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COMPLETION REPORT

CO-TREATMENT OF WATER SOFTENING AND WASTEWATER SLUDGES

BY

Dr. James E. Bowie, Jr.

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Craig A. Gautreaux

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U.S. Department of the Interior
Washington, D.C. 20240

LOUISIANA WATER RESOURCES RESEARCH INSTITUTE

Louisiana State University
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ABSTRACT

Water softening and wastewater treatment processes both produce large quantities of sludge. It was hypothesized that mixing the softening sludge and wastewater sludge would produce a sludge of intermediate quality more suitable for thickening and dewatering than either sludge treated separately. The study revealed that mixing the sludges reduced final sludge volumes in the range of 4 to 52%. The ratios of softening sludge to wastewater sludge solids was the key factor influencing volume reductions. Total solid balance indicates that negligible dissolution and precipitation occurred upon mixing of the sludges. Slight increases in alkalinity and total hardness were observed in the supernate. Co-treatment of the softening sludge with the wastewater sludge reduced BOD_5 and suspended solids in the supernate in the range of 20 to 87%. The improvement was due to improved solids capture. Belt press thickening was accomplished by the addition of a cationic polyelectrolyte to softened and aerobically digested sludge mixtures. A 4% net increase in cake solids was observed when 20% by volume softening sludge was added to aerobically digested sludge with a 160 mg/l polymer dosage. A hypothetical economic analysis for the city of Lafayette, Louisiana (population 80,000), indicated a 16% daily hauling savings by transporting the water softening sludge to the wastewater treatment plant for gravity thickening and final disposal rather than separate gravity thickening sludge disposal.

Keywords: Water softening sludge, wastewater sludge, thickening, dewatering

INTRODUCTION

Nature of the Problem

Water softening and wastewater treatment processes both produce large quantities of sludge. The treatment processes for water softening and wastewater sludges are not markedly different. Both are subjected to volume reduction and removal of water from the sludge (thickening and dewatering).

Water softening sludge is the result of chemical precipitation and the natural hardness of water. With aluminum sulfate addition, the resulting sludge mass settles rapidly. Wastewater sludges are biologically produced and thicken over a long period of time.

The city of Lafayette, Louisiana, currently has a lime softening plant, an activated sludge treatment plant with aerobic digestion and a trickling filter plant with anaerobic digestion. The softening sludge at the city's water treatment plant can cause several problems. If the solids contact reactors are left unattended, the softening sludge becomes so concentrated that it stalls the rake mechanisms and is too thick to flow by gravity out of the sludge blowdown lines. Problems in the gravity thickener have also been encountered due to the concentrated consistency of the softening sludge.

The problems associated with the treatment processes and sludge handling techniques at the wastewater treatment facilities vary from day to day. This is due to the biological treatment processes used.

The primary problem is settling of the biological suldge mass. The microbiological floc present in activated sludge mixed liquor generally settles well in the final clarifier. Sometimes, the sludge rises (sludge bulking), depending on the length of time treatment occurs. The activated sludge mixed liquor is then aerobically digested. Once digestion is complete, the air supply is shut off to allow gravity thickening. The solids are then either dewatered before final disposal or directly wet hauled to final disposal. The method for final disposal is primarily dependent upon the solids concentration in the thickener. The solids concentration depends upon the characteristics of the sludge being digested. Generally, sludges of solids concentration above 2.0% are wet hauled, below 2.0% are dewatered. The dewatering process involves the addition of chemical dosages to the sludge before passing it through a belt press thickener. The sensitivity of the sludge solids can present problems in the variability of the chemical dosages employed.

In Lafayette's trickling plant, primary sludge is anaerobically digested. After digestion has been completed, the mixers are turned off to allow the sludge to thicken. The digested sludge is then typically sent through the belt thickener for chemical addition.

Purpose and Scope of Experimentation

The hypothesis of the study was that mixing of the softening sludge and wastewater sludge would produce a sludge of intermediate quality more suitable for thickening and dewatering than either sludge treated separately. Some synergistic influences might be expected from sludge mixing since softening sludges settle rapidly and wastewater sludges are usually difficult to treat. Concurrent treatment of water softening and wastewater sludges could also eliminate duplicated equipment at one of the plants.

