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Field Evaluation of a Two-Stage Liquid-Solid Separation System at a California Dairy

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Abstract. *A two-stage mechanical separation system was installed on a large dairy farm near Tulare, California to reduce loading on the settling ponds and lagoon and to produce solids to be used as freestall bedding. The system included two inclined screens operated in series. The first separator used a 0.508 mm (0.020 in) screen followed by a low-pressure screw press to provide additional dewatering and a perforated stacking conveyor to stack the residual solids. The second separator was fitted with a 0.254 mm (0.010 in) screen and additional drying occurred on a perforated stacking conveyor. The two-stage system removed 59.7% of the total solids (TS), 65.7% of the volatile solids (VS), but only 22.8% to 34.8% of important major and minor plant nutrients (N, P, Ca, Mg, S). Removal by the first separator accounted for most of the solids and plant nutrient removal. The effluent from the separation system was still rich in valuable plant nutrients and 68.8% of the solids were VS. Therefore, the methane producing potential of the system effluent was still significant. The residue from the first separator had a C:N of 26.6 and would be a valuable substrate for composting. The residue from the second separator had a lower C:N (20.5), but contained a higher concentration of plant nutrients. Residue from the first separator was dried in open lots during the dry season prior to being stored in windrows. The moisture content was reduced from 77.3% to 9.2% prior to use as freestall bedding. Both N and C were lost from the residue during drying and storage.*

Keywords. Liquid-solid separation, manure treatment, manure management, dairy

Introduction

California is the largest milk producing state in the United States producing 21.6% of the nations milk supply. In August 2008, the milking herd in California numbered 1,843,000 head, with an annual milk production of 1,542 million kilograms (3,400 mil lb, NASS, 2008).

Over the last several years, many California dairy producers have converted their animal housing from open lots to flushed freestall barns and flushed milking centers to gain efficiency and to improve their ability to manage the large amount of manure produced by the animals (≈66.2 L/cow-day or 17.5 gal/ cow-/day).

An integral part of this conversion of their animal housing facilities from open lots to freestall barns has been the addition of mechanical liquid-solid separation to provide primary treatment of flushed dairy manure. One of the most popular types of mechanical separator is the inclined static screen. However, many of the first inclined screen separators used large screen sizes ranging from 1.5 to 1.68 mm (0.059 to 0.066 in). Data collected from dairies located in the Eastern and Midwestern regions of the US (e.g. Chastain *et al*., 2001a; Fulhage and Hoehne, 1998; and Zhang and Westerman, 1997) indicated that 46% to 61% of the total solids (TS) in flushed dairy manure could be removed using an inclined screen. However, field experience in California indicated that such screen sizes could only remove on the order of 10% to 20% of the TS. The reason for the discrepancy was the vast differences in the amount and type of bedding used, and the lower TS content of flushed manure on California dairy farms.

In response to these field experiences, several companies have developed improved mechanical separators that use screen sizes ranging from 0.254 to 0.889 mm (0.010 to 0.035 in) to provide higher solids removal for dilute dairy manure.

A two-stage mechanical separation system was developed by US Farm Systems and was installed on the Bos Dairy Farm near Tulare, California. The system included two mechanical separators operated in series. Dried residue (separated solids) from the first machine was used for freestall bedding. The effluent from the second separator received additional treatment in a series of settling ponds and a treatment lagoon.

The objectives of this study were to: (1) evaluate the performance of the two-stage liquid-solid separation system, (2) determine the composition of the system effluent, (3) determine the composition of the separated solids from both stages, and (4) determine the composition of the dried separated solids used for freestall bedding.

Methods

The Bos Dairy farm, located near Tulare CA, began milking about 1750 cows in 1982. In 2001 construction of a new freestall complex and milking center was begun. The waste treatment and storage system included a reception, or processing pit, an inclined screen separator, settling ponds, and a treatment lagoon. Supernatant from the final treatment lagoon was the primary source of flush water for the freestall barns. By 2002, the dairy had expanded to 3450 cows and by late 2006 the herd had increased to 3600 cows producing an average of 31.7 kg (69.9 lb) of milk per cow per day.

Several modifications were made to the manure treatment system as the dairy was expanded. At the time of this study, the manure treatment system consists of a processing pit that was used to collect flushed manure from the freestall barns and milking center, two mechanical separators operating in series, and a series of four settling ponds and a final treatment lagoon (Figure 1).

Manure from the dairy facilities was flushed eight times a day and was collected in a processing pit. Supernatant from the processing pit was used for alley flushing. Water was resupplied to the processing pit as needed from the treatment lagoon.

