EFFECTIVENESS OF LIQUID–SOLID SEPARATION FOR TREATMENT OF FLUSHED DAIRY MANURE: A CASE STUDY

J. P. Chastain, M. B. Vanotti, M. M. Wingfield

ABSTRACT. *Sunny Day Farm was the home of the highest producing registered Jersey herd in the world at the time this study was conducted. The cows are housed in a freestall barn and manure is removed from the barn using a flush system. The manure treatment system on this farm includes the following components in series: an inclined stationary screen separator, a two–chambered settling basin, and a lagoon. Samples were taken to quantify the performance of the existing manure treatment system. The inclined stationary screen separator removed 60.9% of the total solids, 62.8% of the volatile solids, 49.2% of the TKN, 52.2% of the organic–N, and 53.1% of the total P. The complete on–farm manure treatment system removed 93.0% of the TS, 95.6% of the VS, 74.0% of the TKN, 91.1% of the organic–N, and 86.1% of the total P. In addition, settling experiments were carried out with flushed manure (unscreened) and effluent from the mechanical separator (screened) to determine how well settling of dairy manure could be enhanced with a polymer (PAM) and aluminum sulfate. Addition of 250 to 400 mg PAM/L to screened and unscreened dairy manure significantly increased the removal of total and volatile solids, organic–N, total P, Cu, and Zn. The optimum amount of PAM to add was 300 mg/L for screened and unscreened manure. Settling of flushed dairy manure for 60 min following an application of 300 mg PAM/L removed 76.1% of the TS, 80.3% of the VS, 80.8% of the COD, 45.7% of the TKN, 72.3% of the organic–N, and 61.8% of the total P. The largest amount of TKN and total P was removed by a two–stage separation process that combined the stationary inclined screen separator followed by gravity settling with a polymer or aluminum sulfate. Enhancing the gravity stage with 300 mg PAM/L removed 71.1% of the TKN and 86.0% of the P. Application of 3,194 mg alum/L removed 71.1% of the TKN and 99.6% of the total P.*

Keywords. *Manure treatment, Dairy, Solid–liquid separation.*

Sunny Day Farm located in Chester, South Carolina, was home to the highest producing, registered Jersey herd in the world at the time this study was conducted. On the average, 54 cows are milked each day. As of May 1998, the rolling herd averages for this Jersey herd were 9,422–kg milk, 428–kg fat, and 339–kg protein per cow each year. The cows are housed in a naturally ventilated, two–row freestall barn with two concrete alleys. The 54 freestalls are arranged in a tail–to–tail arrangement. Therefore, one alley provides access to the stall area and one alley serves the feeding area. A total mixed ration is fed using a drive–by feeding fence located along the south side of the building. Large amounts of organic bedding (about 0.5 m^3 per stall per week) are used in the freestalls and a generous amount of feed is available for the cows all of the time. The cows are milked twice each day in a parlor and manure is flushed from the freestall alleys each time the cows are milked.

Each alley was flushed with 5,670 L of fresh water from a farm pond and the alley floor slope is 1.5%. The flushed manure was collected in a concrete channel along the end of the barn. The channel contained the manure as it was processed by an AgPro® stationary inclined screen separator that had a screen size of 1.5 mm. The AgPro® separator was installed in one end of the channel and lifts the manure onto the screen using flight–elevator type paddles. The separated solids were conveyed up the inclined screen to the top where they fall onto a concrete storage pad where they form a pile that can be as high as 3.0 m tall (fig. 1). The liquid fraction, or effluent, flows through the screen and is collected and transferred by pipe to a two–chamber settling basin (fig. 2). The effluent from the two–chambered settling basin flows into an anaerobic lagoon. The steps in the manure treatment and handling system are shown in figure 3.

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Figure 1. Inclined stationary screen and solids storage area.

Figure 2. Two–chambered settling basin.

The first chamber of the settling basin receives the effluent from the mechanical separator (fig. 2). A variable height weir controls the detention time of the first chamber and the flow rate between the first and second chambers of the settling basin. The height of the weir is changed by stacking pressure treated boards in slots formed by two pieces of channel iron attached to the sides of a wide slot in the concrete dividing wall. A similar variable height weir controls the detention time in the second settling basin. Basin supernatant flows over the second weir into a concrete sump and flows by gravity to the lagoon through a pipe. The settled solids are removed from each chamber of the settling basin using a concrete ramp and a tractor mounted front–end loader. The settled solids are spread on near–by cropland or pasture.

The lagoon was constructed before the liquid–solid separation system was installed. Therefore, much of the sludge in the bottom of the lagoon accumulated before the liquid–solid separation system was constructed. The lagoon effluent is applied onto near–by hay fields, and pasture using a traveling gun.

In May 1998, a Clemson University Extension in–service training class met at the farm to learn about the manure handling system, and collect manure samples for analysis. In particular the objectives of the study were to:

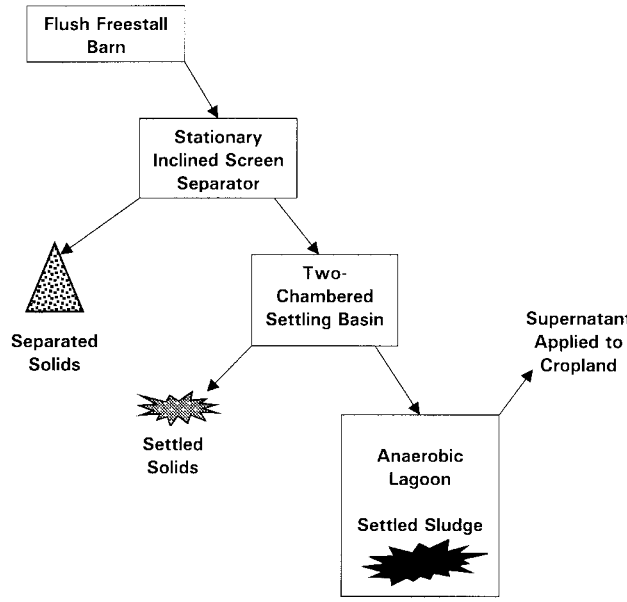

Figure 3. Flow chart of the on–farm treatment system.

- determine the amount of solids and plant nutrients removed from the flushed manure by each component of the liquid–solid separation system and the entire treatment system,
- determine the solids and plant nutrient content of the mechanically separated solids, gravity separated solids, lagoon supernatant, and lagoon sludge, and
- determine how a polymer or liquid aluminum sulfate can be used to enhance the solids and nutrient removal of the separation system.

EXPERIMENTAL METHODS

The dairy producer cleaned all separated solids from below the stationary screen separator the day before the samples were taken. Liquid manure samples analyzed for the present study were collected from the morning flush of the freestall barn. The pile of solids below the mechanical separator represented 29 h of solids accumulation from the evening flush the day before the samples were collected and the morning flush on the sampling day.

