A Thickening Process for Reducing the Cost of Utilizing Dairy Lagoon Sludge

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ABSTRACT

The standard method to remove sludge from a lagoon is to agitate for several hours, pump the agitated sludge-supernatant mixture into a tank spreader, haul the mixture to a remote field, and apply the manure to crop or forage land. A significant decrease in moisture content would greatly reduce the volume of sludge that must be transported and reduce the costs of lagoon renovation or maintenance. Experiments were performed to observe thickening of two mixtures of dairy lagoon sludge and supernatant by gravity. Thickening was achieved by simply allowing a large fraction of the solids to settle for a period of time to increase the density before the supernatant layer was decanted. The optimum thickening time was determined to be 7.0 hours. The volume of material that must be land applied was reduced by 60% on the average. Implementation of a thickening process would be expected to reduce the land application area requirements by 12 to 22%.
Keywords. Lagoon, liquid-solid separation, dairy manure, manure management

INTRODUCTION

Anaerobic treatment lagoons and storage ponds are the most common type of storage structures used to store dairy manure in South Carolina and much of the Southeastern United States. The components of an anaerobic lagoon include the following: anaerobic treatment volume, manure and waste water storage volume, sludge storage volume, and additional depth for the net rainfall (precipitation - evaporation), the 25-year, 24-hour rainfall event and a freeboard of 0.3048 m (1 ft) (ASAE EP403.2, 1998). The lagoon operator must maintain these volumes and depths in order for the lagoon to function properly. A storage pond looks similar to an anaerobic lagoon but it does not include the anaerobic treatment volume or sludge storage volume (ASAE EP393.2, 1998).

The treatment volume of a lagoon is determined based on the volatile solids loading rate (g VS/m^3-day or lb VS/1,000 ft^3-day) which varies with climate (ASAE EP403.2, 1998). Larger loading rates can be used in warm climates than in cold climates. For example, in the coastal plains of South Carolina, the maximum loading rate that should be used is 80 g VS/m^3-day (5 lb VS/1,000 ft^3-day). However, in Iowa the maximum loading rate is 56 g VS/m^3-day (3.5 lb VS/1,000 ft^3-day).

The sludge storage volume recommended by ASAE EP403.2 (1998) for dairy farms is 0.00455 m^3/kg TS added (0.0729 ft^3/lb TS added). However, the actual sludge accumulation rate

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for a particular farm will vary with the loading rate, climate, ration, and stall bedding practices. The use of liquid-solid separation prior to the lagoon can greatly reduce the amount of sludge that will build up in a dairy lagoon (Chastain et al., 1999).

Early in the design of an anaerobic lagoon a sludge storage period is selected. In many cases, the design sludge storage period that is used is 10 to 20 years. Although, most engineers recommend agitation and sludge removal prior to the defined sludge storage period many dairy producers ignore sludge accumulation. As sludge build-up reduces the required treatment volume, biological decomposition slows or stops and strong odors can become a problem (Chastain and Linvill, 1999).

An existing lagoon can be returned to proper function if sludge is removed. In many cases, land application of the sludge based on the fertilizer value is the most realistic alternative. In most cases, crop or pastureland close to the dairy regularly receives lagoon supernatant and the nutrient demand of the crops grown is not sufficient to allow application of additional nutrients contained in the sludge. Instead, a mixture of sludge and lagoon water, typically in the range of 1 to 4% solids, must be hauled to remote fields where manure is not usually applied. The transportation and labor costs associated with hauling sludge with a high moisture content can be very high in some cases. A significant decrease in moisture content will greatly reduce the volume of sludge that must be transported and will significantly reduce the cost of lagoon maintenance or renovation. This can be accomplished by gravity thickening.

Bench-scale gravity settling and thickening experiments was carried out for two dairy lagoon sludge and supernatant mixtures. The objectives of the study were to: (1) characterize the solids and plant nutrient content of the two sludge mixtures, (2) determine the time required to thicken the sludge by gravity settling, (3) determine the volume and nutrient content of the supernatant from the settling process, (4) determine the volume and nutrient content of the thickened sludge.