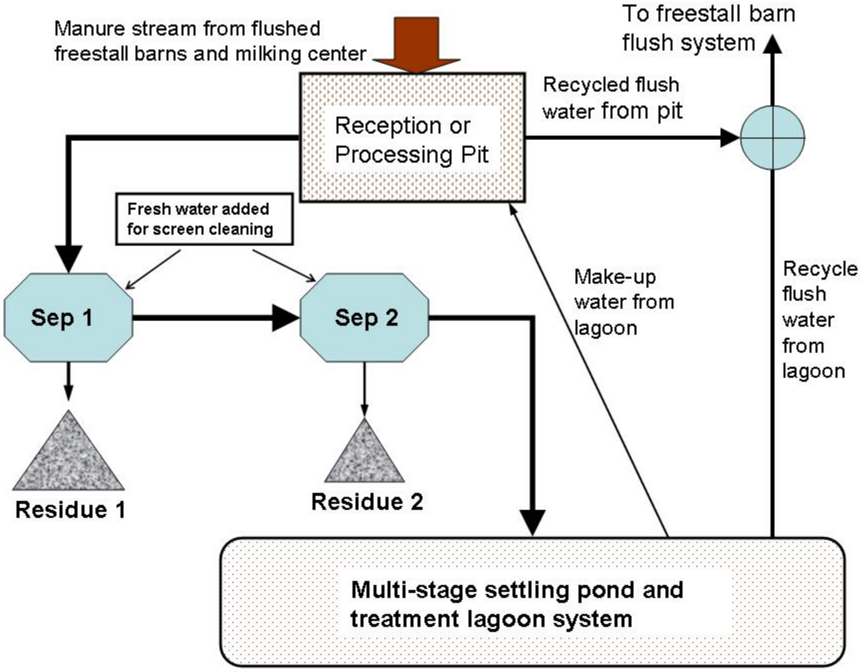

Figure 1. Flow diagram for the manure treatment system at the Bos Dairy.

When the liquid level exceeded the set point the pit contents were agitated and pumped to the first separator. The first separator had an inclined bar screen with a mean opening size of 0.508 mm (0.020 in). The separated solids slid down the screen and were collected in a trough where a low-pressure screw press provided additional dewatering and conveyed the solids to an inclined perforated stacking conveyor. The separated solids, or residue, were stored temporarily on a concrete pad.

Periodically, the solids from the first separator were spread in layers in an open lot between the freestall barns. The solids were disked periodically to enhance drying and exposure to solar radiation. Once the solids were dry they were stored in large covered windrows. The dried separated solids were recycled through the dairy facility as freestall bedding.

The effluent from the first separator was pumped to a second inclined screen separator with a screen size of 0.254 mm (0.010 in). The wet solids were collected on another inclined screen stacking conveyor and were stored on a stacking pad. The conveyor provided additional drying of the solids so that they were of stackable moisture content. The separated solids from the second separator were land applied on near-by cropland.

Both of the inclined screen separators utilized fresh water sprays to keep fine particles from drying and plugging the screens. In addition, the screens were cleaned several times each week with a high-pressure washer.

Two of the settling ponds were operated in series and provided storage for settable solids that remained after mechanical liquid-solid separation. Supernatant from the settling ponds flowed into the final treatment lagoon. Periodically, the effluent waste stream was routed to another pair of settling ponds while solids were allowed to dry. The dewatered solids were then removed and land applied. The two cleaned settling ponds were again brought on-line while the other two were cleaned. The separators were added to the system to reduce the costs of solids management in the four settling ponds.

The final treatment lagoon was originally designed based on anaerobic treatment principles. Surface aerators were added to this pond to provide enough aeration to control odor by maintaining a facultative layer.

Mass Balance

After a site visit to the Bos Farm and preliminary analysis of the available data, it was determined that evaluation of system performance would not be as straight-forward as anticipated. A couple of components of the mass balance were either very difficult or impossible to measure without introducing systematic bias. In particular, the volume of water added by the sprayers used to maintain the screens could not be measured, and it was not possible to collect unbiased, representative samples of the flow from the processing pit to the first separator. Therefore, an analysis method was developed to describe system performance using measurable quantities before additional data were collected.

The mass flow of solids (TS, VS) and plant nutrients (*e.g*. N, P, K,) through the two-stage separation process is described by the flow diagram given in Figure 2.