Samples were collected from the flush of the feed and stall alleys. The feed and stall alleys were flushed independently. The time required to flush an alley was about 15 s. The mechanical separator required about 30 min to process each flush. Teams of four to five people were placed at the following sampling locations and collected a sample from each flush:

- at the point where the flushed manure fell from the floor into the collection channel,
- at the effluent pipe of the stationary screen separator (which is the inlet to the gravity settling basin),
- at the outflow point of the first chamber of the gravity settling basin, and
- at the outflow point of the second chamber of the gravity settling basin.

Each team used long–handled sampling cups that held 500 to 1,000 mL to continuously sample from their respective location throughout the flow period for each flush. The large samples were collected in 18.9–L containers. The team that sampled the flush water had the most difficult job since the duration of flow was only 15 s. However, at least one of the team members drew a sample every second during the flow.

Equal volumes of the samples that were collected from each flush (freestall alley and feed alley) were combined together while being well agitated two provide a representative sample. A paint stirrer powered by a cordless drill was used to agitate the large samples. Well–mixed samples were removed from the buckets using the sampling cups. At least 4 L of sample was bottled from each sampling location, put on ice, and was transported to Clemson University for analysis. In addition, approximately 10 L of well–mixed flushed manure and effluent from the stationary inclined screen separator were transferred during agitation to two large plastic containers. The two containers (one flushed manure and one screened manure) were transported on ice to the USDA–ARS Coastal Plains Soil, Water, and Plant Research Center where gravity settling experiments and a portion of the sample analyses were performed.

All of the separated solids from the mechanical separator were weighted using 18.9–L containers, shovels, and a digital scale that could measure a mass of up to 50 kg to the nearest 0.02 kg. Samples from several locations in the pile were placed in a plastic bag as the pile was mixed during the weighing process. A large, well–mixed sample of the solids from the settling basin, obtained from several locations, was also collected using the long handled sampling cups and placed in a plastic bag. All samples were stored on ice while being transported to Clemson University for analysis.

Lagoon Samples

Four samples of the lagoon supernatant were collected using long–handled cups (3.66 m long) and small plastic buckets on a rope. Two teams used long handled cups to sample the surface water from several locations around the perimeter of the lagoon. The samples were mixed in a bucket and two 2–L samples were stored on ice for analysis. Another two teams used plastic buckets on a rope and threw the bucket out into the lagoon and quickly pulled the bucket back to shore with the rope. Several samples were taken, and mixed in a large bucket. Two representative 2–L samples were poured into plastic bottles, and stored on ice.

Lagoon sludge was sampled by using a metal bucket that had a piece of steel riveted onto one side to serve as a weight. A rope was tied to the handle of the bucket. The bucket was thrown out into the lagoon, allowed to sink to the bottom, and then was pulled in slowly with the rope. This procedure was repeated several times, and 8 well–mixed L were stored on ice in plastic bottles.

Quantities Measured

The samples that were transported to Clemson University were analyzed to measure the concentrations of the following: total solids (TS), total volatile solids (VS), total Kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4^+– N), total phosphorus (expressed as P_2O_5), and total potassium (expressed as K_2O), Ca, Mg, S, Zn, Cu, Mn, and Na. Organic nitrogen (organic–N) was calculated as the difference between TKN and NH_4^+–N. The samples were transported on the day of collection and were stored in a refrigerator until all experiments were complete. Plant nutrient analyses were provided by the Agricultural Service Laboratory at Clemson University. Two replicate plant nutrient analyses were performed for each sample.

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 using standard methods (APHA, 1995). Each sample was poured into a large beaker or bucket and was well mixed using a magnetic stirrer or a paint stirrer. Two 30– to 40–mL subsamples were taken of each sample and were decanted into pre–weighted porcelain dishes. Free water was evaporated from the samples by placing them on a steam table for 12 to 16 h. The samples were dried completely by holding them in a drying oven for 24 h 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 by incinerating the dried solids in a furnace that was maintained at 600° C for 1.5 to 2 h, and allowing the samples to cool in a desiccator. The mass of VS was simply the difference between the total and fixed solids.

Gravity Settling Experiments

Large (10 L) samples of the flushed dairy manure and the effluent from the stationary inclined screen separator were collected, stored on ice, and transported to the USDA–ARS Coastal Plains Soil, Water, and Plant Research Center in Florence, S. C. Experiments were conducted to determine the amount of total solids (TS), total suspended solids (TSS), suspended volatile solids (SVS), TKN, organic–N, ammonium–N, total phosphorous, inorganic phosphorous, COD, total potassium, copper, and zinc that can be removed by gravity settling with and without chemical enhancement.

The total solids are the residues remaining in a vessel after evaporation in a drying oven. The total suspended solids are the solids portions retained on a 2.0–μm glass fiber filter after oven drying (APHA, 1995). Likewise, the SVS are the fraction of the TSS retained on the glass fiber filter that was incinerated in a furnace. Therefore, the TSS and SVS are measurements of the insoluble total and volatile solids that are removable by separation. The soluble fractions of the total or volatile solids can be determined by subtracting the suspended fraction (TSS or SVS) from the total solids or volatile solids, respectively. The measurements of TS, TSS, SVS, and COD were obtained using the standard methods given in APHA (1995).

The settling experiments were conducted with 1–L Imhoff settling cones using the procedures defined by APHA (1995). Settling experiments were performed for the unscreened, flushed manure and the effluent from the AgPro® separator (screened manure). Three replications of the following treatments were applied to the unscreened and screened dairy manure:

- 30 min of settling,
- 60 min of settling,
- 60 min of settling after mixing in a cationic polyacrylamide polymer with a 20% charge density (PAM) at concentrations of 250, 300, 350, and 400 mg/L, and

- 60 min of settling after mixing with 3,194 mg/L (approximately a 1.5 Al/P molar ratio) of liquid aluminum sulfate ($AL_2(SO_4)_3$ 12 H_2O).

The removal of solids, COD, nitrogen, phosphorous, potassium, copper, and zinc was calculated from the difference in the average concentration in the manure poured into the settling cone (influent or initial) and the concentration in the decanted liquid (or supernatant).

RESULTS FOR THE ON–FARM MANURE TREATMENT SYSTEM

The samples collected at the dairy farm were analyzed to determine the nutrient and solids concentration of the influent and effluent for each step in the manure treatment system (fig. 3). The amount of solids and nutrients removed by each component, and the entire system (including the lagoon) was determined. The solids and nutrient content of the separated solids were also measured.

