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Composition and Settling Characteristics of Milking Center Wastewater: A Case Study

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Abstract. Milking center wastes are often included with manure from the animal housing areas for treatment, storage, and land application. On a grazing dairy, milking center wastewater is often handled independent of other manure generated on farm. Very little data are available on the composition and settling characteristics of milking center wastewater.

Large milking center wastewater samples were collected from a storage pit on a grazing dairy farm in South Carolina on two different days. The samples were analyzed to determine the concentrations of the following constituents: TS, VS, TKN, TAN (NH_4^+-N, + NH_3-N), Org-N, NO_3-N, total-P, total-K, Ca, Mg, S, Zn, Cu, Mn, and Na. The large amount of waste milk present on day 2 resulted in significantly higher dry basis concentrations for most constituents than on day 1. In particular, the waste milk introduced 217% more Na, 75% more Ca, and 51% more P.

Gravity settling and thickening experiments were performed for the two milking center waste samples (7165 and 17,024 mgTS/L). Gravity settling was effective at removing a fraction of all of the defined constituents. The greatest mass removals were for TS, VS, Org-N, P_2O_5, S, Cu, and Zn. The mass removal efficiency for the soluble constituents, TAN, K_2O, and Na, was a consequence of volume fractionalization and not a change in concentration.

Keywords. Dairy, sedimentation, waste treatment, manure management

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Introduction

Milking center wastewater contains: dairy manure, bulk tank and pipeline cleaning water, water used to clean floors, and at times large amounts of waste milk. On many dairy farms, the milking center wastes are included with manure from the animal housing areas for treatment, storage, and land application. In some cases, it is desirable to store or treat milking center waste independent of other waste generated on the farm.

Very little information is available in the literature concerning the total solids, volatile solids, plant nutrient, and mineral content of milking center wastewater. In addition, little information is available concerning primary treatment of milking center wastewater by sedimentation.

Large milking center wastewater samples were collected from a holding pit on a grazing dairy farm in South Carolina on two different days. Large samples were transported to Clemson University to determine the composition and settling characteristics.

The objectives of the study were to: (1) determine the concentrations of plant nutrients, minerals, and solids in the milking center wastewater samples, and (2) determine the settling characteristics of the milking center wastewater samples.

Methods

The samples used in this study were collected on two different days from the milking center on a dairy farm located in Orangeburg, County, SC. The milking herd ranged from 150 to 200 cows. Dry cows and replacement animals were kept on pasture on a separate farm operated by the dairy producer. Two hundred cows were milked twice each day on the first day samples were collected. The exact milking herd size was unknown on the second day.

The facilities used for the milking herd on this grazing dairy included a milking center, an outdoor concrete feeding area, upright silos, 24.3 ha of intensively grazed pasture, plus additional pasture and cropland.

In addition to grass from the pastures, cows were fed a corn silage based total mixed ration in concrete feed bunks immediately after each milking. The cows were returned to the intensively grazed pastures after receiving the supplemental feed.

Manure from the concrete feeding area was scraped every few days with a tractor and loader. The scraped manure was stored in a stacking area at the end of the feedlot.

The milking center consisted of a single building that contained a covered holding pen, an old herringbone milking parlor, milk room, office, and other support areas. The parlor and holding area floors were cleaned with water from a high-pressure hose and by scraping when needed. The total time required to milk the herd was about 3 hours per milking.

All of the wastewater from washing the milk pipelines, bulk tank, milk room floors, and parlor and holding area floors were collected and transferred to an uncovered, belowground, concrete holding pit located adjacent to the milking center. Waste milk from cows treated with antibiotics was also transferred and stored in the holding pit. The holding pit had a capacity of 53,000 L. This volume did not include the required freeboard, and depth for net rainfall and the 25-year, 24-hour storm. The wastewater was agitated and emptied approximately once each week. The actual frequency of emptying depended on the number of cows being milked, the amount of rainfall that occurred, and the amount of waste milk generated from treated cows. Milking center wastewater removed from the holding pit was surface applied on pasture or cropland using a tank-type manure spreader.