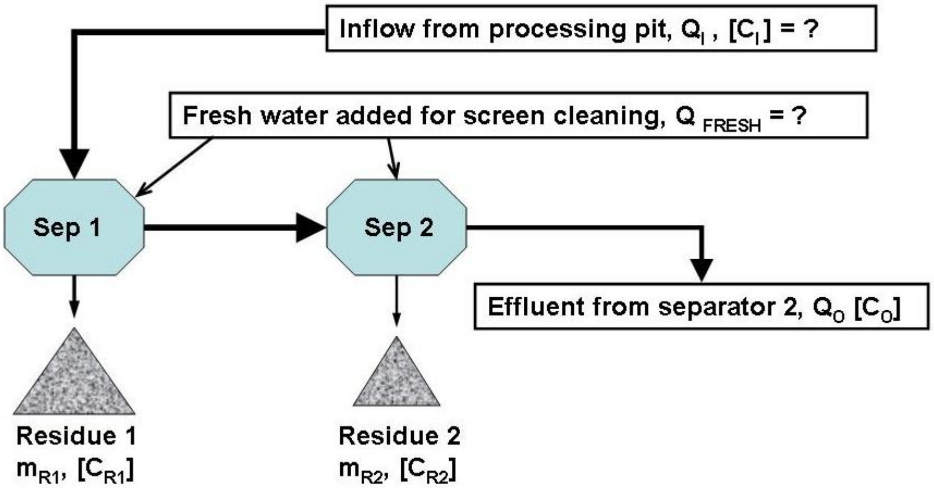

Figure 2. Flow diagram for the two-stage mechanical separation system at Bos Dairy.

The total mass of solids or plant nutrients fed to the system in a day can be calculated as:

$$Q_I [C_I] = m_{R1} [C_{R1}] + m_{R2} [C_{R2}] + Q_O [C_O]. \tag{1}$$

Where,

Q_I = flow into separator 1 (measurement not available),
$[C_I]$ = concentration of a constituent in separator influent (measurement not available)
m_{R1} = mass of the residue removed by separator 1 (kg / day),
$[C_{R1}]$ = concentration of a constituent in residue removed by separator 1 (kg / wet kg),
m_{R2} = mass of the residue removed by separator 2 (kg/day),
$[C_{R2}]$ = concentration of a constituent in residue removed by separator 1 (kg / wet kg),
Q_O = flow from separator 2 (L/day), and
$[C_O]$ = concentration of a constituent in effluent from separator 2, (kg / L).

Based on the information obtained during a site visit, it was determined that the only components of the mass balance that could be measured accurately were the mass of constituents removed by separator 1 (m_{R1} $[C_{R1}]$), the mass of constituents removed by separator 2 (m_{R2} $[C_{R2}]$), and the mass of constituents remaining in the system effluent (Q_O $[C_O]$). The total mass of any constituent that was fed to the system (Q_I $[C_I]$) can be calculated using equation 1.

Mass removal efficiencies were calculated for each of the separators and for the total system. The mass removal efficiency for the entire separation system (MRE_T) was calculated as:

$$MRE_T = 100 (m_{R1} [C_{R1}] + m_{R2} [C_{R2}]) / (m_{R1} [C_{R1}] + m_{R2} [C_{R2}] + Q_O [C_O]). \quad (2)$$

The mass removed by each separator was calculated using the following equations:

$$MRE_{S1} = 100\, m_{R1} [C_{R1}] / (m_{R1} [C_{R1}] + m_{R2} [C_{R2}] + Q_O [C_O]), \text{ and} \quad (3)$$

$$MRE_{S2} = 100\, m_{R2} [C_{R2}] / (m_{R1} [C_{R1}] + m_{R2} [C_{R2}] + Q_O [C_O]). \quad (4)$$

Data Collected to Evaluate the Two-Stage Separation System

Samples and measurements were taken to quantify the variables shown on the right side of the mass balance given by equation 1.

The total effluent volume, Q_O, was measured on two days in 2007 (Feb. 8th and 9th). Daily flow measurements were obtained using a cumulating magnetic flow meter placed in the effluent pipe at a distance that was over 20 pipe diameters from the second separator. The daily flow value was obtained by averaging these two measurements.

The residue masses, m_{R1} and m_{R2}, were measured for each separator on February 9, 2007 and April 8, 2008. All residues beneath the stacking conveyors from the previous day were removed. After the separation system was operated for 24 hours, all of the solids in each of the residue piles was loaded into a truck with a loader and the weight of the solids was determine using a certified truck scale. The amount of residue produced by each of the separators per day was the average of the weights obtained on these two days.