SOLIDS AND NUTRIENT CONTENT OF FLUSHED MANURE AND REMOVAL BY THE STATIONARY INCLINED SCREEN SEPARATOR

The solids and nutrient content of the flushed and screened manure, and the percent removed by the inclined stationary screen separator are shown in table 1. The total solids content of the flushed manure was 38,258 mg/L or 3.83% TS, and was much higher than expected for flushed dairy manure. Flushed dairy manure is typically in the range of 1 to 2% TS. The higher solids content in this case is attributed to the large amounts of organic bedding used (0.5 m^3 perstall per week) and the large amount of wasted feed present in the manure. The total suspended solids accounted for 77.3% of the TS, and 83.8% of the total solids were volatile. On the average, 87.7% of the volatile solids were suspended and were removable by physical means. The TKN concentration in the flushed manure was 1,433 mg/L and was 53.9% organic–N.

Table 1. Removal of solids, COD, plant nutrients, and minerals from flushed dairy manure by an inclined stationary screen separator.

	Flushed Manure (mg/L)[a]	After Inclined Stationary Screen (mg/L)[a]	Amount Removed (%)
Total solids	38,258	14,959	60.9
Total Suspended solids[b]	29,575	11,051	62.6
Volatile solids	32,073	11,937	62.8
Suspended Volatile solids[b]	28,137	9,760	65.3
Chemical oxygen demand[b]	60,096	20,136	66.5
Ammonium–N	661	359	45.7
Organic–N	772	369	52.2
TKN	1,433	729	49.2
P_2O_5[c]	930	436	53.1
K_2O[d]	921	453	50.8
Ca	953	488	48.8
Mg	337	168	50.2
S	179	104	41.6
Zn	14	7	50.0
Cu	11	12	0
Mn	12	6	50.0
Na	288	140	51.2

[a] To convert from mg/L to lb/1,000 gal divide by 119.826.
[b] Computed from data obtained from the Coastal Plains Soil, Water, and Plant Research Center, USDA–ARS. All other sample analysis performed at Clemson University.
[c] Total phosphorous expressed as P_2O_5.
[d] Total potassium expressed as K_2O.

The removal of all of the constituents in dairy manure by the inclined stationary screen separator is given in the table. In particular, the results indicate that 60.9% of the total solids, 62.6% of the suspended solids, 62.89% of the VS, 65.3% of the SVS, 66.5% of the COD, 45.7% of the ammonium–N, 52.2% of the organic–N, 53.1% of the phosphorous, and 50.8% of the potassium was removed by the mechanical separator. The copper concentration was not significantly changed, and as result the percent removed was zero.

The only unexpected result was the large removal of ammonium–N. Ammonium–N is in solution and cannot be screened. In addition, the procedures to measure ammonical–N used by most laboratories typically convert all NH_3^-–N to NH_4^+–N. Therefore, the data includes the concentrations of both ammoniacal forms of N. Flushing dairy manure is a turbulent flow process and the mixing that occurs can promote the conversion of NH_4^+ to NH_3^-. Also, the manure was held in a long open channel for 30 min as it was processed by the mechanical separator. The lifting and spreading of the slurry on the screen would be expected to enhance volatilization of ammonia. Therefore, the large amount of ammonium–N shown as removed by the separator was attributed to enhanced volatilization.

The amount of solids removed by the separator was measured by weighing all of the solids separated from an evening and morning flush. The separator produced 1360 kg of solids from 54 cows in 29 h. Therefore, 20.9 kg solids with a moisture content of 79.7% was removed from the flushed manure per cow per day.

REMOVAL OF SOLIDS AND NUTRIENTS BY THE TWO–CHAMBERED SETTLING BASIN

The second step in the manure treatment system used at Sunny Day Farm was a two–chambered settling basin that was described previously (fig. 2). The two chambers were designed in such a way that the effluent from the first chamber flowed into the second so that the structure performed as two settling basins in series.

The boards that control the outflow of the effluent from the first chamber were set low and channeled flow was observed between the inlet and outlet of the first chamber. An additional board could have been added to provide a longer detention time. The second chamber was observed to remove a significant amount of solids. However, the concentrations of plant nutrients in the effluent from each chamber of the settling basin were the same within experimental error. Therefore, it was impossible to distinguish the treatment effect of the two chambers independent of each other. The solids and nutrient data for the effluent from the second chamber of the settling basin, which includes the effect of both chambers, are given in table 2.

The amount of solids and nutrients removed by the two–chambered settling basin was calculated using the constituent concentrations for the effluent of the inclined screen as the influent, or initial, values (table 1). The combined treatment provided by the two–stage separation process (screening followed by settling) was determined using the constituent concentrations of the flushed manure as the influent values.

The tabulated results indicate that the settling basin removed 23.3% of the TS, 27.1% of the VS, none of the ammonium–N, 17.5% of the organic–N, 14.6% of the total P (expressed as P_2O_5), and none of the potassium. The combination of screening and settling, a two–stage separation process, removed 70.0% of the TS, 72.9 % of the VS, 42.7% of the ammonium–N, 60.6% of the organic–N, 59.9% of the total P, and 47.8% of the potassium. Significant percentages of Cu and Zn were also removed, but the initial concentrations were low.

Sludge is composed of the fixed solids and slow to degrade volatile solids that settle to the bottom of a lagoon. The concentration of fixed solids is the difference between TS and VS. From the data given in tables 1 and 2 it can be determined that the two–stage separation system removed 55.3% of the fixed solids. The majority of these fixed solids would contribute to sludge build–up. Furthermore, a large portion of the VS removed would be expected to be the large particles that are very slow to degrade.

Removal of Solids and Nutrients by the Complete System

The final treatment of dairy manure occurred in the anaerobic lagoon. An anaerobic lagoon treats liquid manure by: dilution, settling, anaerobic decomposition of the volatile solids, and volatilization of ammonia–N. A large fraction of the solids that settle to the bottom of the lagoon are degraded by the anaerobes. The solids that degrade very slowly or not at all form the sludge layer.

The reduction in solids and nutrients by the lagoon alone was estimated as the difference in concentration between the effluent from the settling basin and the lagoon supernatant. The overall treatment provided by the two–stage separation process, and the lagoon was calculated from the concentrations of the flushed manure and the lagoon supernatant. The constituent concentrations found in the lagoon supernatant, the reduction in plant nutrients and solids by the lagoon, and the treatment provided by the complete system are also given in table 2.

The different methods used to measure the lagoon supernatant (bucket and rope vs. long–handled dip cup) were not significantly different. Therefore, all replications of solids and nutrient analyses were averaged for the lagoon supernatant.

The lagoon provided a large amount of treatment for all solids and plant nutrients with respect to the supernatant. The lagoon reduced the concentration of TS by 76.8%, VS by 83.8%, ammonium–N by 20.1%, organic–N by 77.3%, P_2O_5 by 65.4%, and K_2O by 23.7% as compared to the influent concentrations. The complete system (two–stage liquid–solid separation and lagoon) removed 93.0% of the TS, 95.6% of the VS, 54.2% of the ammonium–N, 91.1% of the organic–N, 86.1% of the P_2O_5, and 60.2% of the K_2O.