EXPERIMENTAL METHODS

Experiments were performed in the laboratory to observe the dewatering of mixtures of dairy lagoon sludge and supernatant. Thickening was achieved by allowing the solids to settled and thicken for a period of time before the liquid fraction was decanted.

Two mixtures of dairy lagoon sludge and supernatant were prepared from sludge that was scraped from the bottom of the dairy lagoon at the Lemaster Dairy Center at Clemson University. Several liters of lagoon supernatant were also collected. The lagoon supernatant and sludge was mixed to yield two sludge mixtures, about 5-8 L of each, with a TS content of about 1.9% and 4.0%. These sludge mixtures were selected because this is the TS range that could be agitated and pumped from a typical dairy lagoon.

Settling and Thickening Experiment

Two samples were taken from each of the sludge-supernatant mixtures to quantify the solids and nutrient content prior to settling and thickening. The sludge mixtures were continuously agitated using a paint stirrer powered by an electric drill while the samples were collected. The settling and thickening experiments were carried out as follows: (1) a well mixed, 500 ml sample of a sludge mixture was extracted and poured into a 500 ml graduated cylinder,

(2) the time when the sample was poured into the cylinder was recorded, (3) the volume of the settled solids was measured with respect to time for about 43 hours, and (4) at the end of the thickening period the supernatant was decanted and was analyzed to characterize the solids and nutrient content. This procedure was replicated 3 times for each sludge mixture.

Quantities Measured

The following characteristics were quantified for each sludge mixture and the supernatant after thickening: total solids (TS), fixed solids (FS), volatile solids (VS), total Kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4^+- N), nitrate nitrogen, total phosphorus (expressed as P_2O_5), and total potassium (expressed as K_2O), zinc (Zn), and copper (Cu). Organic nitrogen (organic-N) was calculated as the difference of TKN and NH_4^+- N. Plant nutrient analyses were provided by the Agricultural Service Laboratory at Clemson University. Two well-mixed samples were taken from each sludge mixture to provide 2 replicate plant nutrient analyses for each mixture. The supernatant of each of the graduated cylinders was analyzed for plant nutrients to provide 3 replications for each sludge mixture.

Measurements of TS, and VS, were obtained in the Agricultural Chemical, and Biological Research Laboratory in the Department of Agricultural and Biological Engineering at Clemson University. Three, 40 ml to 50 ml subsamples were taken of each sludge mixture or supernatant during agitation and were decanted into pre-weighted porcelain dishes. Free water was evaporated from the samples by placing them on a steam table for 24 hours. The samples were dried completely by holding them in a drying oven for 24 hours at a temperature of 105 C. The mass of TS was determined after the samples were allowed to cool in a desiccator. The mass of the fixed solids was determined after incinerating the dried solids in a furnace that was maintained at 600 C for 1.5 to 2 hours, and allowing the samples to cool in a desiccator. The mass of VS was simply the difference between the total and fixed solids. The TS and VS concentrations were calculated by dividing the mass in mg by the sample volume in L.

RESULTS

Characteristics of the Two Dairy Lagoon Sludge-Liquid Mixtures

The solids and plant nutrient content of the two sludge mixtures used for the settling and thickening experiments are given in Table 1. Sludge mixture B (3.99 % TS) contained twice as many solids on a volume basis as sludge mixture A (1.93% TS). However, 68% of the solids in sludge mixture B were volatile as compared to 58% for sludge mixture A. About 83% of the solids in fresh dairy manure are volatile (Chastain and Linvill, 1999 and ASAE D384.1, 1998). Therefore, it appears that sludge mixture B contained solids that had not decomposed as long as for sludge mixture A. Nitrate-N was not present at a significant concentration for either sludge mixture. The ammonium-N, Organic-N, and P_2O_5 concentrations were significantly higher for the sludge mixture with a higher TS concentration as would be expected. The potassium content of the two sludge mixtures were essentially the same (only 4% different).

