concentration.

Table 4. TKN and TP levels of manure at different locations along the waste treatment system measured in the spring.

| Raw Manure | Digested Manure | Two-stage Dewaterer | Amount removed in dewaterer |
|------------|-----------------|---------------------|-----------------------------|
| TKN (%) | | | % |
| 0.22 | 0.18 | 0.16 | 11 |
| P (mg/L) | | | |
| 424 | 313 | 238 | 24 |

Figures 6 and 7 show nitrogen and phosphorus levels in the waste at different locations in the system, including before and after EC treatment. Anaerobically digested manure had less nitrogen and phosphorus than raw manure during the time the EC unit was installed. This difference was likely due to solids being retained in the digester. These measurements were

taken before N and P had a chance to build to steady state in the IBR. Nutrient retention in the IBR tanks has been shown in previous studies. The P levels in the “sludge” in the digester can be more than twice the levels of the effluent P concentration. The IBR experiences a gradual buildup of solids in the bottom third of the tank. When there is little sand/grit in the manure as was the case at the dairy where this report was done, the IBR tanks do not need to be cleaned of grit and sludge more than once every two or three years. Grit and sludge are easily removed by opening orifices near the bottom of the IBR tank. This sand/sludge can be land applied along with the separated solids coming daily from the digester. The nutrients in the sludge must be included in the farm’s nutrient management plan otherwise there is no particular problem with the additional P and N in the tanks.

The EC process was very effective at removing both nitrogen and phosphorus removing 74% and 93% respectively from the diluted liquid waste coming from the screw press. EC concentrated these nutrients in the sludge produced. However, N and P are still relatively dilute in the EC sludge (<1%). In other words the EC unit we used would not produce a sludge that could economically be transported long distances as a “fertilizer”. On the plus side, P was concentrated by nearly 63%.

The EC process was placed last in the stream of unit processes because it was necessary to reduce solids to enable the EC process. Since the screw press could not reduce solids to 2%, it was necessary to dilute the effluent from the screw press before treating it in the EC process. The EC unit was not available when the two-stage dewaterer was installed. It was not known to us that a two-stage dewaterer would be installed until it was too late to include the EC unit. It can be assumed that since EC worked well with dilution following the screw press, it would perform as well following the two-stage dewaterer.

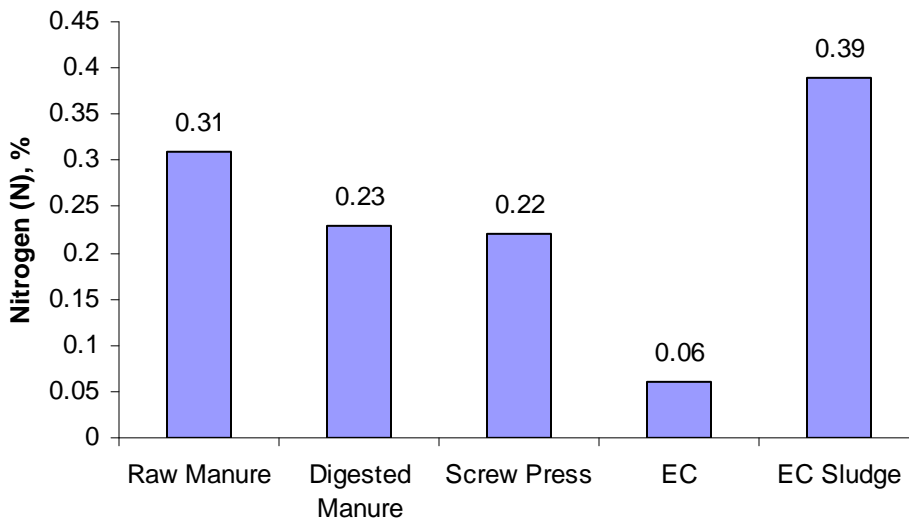


Figure 7. Nitrogen levels of waste at different locations in the waste treatment system and levels of nitrogen before and after EC treatment.

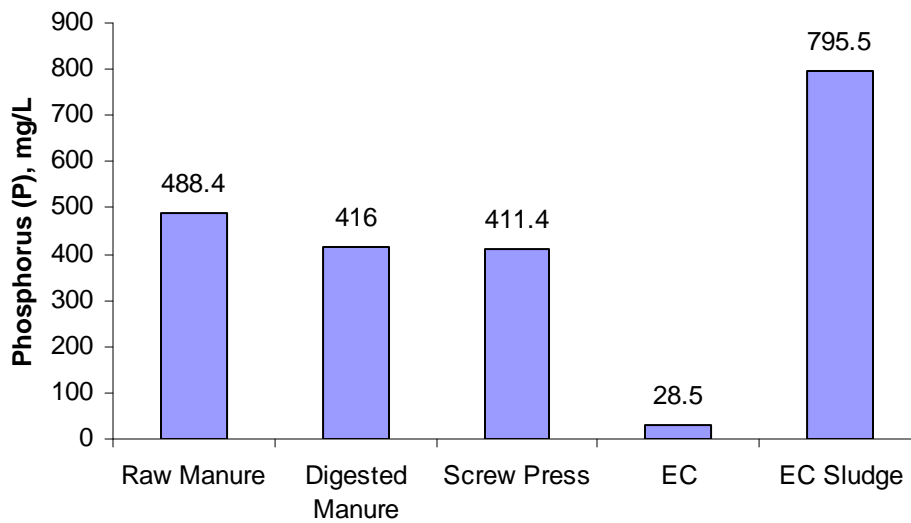


Figure 8. Phosphorus levels of waste at different locations in the waste treatment system and levels of phosphorus before and after EC treatment.