Obviously the minerals, phosphorous, and potassium removed from the liquid were accumulated in the screened solids, settled solids, and lagoon sludge. Biological degradation of the organic–N yields an increase in the concentration of NH_4^+–N. A fraction of the ammonium–N can be lost to the atmosphere by volatilization of ammonia. Removal of a large fraction of the organic–N prior to the lagoon would greatly reduce ammonia losses to the atmosphere. In this case, 60.6% of the organic–N in the waste stream from the dairy barn did not enter the lagoon.

Table 2. Removal of solids and plant nutrients by the two–chambered settling basin, the combined treatment of screening and settling, reduction by the lagoon, and treatment by the complete system (screen, settling, and lagoon).

	Concentrations after Settling (mg/L)[a]	Amount Removed by the Two–Chambered Settling Basin (%)	Amount Removed by the Inclined Screen and Settling Basin (%)	Concentrations in the Lagoon Supernatant (mg/L)	Reduction by the Lagoon (%)	Amount Removed by the Complete System (%)[b]
Total solids	11,470	23.3	70.0	2,665	76.8	93.0
Volatile solids	8,705	27.1	72.9	1,410	83.8	95.6
Ammonium–N	399 (379)	0	42.7 [c]	303	20.1[c]	54.2
Organic–N	304	17.5	60.6	69	77.3	91.1
TKN	703	3.5	50.9	373	46.9	74.0
P_2O_5[d]	373	14.6	59.9	129	65.4	86.1
K_2O[e]	508 (481)	0	47.8[c]	367	23.7[c]	60.2
Ca	423	13.3	55.6	185	56.3	80.6
Mg	158	5.7	53.0	90	43.0	73.3
S	86	17.2	51.7	26	69.8	85.5
Zn	5	25.0	62.5	1	80.0	92.9
Cu	7	45.0	38.9	1	85.7	90.9
Mn	5	10.0	55.0	1	80.0	91.7
Na	151 (146)	0	49.3 [c]	115	23.8	60.1

[a] To convert from mg/L to lb/1,000 gal divide by 119.826.
[b] Calculated based on the nutrient content of the flushed manure given in table 1.
[c] Concentrations of these nutrients were higher in the effluent from the settling basin than in the effluent from the inclined screen, but were within experimental error. Removal was calculated using the average concentration in the effluent from the inclined screen separator and the effluent from the settling basin.
[d] Total phosphorous expressed as P_2O_5.
[e] Total potassium expressed as K_2O.

Solids and Nutrient Content of Separated Solids and Sludge

The total solids and nutrient content of the screened solids, solids from the settling basin, and lagoon sludge are given on an as–sampled basis in table 3. The separated solids from the stationary screen separator had a solids content of 20.3%, were easily handled as a solid, and had low odor. The solids from the settling basin had a higher moisture content, 10.9% TS, and contained more nitrogen and phosphorous than the mechanically separated solids. Organic nitrogen accounts for 96% of the total nitrogen in the mechanically separated solids and 94% of the nitrogen in the solids from the settling basin.

It was also determined that the dry matter concentrations of Ca, Mg, S, Zn, Cu, and Mn in the sludge were much greater than in flushed dairy manure (not shown in fig. 4). The ratio of the dry basis concentration in the sludge to flushed dairy manure was 7.6 for Ca, 3.1 for Mg, 10.7 for S, 11.7 for Zn, 15.1 for Cu, and 22.8 for Mn.

Results for the Gravity Settling Experiments

Large samples (10 L) of the flushed dairy manure (unscreened) and the effluent from the AgPro® separator (screened) were used to conduct settling experiments with and without flocculants. One goal of these experiments was to determine if settling with a flocculent could yield a single–step separation process that would equal or exceed the combination of mechanical and gravity separation currently used on this farm. The other goal was to determine the amount of flocculent needed to significantly enhance the constituent removal of the two–stage process by enhancing the settling of screened manure. The flocculants considered were a cationic polymer (PAM) and liquid aluminum sulfate.

A direct comparison of the concentration of N, P, and K, on a dry basis, in fresh manure (flushed), screened solids, settled solids, and lagoon sludge is provided in figure 4. The flushed dairy manure contained more N, P, and K than the mechanically separated solids. The settled solids contained 1.3 times as much organic–N as flushed manure, but contained less ammonium–N, P, and K on a dry basis.

All of the major and minor plant nutrients are concentrated to some extent in the sludge since it accumulated at the bottom of the lagoon over time. Organic–N, and phosphorous were highly concentrated in the sludge. The organic–N in the sludge was 6.3 times greater than the concentration in the flushed manure, and phosphorous was 7.0 times as concentrated in the sludge as fresh manure. Lagoon sludge contained 1.5 times more NH_4^+–N than flushed manure due to mineralization of organic–N. Potassium was the major plant nutrient that was concentrated the least in the sludge layer. The sludge layer contained 1.5 times more K_2O than flushed manure.

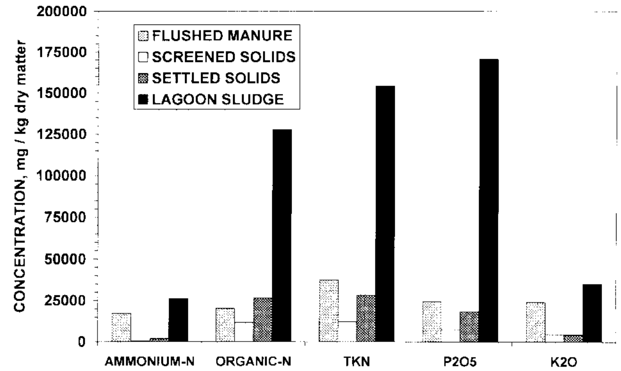

Figure 4. Comparison of the N, P, and K concentrations of flushed dairy manure, separated solids, settled solids, and lagoon sludge on a dry matter bass.

Table 3. Plant nutrients in separated dairy solids and lagoon sludge.

	Solids from Stationary Screen (mg/kg, w.b.)[a]	Solids from Settling Basin (mg/kg, w.b.)[a]	Lagoon Sludge (Scraped from Bottom) (mg/kg, w.b.)[a]
Ammonium–N	100	200	1,840
Organic–N	2,370	2,885	8,950
TKN	2,470	3,085	10,790
P_2O_5	1,530	2,010	11,945
K_2O	930	485	2,465
Ca	2,515	2,755	13,235
Mg	610	325	1,895
S	385	555	3,510
Zn	30	95	300
Cu	50	70	305
Mn	20	35	500
Na	235	120	515
Total Solids (%)	20.3	10.9	7.0

[a] To convert to lb/ton divide by 500.