Liquid samples were collected from the end of the pipe using a long-handled sampling cup on February 7, 2008. The sampling period consisted of a 1-hour interval during system operation. The multiple samples were combined in a bucket and a well-mixed sample was collected and transported to the DELLAVALLE Laboratory (Fresno, CA) for analysis. The sample was analyzed to determine the concentrations of the following constituents: total solids (TS), fixed solids (FS), volatile solids (VS = TS - FS), total nitrogen (Total-N), ammonium-N, nitrate-N, organic-N (organic-N = Total-N - Ammonium-N - Nitrate-N), total phosphorous expressed as P_2O_5, total potassium expressed as K_2O, and moisture content.

Effluent samples were collected again on April 8, 2008 with a modified procedure. Several samples were collected from the end of the effluent pipe throughout the day. About 4L of effluent sample were placed on ice, transported to US Farm Systems headquarters, frozen, and shipped by overnight courier to Clemson University. After thawing, all samples were combined in a single plastic container. Well-mixed aliquots were drawn from this composite sample for analysis. The sample was analyzed for the same constituents previously mentioned as well as calcium, magnesium, sulfur, and sodium (Na) by the Clemson University Agricultural Services Laboratory.

Samples of the separator residues were collected as the material was being loaded into the truck to be moved or weighed. Samples were collected during the beginning, middle, and end of the loading operation. These smaller samples were mixed and the final composite samples were analyzed to determine composition.

Residue samples were collected on February 7th and 8th in 2007 and on April 8, 2008. The samples collected in February were analyzed by DELLAVALLE Laboratory (Fresno, CA) to determine the concentrations of the following constituents: moisture, TS, FS, VS, Total-N, ammonium-N, P_2O_5, K_2O, Na, and carbon (C).

The residue samples collected in April were stored on ice, frozen, and then shipped by overnight courier to Clemson University. After thawing, samples were analyzed by the Clemson University Agricultural Services Laboratory. The Clemson laboratory provided analyses for the same constituents as the commercial laboratory with the addition of calcium, magnesium, and sulfur.

Other Data Collected

Other information that was gathered either by interviewing the farm owner or by sampling were: the amount of separated solids used for freestall bedding per week, composition of the stall bedding, amount of feed dry matter fed to the cows per day, total feed wastage, average animal weight, seasonality of barn and corral use, and flushing schedule.

Several grab samples of the separator residue used for freestall bedding were collected after drying and windrow storage. The grab samples were mixed and a sample was analyzed by the Clemson University Agricultural Services Laboratory for the previously described constituents.

Results

Results for the Two-Stage Separation System

The composition of the residue collected beneath the two separators is given in Tables 1 and 2. On the average, the residue produced by the first separator (0.508 mm) was dryer, higher in carbon, but lower in all major and minor plant nutrients than the residue produced by the second separator. The fact that the residue from the separator with the finer screen (0.254 mm) had more total-N (+22%) , P_2O_5 (+43%), K_2O (+9%), calcium (+39%), magnesium (+33%), and sulfur (+36%) indicated that these key plant nutrients were more associated with the small particles not captured by the screen or were contained in the moisture in the residue.

The high C:N of the residue from separator 2 also indicated that it had the potential to be a net immobilizer of soluble nitrogen in the soil. That is, the break down of the available C in the residue will compete with plants for available nitrogen. It would be best to compost this material prior to land application or to restrict application to crops with a low demand for nitrogen.

The mass of residue that was produced by the separators on two days is provided in Table 3. On the average, the two separators removed 26,689 kg (58,840 lb) of dry matter per day and 84% of the dry matter was removed by the first separator.

Table 1. Concentrations of solids, plant nutrients, sodium, and carbon in the residue from the first separator (screen opening = 0.508 mm).

	Rep 1[a] 2/7/2007	Rep 2[a] 2/8/2007	Rep 3[b] 4/8/2008	Mean	STD	$[C_{R1}]$ Mean
Moisture (%)	76.27%	76.09%	79.40%	77.25%		77.25%
Fraction DM	0.2373	0.2391	0.2060	0.2275	0.0186	0.2275
	------- % dry basis -------			--- % dry basis ---		% wet basis
FS (ash)	6.31	11.59	12.50	10.13	3.342	2.305
VS	93.69	88.41	87.50	89.87	3.342	20.442
Total-N	1.73	1.97	2.11	1.94	0.192	0.441
Ammonium-N	0.11	0.12	0.15	0.12	0.023	0.028
P_2O_5	0.38	0.44	0.55	0.46	0.086	0.104
K_2O_5	0.44	0.58	0.69	0.57	0.125	0.130
Calcium	NM	NM	1.30	1.30		0.296
Magnesium	NM	NM	0.39	0.39		0.089
Sulfur	NM	NM	0.28	0.28		0.064
Na	0.09	0.15	0.14	0.13	0.032	0.029
C	54.48	51.40	46.64	50.84	3.949	11.56
C:N	31.49	26.09	22.10	26. 6	4.711	

[a] Sample analysis by DELLAVALLE Laboratory, Inc., Fresno, CA.