Water softening sludge was mixed with raw wastewater, activated sludge mixed liquor, aerobically digested sludge, primary sludge, and anaerobically digested sludge. The specific aims of this study were to determine: (1) the settling characteristics of the various sludge mixtures; (2) if dissolution or precipitation of solids occurred in the sludge mixtures; (3) changes in supernate quality; and, (4) belt press thickening of the sludge mixtures. An economic analysis of concurrent versus separate treatment of softening and wastewater sludges using the city of Lafayette as a model was also performed.

LITERATURE REVIEW

Background

Sludge disposal is a significant problem facing the water and sewage works industry today. The costs involved for sludge disposal frequently exceed the costs of other processes in the treatment plant. Sludges are considered a liability to treatment plants because there is no known way to profit on their collection and treatment. (1) (9)

Sludge thickening and dewatering reduces sludge volume and hauling costs. In thickening, sludge solids settle by gravity and the supernatant water is removed. Sludge dewatering physically squeezes the moisture from the sludge allowing cost effective ultimate disposal. Dewatering is accomplished by chemical addition followed by a vacuum filter, centrifuge, belt press, or other mechanical processes. (1) (2)

Current ultimate disposal techniques of sludges include incineration, sanitary landfill, composting and liquid disposal. Land spreading is also possible since aerobically digested sludge and water softening sludge are acceptable soil conditioners. (1) (2)

Water softening as practiced today involves the use of lime and/or soda ash process to reduce hardness to a desired level. The resulting calcium carbonate sludge is produced in large quantities (2 to 1, sludge to lime added). In the past, this sludge has been disposed of by direct discharge into water courses, lagooning, recalcining the lime, discharging into sewers and dewatering. The discharge into sewers has been linked with deposition problems in the sewer mains and in anaerobic digesters. Vacuum filters and belt presses have become very expensive operations. Lagooning of the calcium carbonate and magnesium hydroxide sludge is widely used, but land acquisition for expansion has become costly in many communities. Landfill hauling and land spreading are also practiced, but fuel and operating costs are still problems for smaller communities. (1) (2) (13)

Wastewater sludge disposal techniques are not markedly different than softening sludge. Precautions on the disposal technique are generally taken due to the concern with pathogenic organisms and heavy metals. Landfill hauling is the most commonly used form of disposal. This is either done by direct wet hauling or in conjunction with dewatering methods. Incineration and composting are other means of wastewater sludge disposal. (1) (13)

Methods Previously Studied

There has been limited research work done in the area of co-treatment of softening sludge and wastewater sludge. Most of the research done has been on chemical and chemical sludge addition to wastewater treatment processes. (3) (4) (8) Aluminum sulfate, alum sludge from surface water treatment, water softening sludge and lime have improved the physical and chemical characteristics of the treated wastewater in different treatment stages. The sludge from these plants were more readily thickened and dewatered.

Primary Treatment Processes

Hsu and Pipes (4) studied the affect of a synthetic aluminum hydroxide floc on a primary treatment process. They found that while total sludge volume increased, volatile solids, chemical oxygen demand (COD), and biochemical oxygen demand (BOD), decreased with increasing alum floc dosage into the influent. Zakrewski (14) noted removals of 12.4% in suspended solids, 19.9% in BOD and 26.2% in COD at 8% alum sludge dosage into the influent.

Nelson, Joseph, and Culp (8) noted that phosphorus removal improved 12% but efficiency in primary settling decreased by 10% in their studies with alum sludge addition to the wastewater treatment processes. Total solids increased by 69% while volatile solids decreased by approximately 5% at 8% water treatment plant sludge. In addition, Nelson et al, reported that BOD and COD remained the same after dosing.