Gravity Settling of Unscreened and Screened Dairy Manure

The amount of solids, COD, and plant nutrients removed from the unscreened flush manure after 30 and 60 min of settling is shown in table 4. Settling of dairy manure with a solids content of 4.18% for 30 min removed 55.0% of the TS, 60.5% of the TSS, 55.3% of the VS, 64.1% of the SVS, 60.9% of the COD, 26.2% of the organic–N, and 27.8% of the total phosphorous. Increasing the settling time to 60 min removed 5.8% more TS, 11.0% more TSS, 8.5% more VS, 17.1% more organic–N, and 9.9% more total P. Settling did not remove a significant amount of inorganic–P or potassium. Gravity settling for 60 min removed 71.5% of the total suspended solids and 74.1% of the suspended volatile solids. The copper and zinc concentrations in the manure were low, and 60 min of settling removed 40% of the Zn and 33% of the Cu.

Settling flushed dairy manure for 30 and 60 min gave mixed results for the removal of ammonium–N. The results for 30 min of settling indicated that 21.3% of the NH_4^+–N was removed. However, the effluent NH_4^+–N concentration following 60 min of settling was greater than the influent value by 8.9%. In a previous study by Chastain et al. (1999) it was found that the coefficient of variation (CV) for ammonium–N was ±22.4%. It was also determined that the variability in ammonium–N was 1.5 times larger than the variability in TKN (CV = ±14.6%). Therefore, the ammonium–N concentrations measured for the influent, and the two effluents were within the combined sampling and

Table 4. Removal of solids, COD, and plant nutrients from flushed and screened dairy manure by settling.

	Flushed Manure					Screened Manure[a]		
	After Settling for 30 min			After Settling for 60 min		After Settling for 60 min		
Constituent	Influent (mg/L)[b]	Effluent (mg/L)	% Removed	Effluent (mg/L)	% Removed	Influent (mg/L)	Effluent (mg/L)	% Removed
TS	41,763	18,784	55.0	16,376	60.8	11,962	9,795	18.1
TSS	32,955	13,032	60.5	9,378	71.5	7,468	7,321	2.0
VS	34,957	15,640	55.3	12,652	63.8	9,626	8,579	10.9
SVS	30,113	10,796	64.1	7,808	74.1	6,255	5,208	16.7
COD	66,416	25,994	60.9	24,193	63.6	12,789	8,793	31.2
NH_4^+–N	541	426	21.3	589	0	254	274	0
Organic–N	923	681	26.2	524	43.3	390	360	7.7
TKN	1,464	1,107	24.4	1,113	24.0	644	634	1.6
P_2O_5	1,061	766	27.8	661	37.7	370	320	13.5
Elemental–P	467	337	27.8	291	37.7	163	141	13.5
Inorganic–P	136	138	0	137	0	50	47	0
K_2O	958	952	0.6	954	0.4	526	531	0
Zn	15	11	26.7	9	40.0	7	7	0
Cu	6	4	33.3	4	33.3	8	8	0

[a] Settling screened manure for 30 min was not very effective with a TS removal efficiency of 15.6%.
[b] To convert from mg/L to lb/1,000 gal divide by 119.826.

analysis errors. It was concluded that settling had a negligible effect on the ammonium–N concentration.

Comparison of Settling with the Inclined Screen Results

Comparison of the removal of solids and nutrients by 60 min of settling with the results shown for the inclined screen separator (table 1) indicates that the two processes removed essentially the same amounts of total (TS) and volatile solids (VS). Gravity settling removed about 9% more of the suspended total and volatile solids (TSS and SVS). However, the inclined screen was more effective at removing total P (53.1 vs. 37.7%), TKN (49.2 vs. 24.0%), and K_2O (50.8 vs. 0.4%). Screening and sedimentation for 60 min removed about the same amounts of organic–N (52.2 vs. 43.3%).

Gravity Settling of Screened Dairy Manure

Gravity settling of dairy manure that had been processed by an inclined screen for 30 min was not very effective. Only 15.6% of the TS were removed in 30 min. This result was not unexpected since the screen removed 62.6% of the suspended solids. Settling of screened dairy manure for 60 min gave slightly better results and the data are presented in table 4. The laboratory experiments yielded a TS removal of 18.1% by settling for 60 min. The data taken on–farm indicated that the two–chambered settling basin removed slightly more of the total solids (23.3 vs. 18.1%), and about twice as many volatile solids (27.1 vs. 10.9%) than indicated by settling cone experiments (table 2). The removal of P_2O_5 was about the same. The detention time of the two–chambered settling basin was not measured.

Enhanced Settling of Flushed Dairy Manure Using PAM

The amount of solids, COD, and plant nutrients removed from unscreened dairy manure by settling for 60 min with and without the addition of PAM is compared in table 5. The amount of polymer added (PAM) ranged from 250 to 400 mg/L. The polymer was added to the manure, stirred well to enhance the exposure of suspended solids to the polymer, and then was allowed to settle for 60 min. Preliminary experiments indicated that at least 250 mg PAM/L was required to achieve a significant color change in the supernatant. Therefore, 250 mg PAM/L was used as the lower limit. Enhanced settling with PAM did not effect the concentration of inorganic P or ammonium–N significantly.

The data shown in table 5 indicate that the removal of solids, COD, and all plant nutrients increased as the amount of PAM applied was increased from 250 to 400 mg/L. The most significant increase in the removal of manure constituents was achieved for a PAM application rate of 250 mg/L. At this level of treatment, the removal of TSS was increased by a factor 1.26, from 71.5 to 89.9%, as compared to settling alone. The removal of SVS was increased by a factor of 1.22, and corresponded to a removal of 90.7%.

Increasing the PAM concentration by 50 mg/L, from 250 to 300 mg PAM/L, increased the removal of TSS by 2.7%. Adding another 50 mg PAM/L to give a concentration of 350 mg PAM/L gave an additional TSS removal of 3.6% as compared to the results for 300 mg PAM/L. Finally, increasing the PAM concentration to 400 mg/L yielded only a 1.8% improvement in TSS removal. The diminishing benefits of increased PAM concentrations indicates that the maximum practical PAM concentration for flushed dairy manure with a TS of 4.18% is 300 mg/L based on the removal of suspended solids (TSS). The enhancement in the removal of SVS diminished with increases in PAM concentration in a similar manner.

Enhancing the removal of suspended total and volatile solids is not the only objective for the use of PAM with gravity settling. Removal of nitrogen and phosphorous is of great concern in light of new regulations, which may limit the application of animal manure based on phosphorous. The

Table 5. Removal of solids, COD, and plant nutrients from flushed dairy manure by settling for 60 min with and without application of PAM.