Table 1. Characteristics of the two dairy lagoon sludge-supernatant mixtures prior to settling and thickening.

	Sludge Mixture A (mg/L)	Sludge Mixture B (mg/L)
Total Solids	19,340	39,862
Fixed Solids	8,116	12,714
Volatile Solids	11,223	27,148
Ammonium - N	75	240
Organic - N	755	1,395
Nitrate - N	1	1
TKN	830	1,635
Total-N	831	1,636
P_2O_5	547	1,116
K_2O	410	392
Zn	20	18
Cu	19	4

Sludge Thickening

The variation of the settled sludge volume with respect to the elapsed settling time for sludge mixture A and B is shown in Figure 1. The volume of the settled sludge, was expressed as the ratio of the thickened sludge volume (TSV) to the initial volume of the sludge mixture (V-initial). Sludge mixture B, with a TS-initial of 39,862 mg/L, settled at a much faster rate than sludge mixture A (TS-initial = 19,340 mg/L). The thickened sludge volume for mixture B occupied 46% of the total sample volume after 24 min (0.4 hr) of settling as compared to 69% for mixture A following 45 min (0.75 hr) of settling. The minimum thickened sludge volume for mixture B was 42.3% of the initial volume and occurred after 6.58 hr of settling. For mixture A,

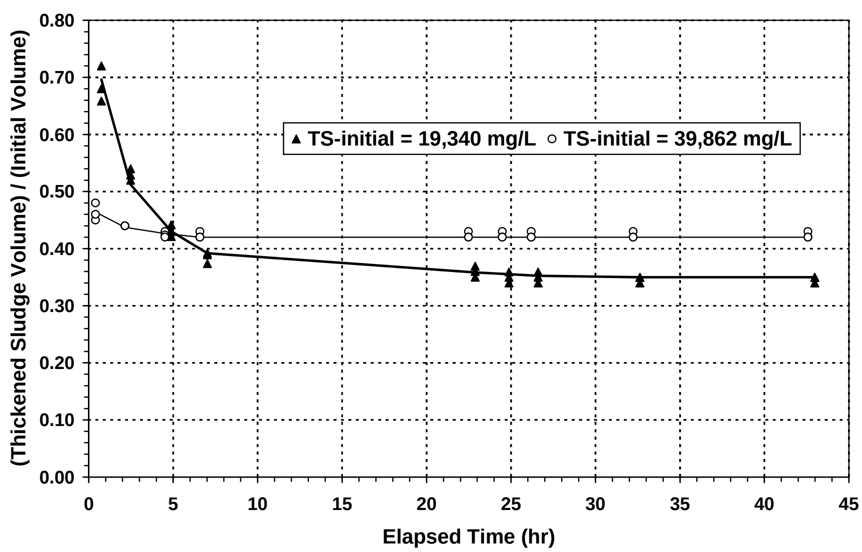

Figure 1. Variation in thickened sludge volume with settling time.

the majority of the thickening occurred after 7.02 hours had elapsed and the thickened sludge occupied 38.5% of the initial volume. Settling for 24.9 hours only decreased the thickened sludge volume by an additional 10% (TSV/V-initial = 0.346). Therefore, the optimum thickening time for each sludge mixture was 7 hours regardless of the initial total solids concentration.

Characteristics of Thickened Sludge

After the thickening experiment was completed (43 hr) the supernatant from each replication was analyzed to determine the concentration of the defined solids and plant nutrients. The characteristics of the two supernatants and the amount of solids and nutrients removed are presented in Table 2. Large amounts of TS, VS, N, P, K, Zn, and Cu were removed during the settling and thickening process. More solids and plant nutrients were removed for mixture B than A since mixture B contained more solids and plant nutrients initially. The nitrate-N concentration increased from 1 to 2 ppm during the experiment due to oxygen exchange at the surface of the supernatant layer.