[b] Sample analysis by Clemson University Agricultural Services Laboratory and Agricultural and Biological Engineering Department, Clemson, SC.

[c] NM = not measured

Table 2. Concentrations of solids, plant nutrients, sodium, and carbon in the residue from the second separator (screen opening = 0.254 mm).

	Rep 1[a] 2/7/2007	Rep 2[a] 2/8/2007	Rep 3[b] 4/8/2008	Mean	STD	[C_{R2}] Mean
Moisture (%)	78.53%	79.63%	83.66%	80.61%		80.61%
Fraction DM	0.2147	0.2037	0.1634	0.1939	0.0270	0.1939
	------- % dry basis -------			--- % dry basis ---		% wet basis
FS (ash)	13.53	14.27	22.10	16.63	4.749	3.226
VS	86.47	85.73	77.90	83.37	4.749	16.168
Total-N	2.21	2.30	2.60	2.37	0.204	0.460
Ammonium-N	0.135	0.138	0.25	0.17	0.066	0.034
P_2O_5	0.58	0.65	0.75	0.66	0.085	0.128
K_2O_5	0.52	0.52	0.81	0.62	0.167	0.120
Calcium	NM	NM	1.81	1.81		0.351
Magnesium	NM	NM	0.52	0.52		0.101
Sulfur	NM	NM	0.38	0.38		0.074
Na	0.10	0.11	0.17	0.13	0.036	0.024
C	50.28	49.84	44.00	48.04	3.505	9.316
C:N	22.75	21.67	16.92	20. 5	3.100	

[a] Sample analysis by DELLAVALLE Laboratory, Inc., Fresno, CA.

[b] Sample analysis by Clemson University Agricultural Services Laboratory and Agricultural and Biological Engineering Department, Clemson, SC.

[c] NM = not measured

Table 3. Mass of residue removed by the two separators on two different days.

	Separator 1	Separator 2
Replication 1 (Feb. 2007)		
Mass of solids removed per day	111, 275 kg (245,320 lb)	26,027 kg (57,380 lb)
Percent dry matter	23.82%	20.92%
Dry matter removed per day	26506 kg (58,435 lb)	5445 kg (12,004 lb)
Replication 2 (April 2008)		
Mass of solids removed per day	89,675 kg (197,700 lb)	18,080 kg (39,860 lb)
Percent dry matter	20.60%	16.34%
Dry matter removed per day	18473 kg (40,726 lb)	2954 kg (6513 lb)
Mean		
Mass of solids removed per day	22,489 kg (49,581 lb)	4200 kg (9259 lb)
Percent dry matter	22.75% [a]	19.39% [b]
Dry matter removed per day	98,869 kg (217,969 lb) [c]	21,655 kg (47,741 lb) [c]

[a] Mean from Table 1.

[b] Mean from Table 2.

[c] Calculated from mean dry matter weight and percent dry matter shown.

The concentration data for the effluent from the second separator are given in Table 4. The results from both days were well within the expected day-to-day variation on a commercial farm. The mean of these two data sets provided a measure of the contents for major plant nutrients and solids. However, minor plant nutrient and sodium data were only available for the samples collected in April 2008.

Table 4. Concentrations of solids, plant nutrients, and sodium in the effluent from the second separator.

	2/7/2007	4/8/2008	[C_O]	
	Rep 1[a]	Rep 2[b]	Mean	
	(mg/L)	(mg/L)	(mg/L)	(lb/1000 gal)
TS (mg/L)	10300	12006	11,153	93.08
FS (mg/L)	3020	3941	3481	29.05
VS (mg/L)	7280	8065	7672	64.03
Total-N	810	932.3	871	7.27
Ammonium-N	15.3	460.1	238	1.98
Organic-N	792.2	460.1	626	5.23
Nitrate-N	2.5	12.0	7.2	0.06
P_2O_5	202.0	288.8	245	2.05
K_2O_5	1016.8	1120.4	1069	8.92
Calcium	NM [c]	427.8	428	3.57
Magnesium	NM	210.9	211	1.76
Sulfur	NM	93.5	93.5	0.78
Na	NM	261.2	261.2	2.18
Moisture (%)	98.97%	98.78%	98.88%	

[a] Sample analysis by DELLAVALLE Laboratory, Inc., Fresno, CA.