Lime addition to wastewater has been established as an effective phosphorus removal technique. (7) (6) (11) Lime reacts with the waters alkalinity to form calcium carbonate thus releasing hydroxyl ions which raises the pH level. Excess calcium reacts with hydrolyzed orthophosphate to precipitate insoluble hydroxyapatite. Increases in pH adversely effects microbiological systems, such that treatment plants generally incorporate lime additives as a tertiary process. Mulbarger, Grossman, Dean, Grant (7) and others (6) (11) agree that lime addition can reduce organic loading, suspended solids loading and stabilize a sludge mass by the increase in pH. In Hamoda's (3) studies on aerobic digestion of sludges precipitated from wastewater by lime addition, the settleability of the sludges increased with lime addition at low dosages. Supernates of the sludge were reported to have low suspended solids in comparison to the control sludge supernate. Schmid (11) noted that with the addition of lime, phosphorus removals of 80% were achieved in the primary clarifier. Biochemical oxygen demand removals of 60% in the primary clarifier were also noted.

Salotta, Farrell, and Dean (10) studied the effects of a softening plant sludge which contained alum and calcium carbonate on a continuous flow activated sludge treatment plant with primary sedimentation. Improvements in clarifier efficiency and turbidity were noted. Turbidity was reduced by 21% in the primary clarifier while the effluent turbidity was reduced by 70%. Chemical oxygen demand and phosphorus removals remained the same after dosing at 84% and 12%. Suspended solids removal increased from 85% to 93%. The primary sludge showed an increase in total solids content with decreasing volatile fraction. Sludge digestion was not studied in this particular test.

In a study done in Daytona Beach, Florida, (2) softening sludge was added to primary treatment utilizing suspended solids contact basins. Biochemical oxygen demand removals of 70 to 80% and suspended solids removal of 75% were noted.

Aeration and Clarification Processes

Limited research has been done in the aeration and clarification phase of wastewater treatment. This is due to the incorporation of chemicals and chemical sludge into the primary clarifier. About 98% of the water plant sludge settles out during this process leaving a minute amount of reactant to pass through the rest of the treatment process. In studies done on the aeration and clarification phase with the addition of alum sludge, improvements in final BOD, COD, turbidity and phosphorus content were noted. (4) (8) Salotto, Farrell and Dean (10) reported an increase in overall plant efficiency with alum and softening sludge addition, but effluent COD and phosphorus remained the same due to low alum sludge addition.

Sludge Treatment

Studies have been done to determine the effects of alum sludge, calcium carbonate sludge and lime on primary sludge and aerobically digested sludge. Nelson, Joseph and Culp (8), studied the effects of alum sludge addition to the primary clarifier on primary sludge characteristics. The study showed that volatile solids of the mixed sludges decreased. The study also brought out that the combined sludges were easier to mix and that sludge retained by centrifugation increased from 12 to 50%. Hamoda and Ganczarczyk (3) studied the effects on aerobic digestion of sludges precipitated from wastewater by lime addition. It was determined that the lime based sludge stabilized the pH and could better resist pH changes that usually occur in aerobic digestion. Sludge settleability was inversely proportional to the dosage of lime. Total volatile solids were in the range of 65% before lime addition. After lime addition, the volatiles were in the

35 to 53% range depending upon the amount of lime added. After 10 days, the reduction of digested volatile solids increased from 20% for untreated to 40% with lime addition. Chemical oxygen demand supernate values ranged from 160 mg/l untreated to 120 mg/l with treatment. Suspended solids in the supernate were also reduced with lime addition.

Filterability when compared on the basis of specific resistance to filtration indicated that the lime primary sludge had considerably better filterability than the raw primary sludge. Calcium carbonate precipitated from lime addition was suspected to be responsible for the improved filterability.

Huang and Nguyen (5) studied the codisposal of water softening and aerobically digested sludge. They reported settling rates increased by a factor of six. Chemical oxygen demand and phorphorus removals in the supernate were in the 80% range. Dewaterability when tested by specific resistance also improved. Resistance was reduced by 90% at a mixing ratio of 1:1. Extended aerobic digestion of the mixtures did not have any impact on dewatering.