Table 2. Solid and plant nutrients in the supernatant after settling for 43 hours.

	Supernatant From A (mg/L)	Percent Removed	Supernatant From B (mg/L)	Percent Removed
Total Solids	3,558	81.6	2,398	94.0
Fixed Solids	1,345	83.4	1,165	90.8
Volatile Solids	2,212	80.3	1,232	95.5
Ammonium - N	57	24.0	187	22.1
Organic - N	217	71.3	200	85.7
Nitrate – N*	2		2	
TKN	273	67.1	387	76.3
Total-N	275	66.9	389	76.2
P_2O_5	174	68.2	234	79.1
K_2O	325	20.6	378	3.6
Zn	3	82.6	1	96.0
Cu	4	79.3	0.2	95.1

* Nitrate concentration increased from 1 to 2 mg/L during the experiment.

During the settling and thickening process the color of the two supernatants remained the same. The supernatant volume increased as the density of the settled sludge increased. The solids and plant nutrient concentrations of the thickened sludge layer were calculated assuming that the solids and plant nutrient concentrations of the supernatant were constant. The following equation was used to calculate the thickened sludge concentration of any constituent:

$$C_{X,SS} = [(C_{X,I}\,V_I) - (C_{X,SUPER}\,V_{SUPER})] / V_{SS}\,. \qquad (1)$$

Where,

$C_{X,SS}$ = Concentration of constituent x in the settled sludge,
$C_{X,I}$ = Concentration of constituent x in the initial sludge mixture,
V_I = Volume of the initial sludge mixture,
$C_{X,SUPER}$ = Concentration of constituent x in the supernatant,
V_{SUPER} = Volume of the supernatant, and
V_{SS} = Volume of the settled sludge.

The variation in average TS for each of the sludge mixtures with respect to thickening time is given in Figure 2. After about 7 hours of thickening the TS of the thickened sludge ranged from 40,985 mg/L (4.10 % TS) for mixture A to 88,499 mg/L (8.85% TS) for mixture B.

The concentrations of solids and plant nutrients, and the volume fraction of the settled sludge after about 7 hours of thickening time is given in Table 3. In addition, the concentration of a constituent in the settled sludge ($C_{X, SS}$) is compared to the concentration in the initial agitated sludge mixture ($C_{X, I}$) using a concentration factor (CF_X) defined as:

$$CF_X = (C_{X, SS} / C_{X, I}) \quad (2)$$

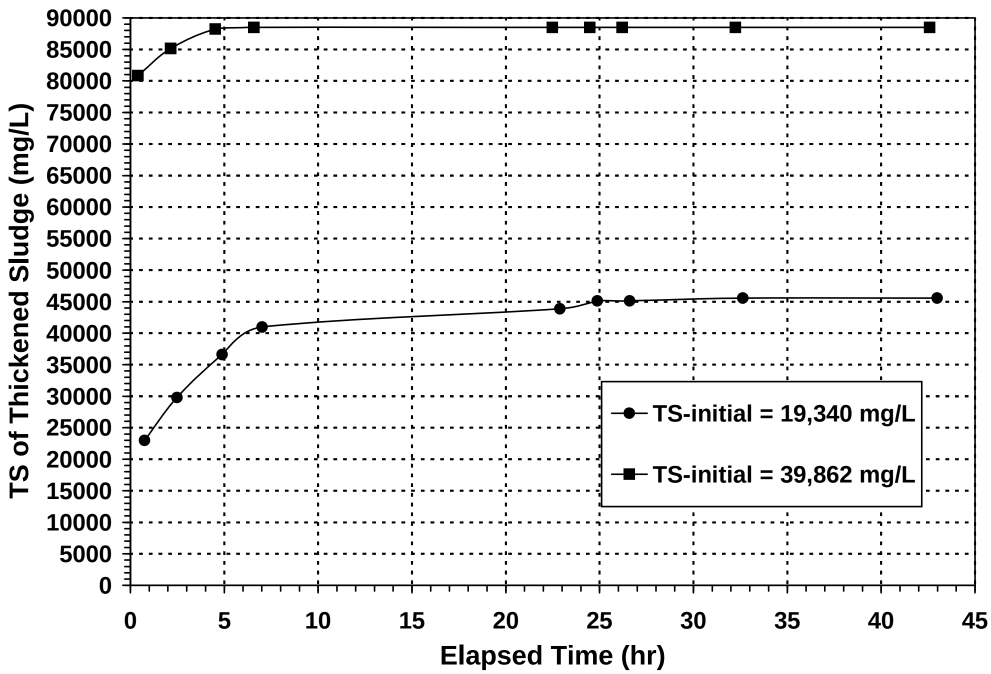

Figure 2. Variation of TS content of thickened sludge with settling time.

As would be expected, the sludge mixture with the greatest initial solids content yielded a thickened sludge with the greatest concentration of solids and major plant nutrients. The most significant results presented in the table are listed below.

- On the average, the thickened sludge occupied 40% of the initial volume for both sludge mixtures. Therefore, the amount of material that would need to be transported to a land application site would be reduced by 60% if the thickening process was used.
- The concentration of each constituent was greatest for the thickened sludge from mixture B. However, the concentration factors (CF_X) for TS, FS, VS, organic-N, TKN, P_2O_5, Zn, and Cu were less than 5% different for the two sludge mixtures. Therefore, the concentration factors for each of these constituents was the same within measurement error. The average CF_X value for the two sludge mixtures would be recommended for use in design calculations.

- The concentration factors for ammonium-N were only 6.5% different. Measurement errors for ammonium-N are often ± 10%. Therefore, an average concentration factor of 1.35 would apply for ammonium-N.
- The least agreement in the concentration factor was for K_2O (21% different).

Table 3. Comparison of the solids and plant nutrient content in the thickened sludge, and concentration factors, CF_X (equation 2), for the two defined sludge mixtures.

	Thickened Sludge From Mixture A TS-initial = 19,340 mg/L		Thickened Sludge From Mixture B TS-initial = 39,862 mg/L	
(TSV) / V-initial	0.385		0.423	
Settling Time (hr)	7.02		6.58	
	Concentration (mg/L)	CF_X ($C_{X,SS}$ / $C_{X,I}$)	Concentration (mg/L)	CF_X ($C_{X,SS}$ / $C_{X,I}$)
Total Solids	40,985	2.12	88,499	2.22
Fixed Solids	18,929	2.33	28,446	2.24
Volatile Solids	25,609	2.28	62,452	2.30
Ammonium - N	104	1.39	313	1.30
Organic - N	1,615	2.14	3,023	2.17
TKN	1,719	2.07	3,336	2.04
P_2O_5	1,143	2.09	2,318	2.08
K_2O	544	1.33	411	1.05
Zn	46	2.30	41	2.28
Cu	44	2.32	9	2.25

DISCUSSION

The results of the settling and thickening experiment indicate that 7 hours of thickening can reduce the sludge volume that must be land applied by about 60% and significantly concentrates nitrogen, phosphorous, copper, and zinc in the thickened sludge. The supernatant from the process would be added back to the lagoon to help reestablish or maintain the desired anaerobic treatment volume. The question that remains is how does the thickening process influence the amount of land needed to utilize the plant nutrients?

Many factors effect the proper application of any type of animal manure including: mineralization rate of organic-N, volatilization losses of ammonia-N, the N and P requirements of the particular crop, and the current fertility level of the soil. Organic-N mineralization rates can vary significantly with soil temperature, moisture content, soil type, and manure type. As a result, mineralization rates are a function of climate. Ammonia volatilization losses depend to a large extent on the methods used to apply manure. These factors are used to estimate the amount of nitrogen that is available to a plant (PAN). The N and P fertilization recommendations vary with the type of crop grown as well as an estimate of the yield.