Sample Collection

Large manure samples were collected from the holding pit on two different days. The samples were transported to Clemson University on the same day for analysis of the composition and gravity settling characteristics. The large (≈ 20 L) milking center waste water samples were stored in large refrigerators prior to composition analysis and the gravity settling experiments.

On the first day (day 1), the holding pit was full with 7 days of milking center wastewater and the milking herd numbered 200 cows. The entire contents of the holding pit were agitated prior to loading the manure spreader. Samples of milking center wastewater were collected as the manure spreader was being filled. Approximately 7 spreader-loads of milking center wastewater were required to empty the holding pit. Samples were collected during the beginning, middle, and end of the emptying and land application operations. The samples were combined in common 20 L containers to yield a composite sample that was representative of the pit contents.

On the second day (day 2), the holding pit was not completely full and it was obvious by the color of the wastewater that a large amount of milk was mixed with the manure. The dairy producer indicated that waste milk from treated cows was disposed of in the pit that week. The pit contents were agitated and approximately 1,900 L of milking center wastewater was pumped into a trailer mounted tank and transported to Clemson University. The manure was pumped into a storage tank. The contents of the storage tank were well-mixed with a pump and 1 L samples were drawn over time to provide ≈ 20L for analysis of the composition and gravity settling characteristics.

Constituents Measured

Well-mixed aliquots were taken from the milking center wastewater samples collected on both days. The aliquots were analyzed to determine the concentrations of the following constituents: total solids (TS), fixed solids (FS), volatile solids (VS), total Kjeldahl nitrogen (TKN), total ammoniacal nitrogen (TAN = NH_4^+- N+ NH_3^--N), nitrate nitrogen, total phosphorus (expressed as P_2O_5), and total potassium (expressed as K_2O), zinc (Zn), and copper (Cu). Organic nitrogen (Org-N) was calculated as: Org-N = TKN - TAN. The Agricultural Service Laboratory at Clemson University provided plant nutrient analyses.

Measurements of TS, FS, 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 oven drying and incineration methods (APHA, 1995). Free water was evaporated from the aliquots 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 fixed solids was determined after incinerating the dried solids in a furnace maintained at 550 to 600°C for 1.5 to 2 hours, and allowing the samples to cool in a desiccator. The TS and FS concentrations were calculated by dividing the mass in mg by the sample volume in L. The VS concentration was the difference between TS and FS.

The analyses for the two milking center wastewater samples were not performed at the same time. Two replicate samples of all defined plant nutrients, minerals, and solids were obtained from the ≈ 20 L of milking center wastewater collected on day 1. Nine replications were used to characterize the 1,900 L of wastewater collected on day 2.

Settling Experiment

Experiments were performed in the laboratory to observe the settling characteristics of the two milking center wastewater samples. Graduated cylinders (500 and 1000 mL) were used to facilitate the measurement of the change in supernatant and settled material volumes with respect to time. One cylinder was used for the wastewater sample collected on day 1, and 2 cylinders were used for the sample collected on day 2.

The gravity selling experiments were carried out using the following procedure: (1) a well-mixed, 500 - 1000 mL sample of wastewater was extracted and poured into a graduated cylinder, (2) the time when the sample was poured into the cylinder was recorded, (3) the volume of the settled material was measured with respect to time for about 60 to 70 min, and (4) at the end of the settling period the supernatant was decanted.

The supernatant was analyzed to measure the concentrations of the previously defined plant nutrients, minerals, and solids. Supernatant composition following settling of the wastewater sample collected on day 1 was determined based on two replications. Six replications, 3 per cylinder, were used to characterize the composition of the supernatant following settling of the wastewater collected on day 2.