All studies agreed on two major points about calcium carbonate sludge addition to wastewater treatment plants. One, there were no adverse effects on overall wastewater treatment performance, and secondly, the alum and calcium carbonate mixed with the biological floc increased density and settleability.

EXPERIMENTAL CONSIDERATIONS

Experimental Procedures

One water and two wastewater treatment plants in the city of Lafayette were selected for sampling and analytical studies. These included: (1) a 20 mgd lime softening plant; (2) a 7 mgd activated sludge treatment plant with aerobic digestion; and, (3) a 3 mgd trickling filter plant with anaerobic digestion. Smith and Loveless belt presses were used at both waste treatment plants for sludge thickening.

The sludge samples included softening sludge, raw wastewater, activated sludge mixed liquor, aerobically digested sludge, primary sludge and anaerobically digested sludge. Each sludge and its supernate or filtrate was analyzed for pH, alkalinity, total hardness, turbidity, BOD_5 and suspended solids according to "Standard Methods." (12)

Settling tests were run to determine the effect of concurrent thickening of softening sludge and the various wastewater sludges. Softening sludge was mixed with the wastewater sludge to represent 20, 40, 60 and 80% by volume mixtures. Control samples of 100% softening sludge and 100% wastewater sludge were tested along with the mixes. The six liter samples were blended on a Phipps Bird six paddle stirrer and allowed to settle. Sludge volume with respect to time was plotted to give settling curves. Three hours settling time was observed for all mixtures. The sludge and supernate were analyzed for solids content to detect solids dissolution or precipitation. A two sample "t" test was also performed to test the significance of solids dissolution or precipitation (Appendix B).

The supernate portions were analyzed for pH, alkalinity, total hardness, BOD_5, suspended solids and turbidity. Throughout the calculations for relative volume reductions and supernate improvements, dilution was taken into account.

Belt press thickening tests were performed at the West Bayou Parkway activated sludge treatment plant in the city of Lafayette to determine the effects of concurrent belt press thickening of softening sludge mixed with aerobically digested sludge. Softening sludge was mixed with the digested sludge to represent 20, 40, 60 and 80% by volume mixtures. A control sample of 100% aerobically digested sludge was tested along with the mixes. The five gallon samples were blended with a wooden paddle. The tests were run twice, once without chemical addition, and secondly, with cationic polyelectrolyte addition. In the first test, after blending was accomplished, the samples were placed on a specified media (PE CAP Mono Screen Cloth, 7-18-1000) and run through the Smith and Loveless belt press thickener. In the second test, cationic polyelectrolyte was added with a 50 ml buret to the five gallon mixtures with constant stirring until the mixture flocculated well. The mixtures were then placed on the specified media and run through the belt thickener. The sludge cake from concurrent treatment was analyzed for changes in moisture content when compared to the control wastewater sludge.

RESULTS AND DISCUSSION

Four objectives of the study were the investigation of the settling of the sludge mixtures, the dissolution or precipitation of sludge solids, the changes in supernate quality and belt press thickening of the sludge mixtures. An economic analysis of concurrent versus separate treatment of softening and wastewater sludges for the city of Lafayette was also performed. Table 1 provides the sludge solids content and supernate characteristics of the sludges tested. Appendix A provides thickening test data on the various sludge mixtures which includes supernate characteristics.

Settling

The study showed overall sludge volume reductions in nearly every case when sludge mixtures were compared to separate settling. Table 2 provides a summary of settling and volume reduction data for the various softening and wastewater sludge mixtures. Appendix B provides sample calculations for volume reduction data. The ratio of softening solids to wastewater solids was the determining factor in volume reduction with higher ratios providing more volume reductions as illustrated in figures 1, 2, 3, 4 and 5. The figures are a graphical representation of the ratio of water softening solids to wastewater sludge solids versus 60 minutes settled volume. Each figure contains at least two curves per test. The curve labeled "separate" illustrates the total volume of sludge produced by settling if the softening and wastewater