2008 Data

As a follow up study during winter and early spring of 2008, manure samples were taken before anaerobic digestion (influent), following IBR anaerobic digestion (effluent) and following the two stage dewaterer after anaerobic digestion (separated solids only). These samples were sent to the USU Analytical lab for nutrient analysis and are presented in Table 5, which is a compilation of duplicate samples (more samples were taken and these were thought to be representative).

This was an interesting analysis because it shows anaerobic digestion removing over half of the nutrients, which is much higher than the main research showed a year earlier. There is no good explanation for this but we feel more samples need to be analyzed. The winter of 2007-2008 was an especially hard one in this region. The farmer had a line that supplied the IBR and mechanical separator system that freeze for over a month. When it thawed, the line was damaged and service to the IBR system was not restored for another month. As a result, operation of the IBR was not steady state during the sampling time. We feel the data would be better if steady state had been reached. Still, Table 5 is provided because it provides additional information about various micronutrients.

Table 5 Nutrient Content:

| Nutrient | Influent before Anaerobic digestion | Effluent from IBR anaerobic digester | Separated solids from the two stage dewaterer |
|----------------------|--------------------------------------------|---------------------------------------------|------------------------------------------------------|
| Nitrogen (N), % | 0.26 | 0.12 | 0.20 |
| Carbon (C), % | 2.18 | 0.65 | 1.67 |
| Phosphorus (P), mg/L | 498.9 | 174.0 | 423.3 |
| Potassium (K), mg/L | 2335.8 | 1291.1 | 2023.7 |
| Calcium (Ca), mg/L | 1809.6 | 637.8 | 1498.1 |
| Magnesium (Mg), mg/L | 891.4 | 338.8 | 740.3 |
| Sodium (Na), mg/L | 808.3 | 395.4 | 700.4 |
| Sulfur (S), mg/L | 360.2 | 115.8 | 277.2 |
| Boron (B), mg/L | 4.26 | 1.84 | 3.37 |
| Zinc (Zn), mg/L | 9.92 | 3.61 | 8.22 |
| Copper (Cu), mg/L | 24.65 | 7.56 | 19.60 |
| Iron (Fe), mg/L | 84.31 | 24.38 | 67.94 |
| Manganese (Mn), mg/L | 11.57 | 4.20 | 9.68 |

Cost of the different systems including capital costs and operating costs

Note: The estimated costs given are for comparisons only and could vary greatly depending on the installation and brand used. All estimates are based on a 1000 cow dairy.

Anaerobic digestion is not to be installed for nutrient removal. This process did help to remove P only if settling was used downstream to remove solids. The capital cost of an IBR digester is about \$700,000 and maintenance would add another \$10,000 per year excluding labor. Capital costs for the installation of a screw press separator would be about \$55,000 and operation and maintenance costs would add another \$5,000 per year. The installation of the two stage dewaterer would be about \$65,000 and operation and maintenance would add another \$5,000 per year. An electrocoagulation system would cost about \$120,000 and the operation and maintenance after mechanical solids separation would be about \$145,000 per year because of the large amount of electricity used in the process unless a more economical EC unit can be found. The unit cost of electricity during our experiments was about \$16/thousand gallons of anaerobic digester effluent. The supplier of our EC unit claimed he could reduce these costs, but we were not able to prove this. Settling ponds would cost about \$30,000 to construct and will have but small maintenance costs.

CONCLUSIONS

Solids

The IBR anaerobic digester functioned well by destroying 36% and 44% of the TS and VS respectively, reducing TS of the manure from 68 mg/L to 44 mg/L. It worked even better in the spring when the IBR removed 44% and 48% of the TS and VS respectively. In the spring the influent contained fewer solids but the percentage of solids removed during digestion was higher

than in the fall. This may have been because the bacteria were better acclimated after the longer operation time when spring samples were taken. The relatively dilute manure in the spring due to snow melt and rain should not have affected IBR performance.

The two-stage dewaterer was effective at removing solids. When it was used with the IBR, overall total solids reduction was 66%. The two-stage dewaterer was more effective at removing solids than a screw press. Utilization of EC suggests that TS reduction of 95% is possible. Future study needs to be done to determine if the cost of EC technology for animal waste treatment can somehow be reduced. Settle ability of the waste is relatively low unless TS levels can be reduced to <2%, therefore significant reduction in solids needs to be made through anaerobic digestion and mechanical liquid solid separation before a settling basin will become particularly effective.

Nutrient separation

Neither mechanical liquid-solid separation nor settling was able to change the concentration of nitrogen in the waste stream significantly. The two-stage dewaterer was more effective at removing phosphorus from the liquid portion of the waste stream than the screw press was. Settling of the waste could concentrate P by 24% if the solids level in the waste was reduced to $\leq 2\%$. Solids could be removed through a combination of anaerobic digestion and liquid-solid separation.

EC treatment was highly effective at removing nitrogen (74% - $P < 0.01$) and phosphorus (93% - $P < 0.01$) from the waste stream. Pretreatment of the waste through other unit operations was needed to reduce the amount of EC treatment needed and thus reduce the cost associated with EC. Even with pre-treatment EC was expensive to operate, costing about \$16/per thousand gallons of effluent treated.

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List of Abbreviations

| | |
|------|-----------------------------------|
| EC | = electrocoagulation |
| HRT | = hydraulic retention time |
| IBR | = induces blanket reactor |
| TS | = total solids |
| TSS | = total suspended solids |
| TV | = total volatile solids |
| TVSS | = total volatile suspended solids |