Analysis and Results

Composition of Milking Center Wastewater

The plant nutrient, mineral and solids content of milking center wastewater was determined for samples collected from a grazing dairy in South Carolina on two different days. The sample collected on the first day (day 1) contained chemicals and milk from cleaning the milk pipelines and bulk tank, and wastewater from washing the floors of the parlor, holding area and milk room. The sample collected on the second day (day 2) also contained a large amount of waste milk from treated cows. The plant nutrient, mineral and solids concentrations of the wastewater on both days are compared on an as-sampled and dry basis in Table 1.

The waste milk and extra water used to wash the waste milk into the holding pit resulted in a TS content on day 2 (7165 mg TS/L) that was less than half the value observed on day 1 (17,024 mg TS/L). As would be expected, all other as-sampled constituent concentrations were very different between day 1 and day 2.

The milking center wastewater samples were also analyzed for nitrate-N. However, the nitrate-N contents were all below detectable levels and were considered zero.

The composition of wastewater on the two days was compared on a dry matter basis (mg/g TS) due to the extreme differences in solids content. A simple one-way analysis of variance (ANOVA), with unequal replication (Steel and Torrie, 1980), was performed on the dry basis concentrations for each constituent, excluding TS, using sample collection day as a treatment (day 1 vs. day 2). The ANOVA provided a pooled variance and standard deviation (SD) with 9 error degrees of freedom for each constituent. A t-test, at the 95% level of probability, indicated that the dry basis concentrations of all constituents were significantly different depending on the day the milking center wastewater was sampled.

The sample collected on day 2 contained significantly higher dry basis concentrations of each constituent than day 1 except for copper and volatile solids. The large amount of waste milk present on day 2 resulted in 217% more Na, 75% more Ca, and 51% more P on a dry basis as compared to day 1.

It is believed that the data shown for day 1 are more representative of the typical milking center wastewater composition on this farm. However, the day 2 results represent the extremes that can occur.

The composition of flushed freestall dairy manure, that does not contain milking center waste, is also shown in Table 1. These data were taken at a different dairy farm in South Carolina. The flushed manure on this farm contained large amounts of wood shavings used for bedding, manure that was no more than 12 hours old, and waste feed (Chastain et al, 2001).

Table 1. Comparison of milking center wastewater composition with flushed freestall dairy manure.

	As-Sampled Basis			Dry Matter Basis			
		Milking Center Wastewater			Milking Center Wastewater		
Constituent	Dairy Freestall (mg/L)	Day 1[1] (mg/L)	Day 2[2] (mg/L)	Dairy Freestall (mg/g TS)	Day 1 (mg/g TS)	Day 2 (mg/g TS)	Pooled SD [3] (mg/g TS)
TS	38,258	17024	7165	---	---	---	---
VS	32,073	13373	4621	838	786	645 *	16.0
TAN	661	756	354	17.3	44.4	49.4 *	2.367
Org-N	772	452	252	20.2	26.5	35.2 *	3.056
TKN	1,433	1207	607	37.5	70.9	84.7 *	4.075
P_2O_5	930	402	255	24.3	23.6	35.6 *	1.528
K_2O	921	917	508	24.1	53.9	70.9 *	3.986
Ca	953	321	237	24.9	18.9	33.1 *	1.638
Mg	337	133	77	8.81	7.81	10.7 *	0.543
S	179	65	39	4.68	3.84	5.44 *	0.337
Zn	14.0	4.2	2.1	0.37	0.25	0.30 *	0.025
Cu	11.0	1.2	0.4	0.29	0.07	0.05 *	0.003
Mn	12.0	3.0	1.7	0.31	0.18	0.24 *	0.022
Na	288	161	214	7.53	9.43	29.9 *	1.233
VS/TS	0.838	0.786	0.645				
TAN/TKN	0.461	0.626	0.583				
TKN/P_2O_5	1.54	3.00	2.38				

* Significantly different from milking center wastewater on day 1 based on a t-test at the 95% level of probability. Where, $t_{CAL} = (Y_1 - Y_2) / SE_{\Delta Y}$, and $SE_{\Delta Y} = [(SD^2/n_1) + (SD^2/n_2)]^{0.5}$ (Steel and Torrie, 1980).