[b] Sample analysis by Clemson University Agricultural Services Laboratory and Agricultural and Biological Engineering Department, Clemson, SC.

[c] NM = not measured

Nitrogen was the predominate major plant nutrient in the effluent followed by K_2O and then P_2O_5. Therefore, the separator effluent would be a good organic fertilizer for many crops.

The daily effluent volume ranged from 1,382,655 to 1,841,976 L/day (365,260 to 486,600 gal/day). The average of 1,612,315 L/day (425,930 gal/day) was used in the mass balance calculations (Table 5).

Table 5. Effluent volume and dry matter remaining in the liquid fraction.

	Effluent Volume, Q_O
Replication 1 (Feb. 8, 2007)	
Effluent volume per day	1,382,655 L (365,260 gal)
Solids content	11. 16 g TS/L (0.0931 lb TS/gal)
Dry matter	15,417 kg/day (33,988 lb/day)
Replication 2 (Feb. 9, 2008)	
Effluent volume per day	1,841,976 L (486,600 gal)
Solids content	10.30 g TS/L (0.0859 lb TS/gal)
Dry matter	18,960 kg/day (41,799 lb/day)
Mean	
Effluent volume per day	1,612,315 L (425,930 gal)
Solids content	11.15 g TS/L (0.0931 lb TS/gal) [a]
Dry matter	17,977 kg/day (39,633 lb/day)

[a] Mean from Table 4.

The mean residue masses, effluent volume, and the corresponding constituent concentrations were used to compute the components of the mass balance as defined by equation 1. Based on these values the mass removal efficiencies for the two-stage system as well as each separator were calculated (equations 2, 3 and 4). The results are given in Table 6.

Table 6. Mass of solids and plant nutrients fed to and removed by the two-stage separation system.

	S1 $m_1[C_{R1}]$ kg/day (lb/day)	S2 $m_2[C_{R2}]$ kg/day (lb/day)	Effluent $Q_O[C_O]$ kg/day (lb/day)	INPUT (S1+S2+Eff) kg/day (lb/day)	S1 MRE_{S1} (%)	S2 MRE_{S2} (%)	(S1 + S2) MRE_T (%)
TS (dm)	22,489 (49,581)	4200 (9259)	17,982 (39,644)	44,671 (98,484)	50.3	9.4	59.7
FS (ash)	2279 (5024)	699 (1540)	5612 (12,372)	8590 (18,936)	26.5	8.1	34.7
VS	20,211 (44,557)	3501 (7719)	12,370 (27,272)	36,082 (79,548)	56.0	9.7	65.7
Total-N	435.4 (960)	99.3 (219)	1404.3 (3096)	1939 (4275)	22.5	5.1	27.6
Ammonium - N	28.1 (62)	7.3 (16)	383.3 (845)	418.7 (923)	6.7	1.7	8.4
P_2O_5	102.5 (226)	27.7 (61)	395.5 (872)	525.8 (1159)	19.5	5.3	24.8
K_2O_5	128.4 (283)	25.8 (57)	1722.7 (3798)	1876.9 (4138)	6.8	1.4	8.2
Na	28.5 (62.8)	5.3 (11.7)	421.2 (928.5)	455.0 (1003)	6.3	1.2	7.4
C	11,433 (25,206)	2018 (4448)	NM	---	---	---	---
Calcium	292.6 (645)	76.2 (168)	689.9 (1521)	1058.7 (2334)	27.6	7.2	34.8
Magnesium	87.5 (193)	21.8 (48)	340.2 (750)	449.5 (991)	19.5	4.9	24.4
Sulfur	63.0 (139)	15.9 (35)	150.6 (332)	229.5 (506)	27.4	6.9	34.4

The two-stage separation system removed 59.7% of the dry matter from the manure stream and 65.7% of the volatile solids (VS). The majority of the solids removal was accomplished by the first separator with the second screen providing only 9.4% removal of TS and 9.7% removal of VS.

The total system was able to remove 27.6% of the total-N, 24.8% of the phosphorous, and 24.4% to 34.8% of the magnesium, sulfur, and calcium. Only small amounts of the soluble constituents (ammonium-N, potassium, and sodium) were removed by screening as expected. The small amounts of soluble constituents removed were contained in the moisture of the residues. Theses results indicate that two thirds to three quarters of the nitrogen, phosphorous, calcium, magnesium, and sulfur was contained in the particles that passed through a 0.254 mm (0.010 in) screen or in the liquid. This agrees with many previous studies that demonstrated that plant nutrients in dairy manure are mostly associated with fine particles (< 0.254 mm) or are contained in solution (*e.g.* Meyer *et al.*, 2007; Wright, 2005; Zhang and Westerman, 1997).