Constituent	Initial Concentration (mg/L)	Amount of PAM Added (mg/L) 0 (% Removed)	250 (% Removed)	300 (% Removed)	350 (% Removed)	400 (% Removed)
TS	41,763	60.8	72.9	76.1	78.0	80.1
TSS	32,955	71.5	89.9	92.6	96.2	98.0
VS	34,957	63.8	78.1	80.3	83.1	84.7
SVS	30,113	74.1	90.7	93.2	96.5	98.3
COD	66,416	63.6	79.3	80.8	84.5	86.5
TKN	1,464	24.0	43.8	45.7	50.9	53.6
Organic–N	923	43.3	70.3	72.3	81.1	84.4
P_2O_5	1,061	37.7	58.6	61.8	64.9	66.8
K_2O	958	0.4	2.6	3.5	4.4	5.2
Zn	15	40.0	79.8	82.0	93.1	96.7
Cu	6	33.3	80.0	82.8	92.8	96.7

settling process without flocculation can remove 43.3% of the organic–N and 37.7% of the total P (71% of total P is organic, table 4). Addition of 250 mg PAM/L resulted in an increase in the removal of organic–N and P_2O_5 by a factor of 1.62 and 1.55, respectively. Gravity settling with PAM did not improve the removal of K_2O to a great extent. Increasing the PAM concentration to 300 mg/L increased the removal of total P by 3.2% and organic–N by 2.0%. The data presented in table 5 indicate that the removal of total–P and organic–N followed the same pattern as TSS, and the nutrient data support a maximum practical PAM concentration of 300 mg/L.

Flocculation with 250 to 300 mg PAM/L provided some additional removal of COD. Enhancing gravity settling with the addition of 300 mg PAM/L increased the removal of COD by a factor of 1.27 as compared to gravity settling without chemical enhancement.

The concentrations of zinc and copper in the flushed dairy manure were low (15 and 6 mg/L, respectively). However, addition of 300 mg PAM/L removed about 82% of these elements.

Enhanced Settling of Screened Dairy Manure Using PAM

The influence of adding 250 to 400 mg PAM/L prior to settling of screened manure (1.20% TS) for 60 min is shown in table 6. It should be noted that the removal of plant nutrients in this table is based on the concentration that entered the settling process, that is the effluent from the inclined screen. While settling of screened manure (0 mg PAM/L) removed only a small amount of the suspended solids and plant nutrients the addition of PAM greatly enhanced the effectiveness of settling. For example, addition of 250 mg PAM/L increased the removal of SVS by a factor of 4.13, and increased the removal of P_2O_5 by a factor of 3.55. Increasing the PAM concentration from 250 to 300 mg/L resulted in a 11.2% increase in the removal of P_2O_5 and an additional 19.3% removal of TSS. Addition of more than 300 mg PAM/L gave only a modest increase in the removal of TSS. Therefore, the maximum practical PAM concentration was the same as for the unscreened manure (300 mg PAM/L).

The combined effects of screening followed by settling with and without PAM is shown in table 7. It should be noted that the removal of solids, COD, and plant nutrients in this table is based on the solids and nutrients present in the flushed manure. The data indicate that most of the removal using this two–stage approach is achieved using 300 mg PAM/L. Settling with 300 mg PAM/L following a 1.5 mm inclined screen resulted in the removal of 92.4% of the TS, 97.1% of the TSS, 88.1% of the VS, 97.3% of the SVS, 93.5% of the

Table 6. Removal of solids, COD, and plant nutrients from screened dairy manure by settling for 60 min with and without application of PAM.

Constituent	Initial Concentrations (mg/L)	Amount of PAM Added (mg/L) 0 (% Removed)	250 (% Removed)	300 (% Removed)	350 (% Removed)	400 (% Removed)
TS	11,962	18.1	64.1	73.6	74.7	77.9
TSS	7,468	2.0	68.1	87.4	89.7	94.6
VS	9,626	10.9	44.7	56.7	57.8	60.8
SVS	6,255	16.7	68.9	87.2	89.0	93.5
COD	12,789	31.2	57.2	66.2	75.2	80.0
TKN	643	1.0	25.2	34.1	38.9	41.9
Organic–N	390	0.9	39.9	62.4	62.3	73.9
P_2O_5	370	13.7	48.7	59.9	65.4	68.3
K_2O	526	0.0	3.7	0.2	4.4	4.3
Zn	7	0.0	70.0	82.9	89.5	96.2
Cu	8	0.0	59.2	80.8	87.5	96.7

Table 7. Removal of solids, COD, and plant nutrients from flushed dairy manure separation by an inclined stationary screen separator (1.5 mm) followed by settling for 60 min with and without application of PAM.

Constituent	Initial Concentration (mg/L)	Amount of PAM Added (mg/L) 0 (% Removed)	250 (% Removed)	300 (% Removed)	350 (% Removed)	400 (% Removed)
TS	41,763	76.5	89.7	92.4	92.8	93.7
TSS	32,955	77.8	92.8	97.1	97.7	98.8
VS	34,957	75.5	84.8	88.1	88.4	89.2
SVS	30,113	82.7	93.5	97.3	97.7	98.7
COD	66,416	86.8	91.7	93.5	95.2	96.1
TKN	1,464	54.9	67.1	71.1	73.1	74.5
Organic–N	923	58.2	74.6	84.1	84.1	89.0
P_2O_5	1,061	69.9	82.1	86.0	87.9	88.9
K_2O	958	49.9	52.3	50.5	52.6	52.5
Zn	15	53.3	86.0	92.0	95.1	98.2
Cu	6	0.0	45.6	74.4	83.3	95.6

COD, 84.1% of the organic–N, 71.1% of the TKN, 86.0% of the P_2O_5, and 50.5% of the K_2O.

Use of Aluminum Sulfate to Enhance Settling of Dairy Manure

Settling experiments were performed using 3,194 mg of liquid aluminum sulfate per liter of unscreened and screened dairy manure. A large fraction of the solids in the unscreened (flushed) manure floated and did not settle. It was concluded that aluminum sulfate was not feasible to use with unscreened dairy manure. Settling with alum performed well with screened dairy manure. Therefore, the same two–stage separation process can also be used substituting 3,194 mg/L of alum for PAM to enhance the gravity separation stage. The use of 300 and 400 mg PAM/L, and 3,194 mg alum/L to enhance the two–stage process is compared in figure 5. The application of alum removed slightly less TS but almost all of the suspended total and volatile solids. The two–stage separation process enhanced with alum removed 99.6% of the P_2O_5 and 93.0% of the organic–N. The greater removal of phosphorous was because aluminum sulfate precipitateda large portion of the soluble phosphorous. Application of 400 mg PAM/L provided almost the same removal of organic–N but removed significantly less phosphorous (99.6 vs. 88.9%).