[1] Number of replications on day 1 = 2.

[2] Number of replications on day 2 = 9. The milking center wastewater sample collected on day 2 was diluted with a large amount of waste milk.

[3] Pooled standard deviation using all milking center wastewater data with the day the sample was collected serving as the treatment. Error degrees of freedom = 9.

Again, the large differences in TS content precluded any comparisons on an as-sampled basis. Comparison of the dry basis constituent contents of the freestall manure to the milking center wastewater sampled on day 1 indicates that the greatest differences between the two manures were the nitrogen, potassium, copper and sodium contents. In particular, typical milking center waste (day1) contained 157% more TAN, 32% more Org-N, 89% more TKN, 124% more K_2O, 76% less Cu, and 25% more Na than freestall manure. The Ca content of the freestall manure was in between the Ca content observed on day 1 and 2 for the milking center waste.

The volume of milking center wastewater was estimated on day 1 based on the number of manure spreader loads removed and land applied. It was estimated that 52,990 L of wastewater were removed from a pit that held 7 days of waste for a milking herd of 200 cows. Therefore, it was estimated that, on a typical day, 37.9 L of milking center wastewater were per produced per cow on this farm. Large amounts of waste milk would increase the volume. However, there was no way to estimate the actual amount of milk added prior to sample collection on day 2.

Settling Characteristics of Milking Center Wastewater

Gravity settling experiments were performed in the laboratory using graduated cylinders for both of the milking center wastewater samples collected from the holding pit at the cooperator's farm. The equations used to describe the effectiveness of gravity settling were derived based on an application of a unit volume mass balance for each of the defined constituents.

Mass Balance on Gravity Settling

Application of the law of conservation of mass on the graduated cylinder used for the settling experiments gave:

$$C_I V_I = C_{SUP} V_{SUP} + C_{SM} V_{SM}. \quad (1)$$

Where,

C_I = initial concentration of a constituent in the wastewater (mg/L),

V_I = initial volume of the wastewater (L),

C_{SUP} = concentration of a constituent in the supernatant (mg/L),

V_{SUP} = volume of the supernatant layer (L),

C_{SM} = concentration of a constituent in the settled material (mg/L), and

V_{SM} = volume of the settled material (L).

The mass balance for gravity settling was written on a unit volume basis by dividing through equation 1 by V_I to yield:

$$C_I = C_{SUP} (V_{SUP} / V_I) + C_{SM} (V_{SM} / V_I). \quad (2)$$

The settled volume fraction, SVF, was defined as:

$$SVF = V_{SM} / V_i. \quad (3)$$

Since all of the volumes in equation 2 were measured, the unit volume mass balance was written in terms of SVF as:

$$C_I = C_{SUP} (1 - SVF) + C_{SM} SVF. \quad (4)$$

The only quantity in equation 4 that was not measured was C_{SM}. Equation 4 was solved for the concentration of a constituent in the settled material to give:

$$C_{SM} = [C_I - C_{SUP} (1 - SVF)] / SVF. \quad (5)$$

The mass of any constituent, C, in the settled material is simply (C_{SM} SVF). Solving equation 4 for (C_{SM} SVF) indicates that the mass fraction removed from the wastewater can be written as:

$$MFR_C = [C_I - C_{SUP} (1 - SVF)] / C_I. \quad (6)$$

It also follows that the mass removal efficiency was:

$$MRE_C = 100\ MFR_C . \quad (7)$$

The concentration reduction of any constituent (CR_C) by gravity settling was simply:

$$CR_C = 100\ [(C_I - C_{SUP}) / C_I]. \quad (8)$$

Change in Volume of Settled Material with Time

The settled volume fraction, as defined by equation 3, is the volume of the settled material normalized to the initial volume placed in a graduated cylinder. In a practical design, the initial volume would be the volume of wastewater that flows into a primary clarifier over a given time period.