The ratio of VS to TS (VS/TS) of the manure fed to the separation system was calculated from the mass balance results and found to be 0.81. A previous study on a South Carolina dairy provided a VS/TS value for flushed dairy manure of 0.84 (Chastain *et al.*, 2001a). The VS/TS values from manure sampled at a California dairy and a South Carolina dairy agreed within 4%.

The separation system effluent had a VS/TS of 0.688. Although the two-stage separation system reduced a significant amount of VS the effluent still had a VS/TS ratio that was not significantly different from swine manure from a pit-recharge building (VS/TS = 0.687) in South Carolina (Chastain *et al.*, 2001b). Therefore the system effluent would still have a significant potential for methane production in an anaerobic lagoon or digester.

During the time period that this study was conducted the milking herd size averaged 3600 cows. The average weight per cow was 626 kg (1380 lb). Therefore, the average production live weight was 22,536 kg (496,800 lb). The mass balance results are given in Table 7 in terms of mass of constituent per day per 1000 kg (1000 lb) of average production live weight.

The data indicate that 19.82 kg of total solids per 1000 kg of live animal weight were present in the manure stream that was treated by the separation system each day. The volatile solids composed 80.7% of the dry matter.

Table 7. Mass of solids and plant nutrients fed and removed per 1000 kg (1000 lb) of average production live weight.

	Mass IN	Total Mass Removed	Mass Remaining in Liquid
	kg / 1000 kg-day = lb / 1000 lb-day		
TS (dm)	19.82	11.84	7.98
FS (ash)	3.81	1.32	2.49
VS	16.01	10.52	5.49
Total-N	0.861	0.237	0.623
Ammonium - N	0.186	0.016	0.170
P_2O_5	0.233	0.058	0.176
K_2O_5	0.833	0.068	0.765
Na	0.20	0.015	0.187
Calcium	0.4695	0.1635	0.3061
Magnesium	0.1995	0.0486	0.1509
Sulfur	0.1019	0.0350	0.0669

This study was conducted during the cool part of the year when the cows were kept in total confinement. During an interview with the owner it was also determined that during the hot summer months the milking cows are given free access to outside corrals for seven to eight hours each night. Therefore, up to one third of the manure in the freestall barns will not be collected and the loading on the manure treatment system will be reduced. Almost all of the cows take advantage of the outside corral part of this time, but it was difficult to quantify the actual amount of manure that would not be conveyed to the treatment system. The best way to quantify this seasonal difference would be to collect additional data during the hot season.

Composition of Freestall Bedding

The residue from the first separator was treated by spreading it out in layers in the space between the freestall barns. Periodically, the solids were mixed by disking to enhance drying and to promote exposure of the material to solar radiation. The dried material was stored in windrows and was used for freestall bedding.

A well-mixed sample of bedding material was analyzed to determine the solids and plant nutrient composition. The moisture content and the concentrations of solids and plant nutrients are compared with fresh residue from the first separator in Table 8.

The drying process was very effective as indicated by a drop in moisture content from 77.25% to 9.24%. Also, most of the organic constituents became more concentrated, that is the dry matter concentrations increased, as would be expected for a drying process. Therefore, drying conserved most of the plant nutrients and sodium and these nutrients were recycled back to the manure stream by being used as freestall bedding.

The only constituents that were appeared to be lost during the drying process were ammonium-N and carbon. Ammonium-N was reduced by 50% during drying. It is likely that a portion was converted to nitrate-N and was lost from the drying layer or windrow by leaching. However, the predominate loss of ammonium-N was by ammonia volatilization. Carbon was reduced by 23%. It is believed that this fraction of carbon was utilized by microbes and was lost as CO_2 by respiration. Consequently, C:N was reduced by 43% even though the material was not composted. Therefore, the drying process resulted in a loss of N and C from the farm.

Table 8. Comparison of residue from the first separator with the dried solids used for freestall bedding.

	Residue from Separator 1 [a]	Freestall Bedding [b]
Moisture (%)	77.25%	9.24%
Fraction DM	0.2275	0.9076
	% dry basis	% dry basis
FS (ash)	10.13	24.59
VS	89.87	75.41
Total-N	1.94	2.57
Ammonium-N	0.12	0.06
P_2O_5	0.46	0.83
K_2O_5	0.57	2.13
Calcium	1.30	2.09
Magnesium	0.39	0.61
Sulfur	0.28	0.46
Na	0.13	0.20
C	50.84	39.01
C:N	26.6	15.2

[a] Means from Table 1.