In order to discuss the influence of a sludge thickening process on land application of lagoon sludge, plant available nitrogen estimates for the climatic conditions and soil types common in South Carolina (Chastain et al., 1999) and fertilization rates of 112 kg N/ha (100 lb N/ac) and 56 kg P_2O_5/ha (50 lb P_2O_5/ac) were used. Estimates of the PAN and the land area needed for fertilization along with the assumptions used are given in Table 4. The tabulated results indicate the following.

- The thickening process had a negligible impact on the PAN/P_2O_5 ratio. The method of application was more important.
- Based on a fertilization rate of 112 kg N/ha, the land application area needed per 100,000 L of agitated sludge mixture removed from a lagoon would be expected to decrease by 14 to 22% if a sludge thickening process is used.
- If P is used as the limiting nutrient for land application, the land area needed would decrease by 12 to 19% if sludge thickening is implemented.
- The main benefit of implementing a sludge thickening process is the reduction in the transportation and application costs since 60% of the material agitated and removed from the lagoon could be returned to the lagoon. The reductions in land area requirements are significant, but small.

Table 4. Estimates of the plant available nitrogen and land area needed based on application levels of 112 kg N/ha and 56 kg P_2O_5/ha for sludge-lagoon liquid mixtures and thickened lagoon sludge.

	Sludge Mixture A	Thickened Sludge From Mixture A	Sludge Mixture B	Thickened Sludge From Mixture B
Total Solids, mg/L	19,340	40,985	39,862	88,499
Plant Available Nitrogen Estimates (PAN), mg/L				
Surface Spread [1]	415	860	818	1668
Incorporated [2]	513	1052	1029	2064
Injected [3]	527	1071	1072	2121
P_2O_5, mg/L	547	1,143	1,116	2,318
PAN/P_2O_5				
Surface Spread [1]	0.76	0.75	0.73	0.72
Incorporated [2]	0.94	0.92	0.92	0.89
Injected [3]	0.96	0.94	0.96	0.92
Land Area Needed to Provide 112 kg N/ha (100 lb N/ac) per 100,000 L of Sludge Mixture Removed From the Lagoon [4]				
Surface Spread	0.37 ha	0.30 ha	0.73 ha	0.63 ha
Incorporated	0.46 ha	0.36 ha	0.92 ha	0.78 ha
Injected	0.47 ha	0.37 ha	0.96 ha	0.80 ha
Land Area Needed to Provide 56 kg P_2O_5/ha (50 lb P_2O_5/ac) per 100,000 L of Sludge Mixture Removed From the Lagoon [4]	1.09 ha	0.88 ha	1.99 ha	1.75 ha

[1] PAN estimate for surface spread manure = 0.5 x TKN.

[2] PAN estimate for incorporated manure = 0.6 x organic-N + 0.8 x Ammonium-N

[3] PAN estimate for injected manure = 0.6 x organic-N + 0.98 x Ammonium-N

[4] Volume land applied for thickened sludge from mixture A = 38,500 L. Volume land applied for thickened sludge from mixture B = 42,300 L.

CONCLUSIONS

Gravity settling and thickening experiments was carried out for two dairy lagoon sludge and supernatant mixtures. The results from the experiments indicated the following.

- The optimum amount of settling time for dairy lagoon sludge-water mixtures ranging from 1.93 to 3.99% total solids is 7.0 hours.
- The settled sludge occupied 40% of the volume on the average and the majority of the TS, VS, organic-N, TKN, P_2O_5, Cu, and Zn was concentrated in the thickened sludge. The supernatant from the thickening process can be returned to the lagoon to restore or maintain treatment volume and as a result the volume of sludge that would require transport and land application can be reduced by 60%.
- A concentration factor was defined to compare how well the thickening process concentrated the TS, FS, VS, N, P, K, Cu, and Zn in the settled sludge. Except for K, the concentration factors for the two sludge mixtures agreed within measurement error of the manure constituents.
- Implementation of the thickening process would be expected to reduce the land application area by 12 to 22%. Therefore, the main advantage is the reduction in hauling costs.

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