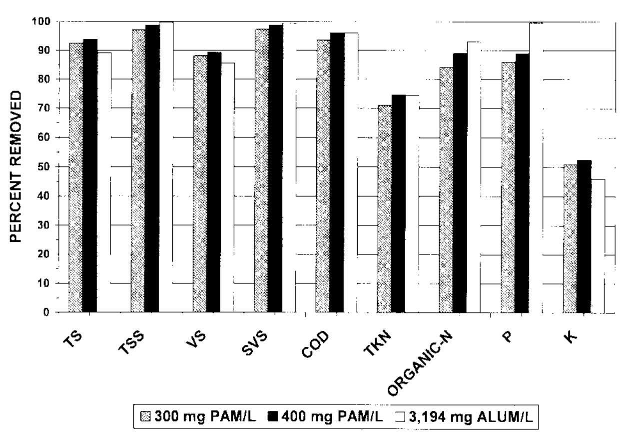

Figure 5. Removal of total solids, COD, and major plant nutrients from flushed dairy manure using a two–stage system composed of mechanical separation followed by gravity settling with a cationic polymer (PAM) or aluminum sulfate (alum).

Discussion and Implications

Comparison of Stationary Inclined Screen Results with Data from the Literature

The results obtained for the AgPro® inclined screen separator at Sunny Day Farm are compared with three reports found in the literature in table 8. The separator evaluated by Fulhage and Hoehne (1998) was the same type used in the current study. The AgPro® separator moves the solids from a channel up the inclined screen using elevator–type paddles. The data presented by Zhang and Westerman (1997) and Graves et al. (1971) were for inclined screens that were loaded with manure from the top of the screen.

The quantity of solids and plant nutrients removed by the AgPro® separator in the current study were substantially greater than reported by Fulhage and Hoehne (1998) at the University of Missouri Dairy Farm. The differences in separator performance are attributed to the following

Table 8. Comparison of solid and nutrient removal efficiencies of the inclined screen separator used in the current study with data presented in the literature.

Quantity	Current Study	Fulhage and Hoehne (1998)	Zhang and Westerman (1997)	Graves et al. (1971)
Screen size (mm)	1.5	1.5	1.68	0.51
Influent TS (%)	3.83	NR[a]	4.6	NR
TS removed (%)	60.9	45.5	49.0	55 – 74
VS removed (%)	62.8	50.1	NR	57 – 75
TKN removed (%)	49.2	17.1	NR	NR
Org.–N removed (%)	52.2	19.0	NR	33 – 52
NH_4^+–N removed (%)	45.7	8.3	NR	18 – 33
TP removed (%)	53.1	11.0	NR	NR
TK removed (%)	50.8	9.9	NR	NR
COD removed (%)	66.5	NR	NR	41 – 68
Separated solids TS (%)	20.3	23.1	NR	NR
kg solids/cow/day	20.9	14	NR	NR
kg solids/1,000 kg live–weight/day[b]	51	23	NR	NR

[a] NR = not reported.
[b] Computed assuming Jersey cows have an average mass of 408.6 kg and Holsteins have an average mass of 612.9 kg.

management differences between Sunny Day Farm and the University of Missouri Dairy Farm: (1) an unusually large amount of organic bedding was used in the freestalls at Sunny Day Farm, and (2) fresh water was used to flush the alleys at Sunny Day farm whereas recycled lagoon water was used for flushing at the University of Missouri Dairy.

The large solid particles associated with organic bedding and wasted feed increased the TS concentration of the flushed manure and was readily removed by the separator. The amount of organic bedding used in a typical freestall barn is on the order of 0.04 m^3/stall/week for Jersey cows (Bickert et al., 1995). It was estimated that 0.5 m^3 of organic bedding was used per stall per week on the cooperator's farm. Therefore, the bedding used on this farm was 12 times the expected value. It is also believed that the large quantity of bedding in the flushed manure helped to trap a fraction of the smaller manure particles that would normally pass through the 1.5–mm screen. The bedding particles would also be expected to absorb a large amount of moisture and soluble plant nutrients, such as NH_4^+–N and K_2O, and accentuate the removal of these nutrients.

In any type of recycle flush system the solids and plant nutrients in the lagoon supernatant will be recycled through the barn and will be included in the measured values of all constituent concentrations (i.e. TS, VS, TKN, etc). In addition, if the lagoon were overloaded, as was the case at the University of Missouri Dairy, the concentration of all manure constituents would be expected to be elevated. None of the solids and nutrients in the recycled supernatant can be removed by an inclined screen separator.

Comparison of the On–Farm Liquid–Solid Separation System with Single– and Two–Stage Separation

The results of the gravity settling experiments indicated that the best liquid–solid separation techniques were: gravity settling of flushed manure for 60 min after application of 300 mg PAM/L (a single stage process), mechanical screening followed by 60 min of settling with 300 mg PAM/L, and mechanical screening followed by 60 min of settling following the application of 3,194 mg alum/L. The amount of solids and major plant nutrients removed by these three separation processes are compared with the results for the on–farm separation system (screening followed by settling) in figure 6.

The data indicate that gravity settling for 60 min following the application of 300 mg PAM/L, a single stage process, removed 6.1% more TS, 7.4% more VS, 11.7% more organic–N, and 1.9% more total P than the two–stage on–farm system. The on–farm separation system removed 44.3% more K than settling with 300 mg PAM/L as a result of the incline screen separator. The greater removal of TKN was because more ammonium–N was removed by screening than by settling. The main advantage of gravity settling with a flocculent over a combination of mechanical separation followed by gravity settling without a flocculent is that the installation, energy, and maintenance costs associated with the mechanical separator can be avoided. However, if maximum removal of TS, VS, N, or P were the primary goal then a two–stage separation process that combines a mechanical separator followed by chemically enhanced gravity settling would be desirable. Enhancing the on–farm separation system by settling separator effluent with 300 mg

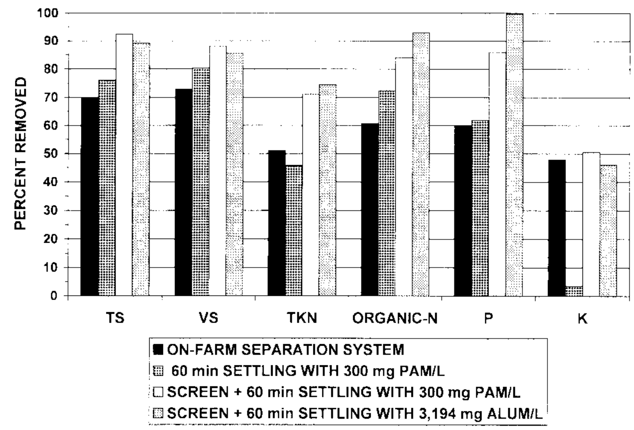

Figure 6. Comparison of the treatment provided by the on–farm separation system (screening followed by settling) with flocculation and settling of flushed dairy manure with 300 mg PAM/L, and two–stage separation that includes flocculation.