The values of SVF for the two samples of milking center wastewater are plotted with respect to the elapsed time in Figure 1. For the sample collected on day 1, the settled volume was measured at 30, 60, and 74 min after adding the sample to the cylinder. It was apparent that settling occurred rapidly. For the sample collected on day 2, volume measurements began at 7 min and continued for 64 min.

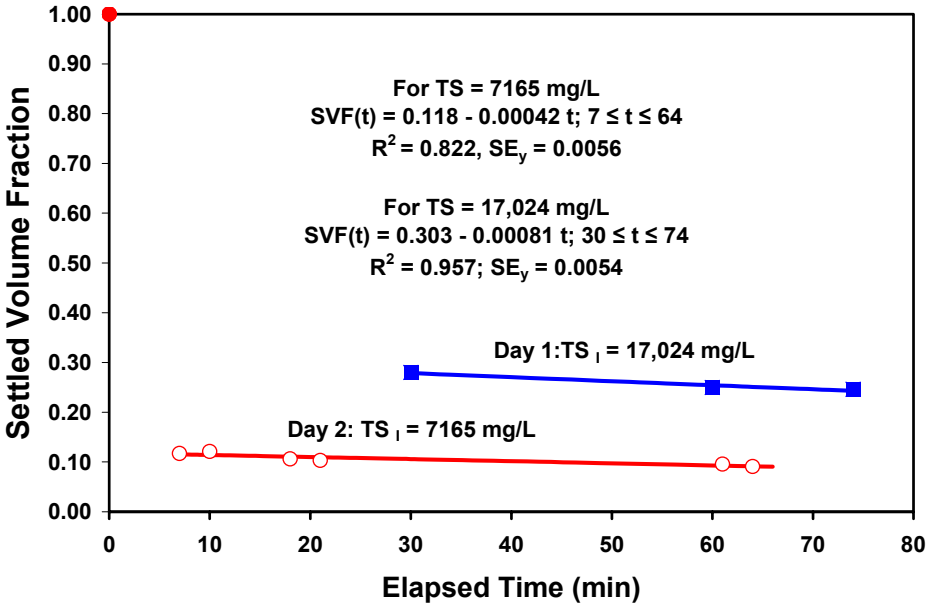

Figure 1. Change in volume of the settled material with respect to time and the initial TS concentration. ($SVF(t) = V_{SM}(t) / V_I$).

Regression lines were fit to the data for each milking center waste sample as indicated in the figure. The standard error of the y-estimate, SE_y, is the magnitude of 1 standard deviation about the regression equation. The value of SE_y was essentially the same for both relationships. The coefficient of variation ranged from 2.1% for the day 1 sample to 5.3% for the day 2 sample.

The majority of the settling occurred for both waste samples after 30 min of settling. The value of SVF decreased from 0.279 at 30 min to 0.254 at 60 min for the sample with a TS of 17,024 mg/L (day 1). The settled volume fraction for 7165 mg TS/L (day 2) was 0.105 at 30 min and 0.093 at 60 min. Therefore, increasing the settling time from 30 to 60 min decreased the settled volume by only 9% for the day 1 sample to 11% for the sample collected on day 2.

The data and results given in the figure imply that the settled volume fraction was a function of the initial TS content of the wastewater and the amount of time that the material was in a quiescent state. The data also indicate that once the majority of settling occurred, the settled material thickened under the mass of the supernatant column in a linear manner. These characteristics agree with previous data on gravity settling of dairy manure provided by Sobel (1966).

Supernatant Concentrations

The supernatant was decanted from the graduated cylinders and was analyzed for the same constituents as the initial milking center wastewater samples. The initial and supernatant concentrations for samples collected on day 1 and 2 are provided in Table 2.