[b] Grab sample collected on 4/8/2008.

Based on an interview with the owner it was estimated that about 174,179 kg (384,000 lb) of dried residue from separator 1 was used for freestall bedding per week. The moisture content of the bedding was 9.24%. Therefore the amount of bedding dry matter used was 7.1 kg / 1000 kg (7.1 lb / 1000 lb) per day. The owner also indicated that the cows were fed 22.7 kg (50 lb) of feed dry matter per day and farm records indicated that feed wastage was small at 2%. Therefore, feed wastage did not appear to be a large source of dry matter in the flushed manure. Assuming that the cows produce 14.4 kg of manure dry matter per 1000 kg (14.4 lb/1000 lb) per day gave an expected solids production of 21.5 kg TS/1000 kg-day (21.5 lb TS/1000 lb-day). Mass balance results indicated that 19.82 kg TS / 1000 kg were fed to the separation system per day. Therefore, the solids production estimate based on an assumed value of manure dry matter production was 8.5% greater than observed. Given the uncertainties in the measurements for the mass balance and the manure TS production estimate this level of agreement was considered fortuitous.

Conclusions

1. The two-stage separation system removed 59.7% of the TS, and 65.7% of the VS from flushed dairy manure. However, two thirds to three quarters of the nitrogen, phosphorous, calcium, magnesium, and sulfur remained in the separator effluent. These results agree with other studies that have demonstrated that the majority of the plant nutrients in dairy manure are contained in fine particles (< 0.254 mm) or in the liquid fraction.
2. The majority of the solids and plant nutrients removed by the two-stage system were removed by the first separator.

3. The separation system effluent contained 11,153 mg TS/L (93.08 lb TS/1000 gal) of which 68.8% were volatile solids. Therefore, the separator effluent would still has a significant potential for methane production in an anaerobic lagoon or digester.
4. The residues from both of the separators in the two-stage system were dry enough to store and handle as a solid. The C:N of the residue from the first separator was 26.6 with a moisture content of 77.25%. With a small amount of drying, this material would be an excellent substrate for composting. The C:N of the second residue was 20.5 with a moisture content of 80.6%. This material would also be an excellent material for composting, but additional dry carbon is needed to increase the C:N and reduce the moisture content. The high C:N of the residue from the second separator would cause it to be a net immobilizer of nitrogen if land applied without composting.
5. The residue from the first separator was dried and recycled as freestall bedding. The drying process was found to be effective since the moisture content was decreased from 77.25% to 9.24%. During the drying process 50% of the ammonium-N and 23% of the carbon was lost from the bedding material. Ammonia volatilization and cellular respiration are believed to be the two dominate modes of loss.

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References

Chastain, J.P. 2006. Estimation of sludge accumulation in lagoons. Paper no. 064114. St. Joseph, Mich.: ASABE.

Chastain, J.P., M.B. Vanotti, and M.M. Wingfield. 2001a. Effectiveness of liquid-solid separation for treatment of flushed dairy manure: a case study. *Applied Eng. in Agric*. 17(3): 343-354.

Chastain, J.P., W.D. Lucas, J.E. Albrecht, J.C. Pardue, J. Adams, III, and K.P. Moore. 2001b. Removal of solids and major plant nutrients from swine manure using a screw press separator. *Applied Eng. in Agric*. 17(3): 355-363.

Fulhage, C.D., and J.A. Hoehne. 1998. Performance of a screen separator for flushed dairy manure. In Proceedings of the Fourth International Dairy Housing Conference, ed. J.P. Chastain, pp 130-135. St. Joseph, Mich.: ASABE.

Meyer, D., P.L. Ristow, and M. Lie. 2007. Particle size and nutrient distribution in fresh dairy manure. Applied Engineering in Agriculture 23(1):113-117.

NASS. 2008. Milk Production. Washington, DC: National Agricultural Statistics Service, USDA. Available at http://usda.mannlib.cornell.edu/usda/current/MilkProd/MilkProd-10-17-2008.pdf.

Wright, W.F. 2005. Dairy manure particle distribution, properties, and implications for manure handling and treatment. Paper No. 054105. St. Joseph, Mich.: ASABE.

Zhang, R.H. and P.W. Westerman. 1997. Solid-Liquid Separation of Animal Manure for Odor Control and Nutrient Management. Applied Engineering in Agriculture, vol. 13(5): 657-664.