PAM/L removed 22.4% more TS, 15.2% more VS, 20.2% more TKN, and 26.1% more total P than the current system. If 3,194 mg alum/L is used to enhance gravity settling then slightly less TS and VS was removed as compared to flocculation with PAM, but 23.5% more TKN, and almost all of the total P was removed as compared to the on–farm system.

All four of the separation systems defined in figure 6 provided a significant removal of solids and plant nutrients. Large removals of VS and TS would greatly reduce the required treatment volume for an anaerobic lagoon, and the rate of sludge build–up (ASAE, 1998). Removing a large portion of the VS would make lagoon design at lower loading rates more economical and would reduce the potential for strong odor. Large reductions in P and N in the liquid fraction of the manure would allow for better management of P. The enhanced removal of N and P would make it easier to manage land application of the lagoon effluent based on crop N or P requirements since irrigation of the effluent onto cropland adjacent to the dairy would be more feasible in many cases. All of the removed P is concentrated in the separated solids. However, the higher TS content and lower volume of the separated solids would be more economical than liquid manure to transport to remote crop, pasture, or forage land that could utilize the organic–N and P. Separated dairy solids could be composted if additional biomass is added to reduce the moisture content and improve the carbon–nitrogen ratio. The amount of nutrient removal that is needed will depend on how much land application area is available close to the dairy farm and the market opportunities for using the separated solids for compost.

The solids and nutrient removal provided by screening followed by 60 min of settling after adding 300 mg PAM/L or 3,194 mg aluminum sulfate/L was very close to or exceed the treatment provided by the complete on–farm treatment system as described in table 2. For example, the complete on–farm system removed 95.6% of the VS from the lagoon liquid whereas screening combined with chemically enhanced settling removed 85 to 88% of the VS. The effluent could be recycled through the flush system with very little additional treatment. If additional treatment for ammonium–N is desired then aerobic processes such as a trickling filter, aerobic lagoon, or aerated tank could be used.

Summary and Conclusions

The manure handling and treatment system at the Sunny Day farm is composed of the following: fresh water flush of the freestall barn, mechanical separation using an inclined stationary screen separator (1.5–mm screen openings), a two–chambered settling basin, and an anaerobic lagoon. Samples were collected and analyzed to characterize the removal of total (TS) and volatile solids (VS), nitrogen, phosphorous, potassium, copper, and zinc by each treatment step and the complete system. Large samples of the flushed manure and the effluent from the inclined screen were transported to a laboratory and settling experiments were carried out to determine the effectiveness of gravity settling of unscreened and screened dairy manure with and without addition of a cationic polyacrylamide polymer (PAM) and liquid aluminum sulfate ($AL_2(SO_4)_3$ 12 H_2O). In addition to the major plant nutrients, TS, and VS, these samples were also analyzed to determine the removal of the suspended total (TSS) and volatile solids (SVS), and the chemical oxygen demand (COD). The most important observations are summarized below.

- The inclined stationary screen separator removed 60.9% of the total solids, 62.8% of the volatile solids, 66.5% of the chemical oxygen demand, 49.2% of the TKN, 52.2% of the organic–N, 53.1% of the total phosphorous, 50.8% of the total potassium, 50.0% of the zinc, and none of the copper from dairy manure with a solids content of 3.83%.
- The combination of the inclined screen and the settling basin removed 70.0% of the TS, 72.9% of the VS, 50.9% of the TKN, 60.6% of the organic–N, 59.9% of the total P, 63% of the Zn, and 39% of the Cu. The gravity–settling basin did not remove additional potassium.
- The effluent from the settling basin flowed by gravity into a lagoon. Comparison of the constituent concentrations of the flushed manure and the lagoon supernatant indicated that the complete manure treatment system removed 93.0% of the TS, 95.6% of the VS, 74.0% of the TKN, 91.1% of the organic–N, 86.1% of the total P, 60.2% of the total K, 92.9% of the Zn, and 90.9% of the Cu.
- Settling of flushed manure (TS = 41.8 g/L) for 60 min without the addition of a polymer or alum removed 60.8% of the TS, 63.8% of the VS, 63.6% of the COD, 24.0% of the TKN, 43.3% of the organic–N, 37.7% of the total P, only 0.4% of the total K, 40.0% of the Zn, and 33.3% of the Cu. Most of the solids and nutrients were removed in the first 30 min of settling.
- Settling of screened manure (TS = 12.0 g/L) for 30 min removed only 15.6% of the TS. Increasing the settling time to 60 min removed 18.1% of the TS.
- Addition of 250 to 400 mg PAM/L to screened and unscreened dairy significantly increased the removal of suspended total and volatile solids, COD, organic–N, total P, Cu and Zn by settling. The minimum amount of PAM that can be recommended for flocculation of dairy manure is 250 mg/L. The optimum amount of PAM to add was 300 mg/L for screened and unscreened manure.
- Settling of unscreened flushed dairy manure after mixing it with 300 mg PAM/L removed 76.1% of the TS, 92.6% of the TSS, 80.3% of the VS, 80.8% of the COD, 45.7% of the TKN, 72.3% of the organic–N, 61.8% of the total P, 3.5% of the K, 82.0% of the Zn, and 82.8% of the Cu.
- A two–stage separation process that combines an inclined screen followed by settling of the separator effluent for 60 min after mixing with 300 mg PAM/L removed 92.4% of the TS, 97.1% of the TSS, 88.1% of the VS, 93.5% of the COD, 71.1% of the TKN, 84.1% of the organic–N, 86.0% of the total P, 50.5% of the total K, 92.0% of the Zn, and 74.4% of the Cu.
- Settling of unscreened flushed dairy manure containing 41.8 g TS/L for 60 min with the addition of 3,194 mg alum/L was not very effective. Many of the precipitated solids floated and removals were too difficult to quantify.
- Alum was very effective for enhancing the settling of the effluent from the inclined screen separator. The defined two–stage separation process that substituted 3,194 mg alum/L for PAM removed 89.1% of the TS, 99.7% of the TSS, 85.6% of the VS, 99.4% of the SVS, 96.0% of the COD, 74.4% of the TKN, 93.0% of the organic–N, 99.6% of the total P, and 45.8% of the total K.
- Settling unscreened flushed dairy manure for 60 min following the application of 300 mg PAM/L, a single stage process, provided better treatment for TS, VS, organic–N, and total P than did the on–farm system that included mechanical separation followed by a gravity settling basin. Therefore, the use of a flocculent could provide a high level of primary treatment and eliminate the initial, energy, and maintenance costs associated with mechanical separation.
- The chemically enhanced two–stage liquid–solid separation system (mechanical screening followed by settling with 300 mg PAM/L or 3,194 mg alum/L) provided similar TS, VS, N and P removals as the liquid–solid separation and lagoon system installed on the farm. Therefore, the effluent from this system may be stored in a tank and recycled through the flush system without concern about significant odor.

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