Table 2. Initial and supernatant concentrations of milking center wastewater following 60 to 70 min of gravity settling (as-sampled).

	Day 1 [1]		Day 2 [2]		Pooled	
	Initial	Supernatant	Initial	Supernatant	SD [3]	$U_{\Delta C}$ [4]
Constituent	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
TS	17024	8960	7165	4645	236	333
VS	13373	6049	4621	2690	137	194
TAN	756	785	354	375	32	46
Org-N	452	167	252	153	25	35
TKN	1207	951	607	528	40	57
P_2O_5	402	296	255	146	17	24
K_2O	917	961	508	533	43	61
Ca	321	286	237	195	16	22
Mg	133	102	77	48	6.0	8.5
S	65	47	39	25	3.2	4.5
Zn	4.2	3.0	2.1	1.2	0.40	0.56
Cu	1.2	0.6	0.4	0.2	0.10	0.14
Mn	3.0	2.4	1.7	1.1	0.28	0.40
Na	161	167	214	228	10	15
VS/TS	0.786	0.675	0.645	0.579		
TAN/TKN	0.626	0.825	0.583	0.710		
TKN/P_2O_5	3.00	3.21	2.38	3.62		

[1] Number of replications was 2 for initial and supernatant .

[2] Number of replications was 9 for initial and 6 for supernatant.

[3] Pooled standard deviation, error degrees of freedom was 15.

[4] The pooled SD was used as an estimate of the uncertainty in measurement for each constituent. The uncertainty in the difference in concentrations was calculated using equation 10.

A one-way ANOVA with unequal replication was performed for all the initial and supernatant data to provide a pooled estimate of the standard deviation for each of the defined constituents. The error degrees of freedom for each SD was 15.

Milking center wastewater is a non-homogeneous mixture and a certain amount of error is associated with obtaining a representative sample. The pooled standard deviation was used as an estimate in the uncertainty in the measurement for each of the defined constituents.

The change in concentration of a constituent is the controlling error in the calculation of the concentration reduction (equation 8) and the mass fraction removed (equation 6). The error in knowing SVF was approximately 0.3% to 0.8%.

Taking a difference in concentrations, ΔC, accentuates this error. The uncertainty in taking a difference in two concentrations, $U_{\Delta C}$, can be computed as (Holman 1978):

$$U_{\Delta C} = [U_{C\text{-}INITIAL}^{2} + U_{SUP}^{2}]^{0.5} . \quad (9)$$

Where,

$U_{C\text{-}INITIAL}$ = the estimate of the uncertainty of the initial concentration, and

U_{SUP} = the estimate in the uncertainty of the supernatant concentration.

Since the estimate of the uncertainty of the initial and supernatant concentrations was the pooled value of SD, equation 9 simplified to:

$$U_{\Delta C} = [\, 2\, SD^{2}\,]^{0.5} . \quad (10)$$

The uncertainty in ΔC can be normalized to the initial concentration as:

$$U_{\Delta C}(\%) = [U_{\Delta C} / C_I] \times 100. \quad (11)$$

Concentration Reduction and Mass Removal Efficiency

The concentration reduction and mass removal efficiencies were calculated using the defining equations (equation 7 and 8) with the concentration data given in Table 2, and the SVF data provided in Figure 1. The mass removal efficiencies were calculated for settling times of 30 and 60 min. The results are given in Table 3.

The supernatant concentrations at about 60 min were assumed to be the same at 30 min since the active settling phase was completed, and compression thickening had begun as indicated by the linear relationships for SVF (Figure 1). During the thickening phase, the volume of the supernatant increases, but the constituent concentrations in the supernatant does not change significantly. This has been observed in previous studies by the author and by Moore et al. (1975).

The supernatant concentrations of the soluble constituents, TAN, K_2O, and Na, were not affected by gravity settling as indicated by CR-values that were within the estimates of uncertainty, $U_{\Delta C}(\%)$.

The mass removal efficiency was significant for all of the defined constituents. In all cases, the MRE was greater than CR.

For the soluble constituents, the concentration in the supernatant layer must be the same in the settled material within measurement error. Setting C_{SUP} equal to C_I in the equation for the mass fraction removed (equation 6) and simplifying indicates that for soluble constituents the mass removal efficiency is equal to 100 x SVF. Therefore, any value of MRE in Table 3 that is less than 100 x SVF is due to the uncertainty in measuring concentrations.

In practice, one would average C_I and C_{SUP} and use the mean value as the concentration for the influent, supernatant, and settled material. Then MRE would equal 100 x SVF.

The thickening rate was very slow after 30 min of settling had occurred for both milking center wastewater samples. The mass removal efficiencies were not significantly different for 30 or 60 min of settling. Consequently, 30 min of retention at a quiescent state was sufficient for these wastewater samples.

Table 3. Concentration reductions and mass removal efficiencies for primary treatment of milking center wastewater by sedimentation for 30 and 60 min.

	Day 1				Day 2			
			MRE_C [3]				MRE_C [4]	
	CR_C [1]		30 min	60 min	CR_C		30 min	60 min
Constituent	(%)	$U_{\Delta C}$ (%)[2]	(%)	(%)	(%)	$U_{\Delta C}$ (%)	(%)	(%)
TS	47	2.0	62	61	35	4.6	42	41
VS	55	1.4	67	66	42	4.2	48	47
TAN	-4 [NS]	6.1	25 [5]	23 [5]	-6 [NS]	13.0	5 [5]	4 [5]
Org-N	63	7.8	73	73	39	13.9	46	45
TKN	21	4.7	43	41	13	9.4	22	21
P_2O_5	26	6.0	47	45	43	9.5	49	48
K_2O	-5 [NS]	6.6	24 [5]	22 [5]	-5 [NS]	11.9	6 [5]	5 [5]
Ca	11	6.9	36	34	18	9.3	26	25
Mg	23	6.4	45	43	38	11.0	44	43
S	28	6.9	48	46	36	11.6	43	42
Zn	29	13.3	48	47	50	26.7	55	55
Cu	50	11.7	64	63	50	35.0	55	55
Mn	20	13.3	42	40	50	23.5	55	55
Na	-4 [NS]	9.3	25 [5]	23 [5]	-7 [NS]	7.0	5 [5]	3 [5]

[1] Concentration reduction computed using equation 8.

[2] Uncertainty in the difference in concentration normalized to the initial concentration (equation 11).

[3] Calculated using equation 7 with SVF (30 min) = 0.279, and SVF (60 min) = 0.254.

[4] Calculated using equation 7 with SVF (30 min) = 0.105, and SVF (60 min) = 0.093.

[5] Actual mass removal efficiency = 100 x SVF(t).

[NS] Concentration reduction was within the propagation of measurement error. Therefore, it was not distinguishable from zero.

The mass removal efficiencies were greater for the milking center wastewater that had the greater initial concentrations (day 1: TS = 17,024 mg/L). A similar increase in settling performance with an increase in TS was observed by Chastain and Vanotti (2003) for liquid swine manure.

Overall, gravity settling was effective at removing a fraction of all of the defined constituents. The mass removal efficiency for the soluble constituents, TAN, K_2O, and Na, was a consequence of volume fractionalization and not a change in concentration. Gravity settling provided the greatest removals for TS, VS, Org-N, P_2O_5, S, Cu, and Zn. The best performance was for the milking center wastewater with the highest initial concentrations. This was due to two factors, a greater change in constituent concentrations, and a greater settled volume fraction.

Composition of the Settled Material

Primary treatment by gravity settling divides a wastewater into two effluent streams; the supernatant and the settled material. Further treatment or utilization requires knowledge of the composition of both effluents. The supernatant concentrations were measured. However, application of a unit volume mass balance indicated that the constituent concentrations of the settled material can be calculated from the data using equation 5.

Equation 5 was used to compute the composition of the settled material following 30 and 60 min of gravity settling for both wastewater samples. The results are compared in Table 4. As expected the concentrations were only slightly greater as settling time was increased from 30 to 60 min.

Table 4. Constituent concentrations in the settled material following 30 and 60 min of settling.

	Day 1: TS_I = 17,024 mg/L				Day 2: TS_I = 7165 mg/L			
	t= 30 min		t= 60 min		t= 30 min		t= 60 min	
SVF(t) =	0.279		0.254		0.105		0.093	
Constituent	C_{SM}	C_{SM} / C_I	C_{SM}	C_{SM} / C_I	C_{SM}	C_{SM} / C_I	C_{SM}	C_{SM} / C_I
TS	37894	2.23	40658	2.39	28554	3.99	31800	4.44
VS	32328	2.42	34838	2.61	21011	4.55	23498	5.09
TAN	771[1]	1	771[1]	1	365[1]	1	365[1]	1
Org-N	1190	2.63	1288	2.85	1092	4.33	1220	4.84
TKN	1869	1.55	1957	1.62	1278	2.10	1379	2.27
P_2O_5	676	1.68	713	1.77	1180	4.63	1321	5.18
K_2O	939[1]	1	939[1]	1	521[1]	1	521[1]	1
Ca	413	1.28	425	1.32	593	2.50	648	2.73
Mg	214	1.61	224	1.69	323	4.20	361	4.68
S	112	1.71	118	1.81	158	4.05	176	4.51
Zn	7.3	1.74	7.7	1.84	10.5	5.24	11.8	5.89
Cu	2.7	2.29	3.0	2.47	2.1	5.24	2.4	5.89
Mn	4.5	1.52	4.8	1.59	10.5	5.24	11.8	5.89
Na	164[1]	1	164[1]	1	221[1]	1	221[1]	1

[1] Mean of initial and supernatant concentrations, Concentrations not significantly affected by sedimentation, therefore C_{SM} / C_I = 1.

Conclusions

Large samples of milking center waster water were collected from the holding pit on a grazing dairy farm in South Carolina on two different days. The sample collected on the first day was representative of the typical wastewater composition on this farm. The sample collected on day 2 contained a large amount of waste milk from sick cows.

The samples from both days were analyzed to determine the concentrations of TS, VS, TKN, TAN (NH_4^+- N+ NH_3^--N), NO_3-N, P_2O_5, K_2O, Zn, and Cu. Data were also collected to determine the quantity of milking center wastewater generated per cow on a typical day.

The following conclusions were developed from the data analysis and results.

- On a typical day, 37.9 L of milking center wastewater, with a TS of 17,024 mg/L, were generated per cow per day.
- On the second day, the wastewater contained a large amount of waste milk and the TS content was 7165 mg/L.
- The large amount of waste milk present on day 2 resulted in significantly higher dry basis concentrations of each constituent than day 1 except for Cu and VS. In particular, the waste milk introduced 217% more Na, 75% more Ca, and 51% more P.

Gravity settling experiments were performed to observe the settling characteristics of the two milking center wastewater samples. The following conclusions were developed based on the gravity settling results.

- The settled volume fraction was a function of the initial TS content of the wastewater and the amount of time that the material was in a quiescent state.
- Gravity settling was effective at removing a fraction of all of the defined constituents. The greatest mass removals were for TS, VS, Org-N, P_2O_5, S, Cu, and Zn. The mass removal efficiency for the soluble constituents, TAN, K_2O, and Na, was a consequence of volume fractionalization and not a change in concentration.
- The constituent concentrations of the settled material may be calculated by application of a unit volume mass balance.

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