TABLE 1

Characteristics of Supernate from Softening Sludge and Wastewater Sludge

	Softening Sludge	Raw Sewage	Act. Sludge Mixed Liquor	Aerobic Dig. Sludge		Primary Sludge		Anaerobically[4] Dig. Sludge
Total Solids of Sludge (%)	2.0	0.06	0.55	1.0	3.0	3.6	4.8	5.3
% Settled Sludge[1] Volume	4.5	2.8	75.0	94.0	100.0	88.0	94.4	100.0
pH[2]	8.6	8.2	7.7	6.8	7.2	6.6	6.9	5.2
Total Hardness[2] (mg/l as $CaCO_3$)	100.0	120.0	110.0		200.0		500.0	1000.0
Alkalinity (mg/l as $CaCO_3$)	125.0	224.0	176.0		330.0		550.0	370.0
Turbidity[3] (NTU)	25.0	34.0	4.0		1000.0		1000.0	1000.0
BOD_5[3] (mg/l)	0.0	120.0	75.0		500.0		1770.0	190.0
Suspended Solids[3] (mg/l)	50.0	62.0	20.0				55.0	

[1]% sludge volume after 3 hours settling in a 1000ml graduated cylinder
[2]Filtered samples
[3]Supernate of settled sample
[4]Digester experiencing severe upset conditions.

TABLE 2

Sludge Settling Characteristics for Softening and Wastewater Sludges

Mixture	Control Soft. Sludge %S.	Control Soft. Sludge %Vol. Red.	Control WW. Sludge %S.	Control WW. Sludge %Vol. Red.	Vol. Ratio	Mix Vol(ml)	Mix Vol(ml)	Separate Settling Vol(ml)	Combined Settling Vol(ml)	% Mix Vol Red.
Raw WW.	2.06	8.0	0.06	2.8	20/80	900	35	35	35	0.0
					40/60	900	40	44	40	9.0
					60/40	900	45	53	45	15.0
					80/20	900	60	63	60	5.0
W.A.S.	1.01	4.5	.55	75.0	20/80	850	350	518	350	32.0
					40/60	850	215	398	215	46.0
					60/40	900	150	294	150	49.0
					80/20	875	85	162	85	48.0
Aero. D.S. (1)	3.15	7.1	3.02	100.0	20/80	850	845	692	845	-18.0[1]
					40/60	850	815	534	815	-34.5
					60/40	875	700	387	700	-45.0
					80/20	780	250	200	250	-20.0
(2)	3.4	7.0	1.0	94.0	20/80	500	250	397	250	37.0
					40/60	510	165	309	165	47.0
					60/40	510	105	221	105	52.0
					80/20	485	70	133	70	47.0

TABLE 2 - Cont.

Mixture	Control Soft. Sludge %S.	Control Soft. Sludge %Vol. Red.	Control WW. Sludge %S.	Control WW. Sludge %Vol. Red.	Vol. Ratio	Mix Vol(ml)	Mix Vol (ml)	Separate Settling Vol(ml)	Combined Settling Vol(ml)	% Mix Vol Red.
Primary Sludge(1)	2.1	6.8	4.8	94.4	20/80	900	715	693	715	-3.1
					40/60	900	575	535	575	-6.9
					60/40	925	460	387	460	-16.0
					80/20	950	260	231	260	-11.0
(2)	15.0	33.3	3.6	88.0	20/80	510	370	385	370	3.9
					40/60	510	310	331	310	6.3
					60/40	495	220	276	220	20.0
					80/20	490	165	221	165	25.0
Anaer. D.S.	1.0	4.4	5.3	100.0	20/80	925	870	748	870	-14.0
					40/60	915	725	565	725	-22.0
					60/40	915	430	390	430	-9.3
					80/20	900	195	212	195	-8.0

[1]% gain in volume

ABBREVIATIONS:

Raw WW. - Raw Wastewater
W.A.S. - Waste Activated Sludge
Aero. D.S. - Aerobically Digested Sludge
Anaero. D.S. - Anaerobically Digested Sludge
% S. - Solids Content in Percent
% Vol. Red. - Volume Reduction in Percent
WW. - Wastewater

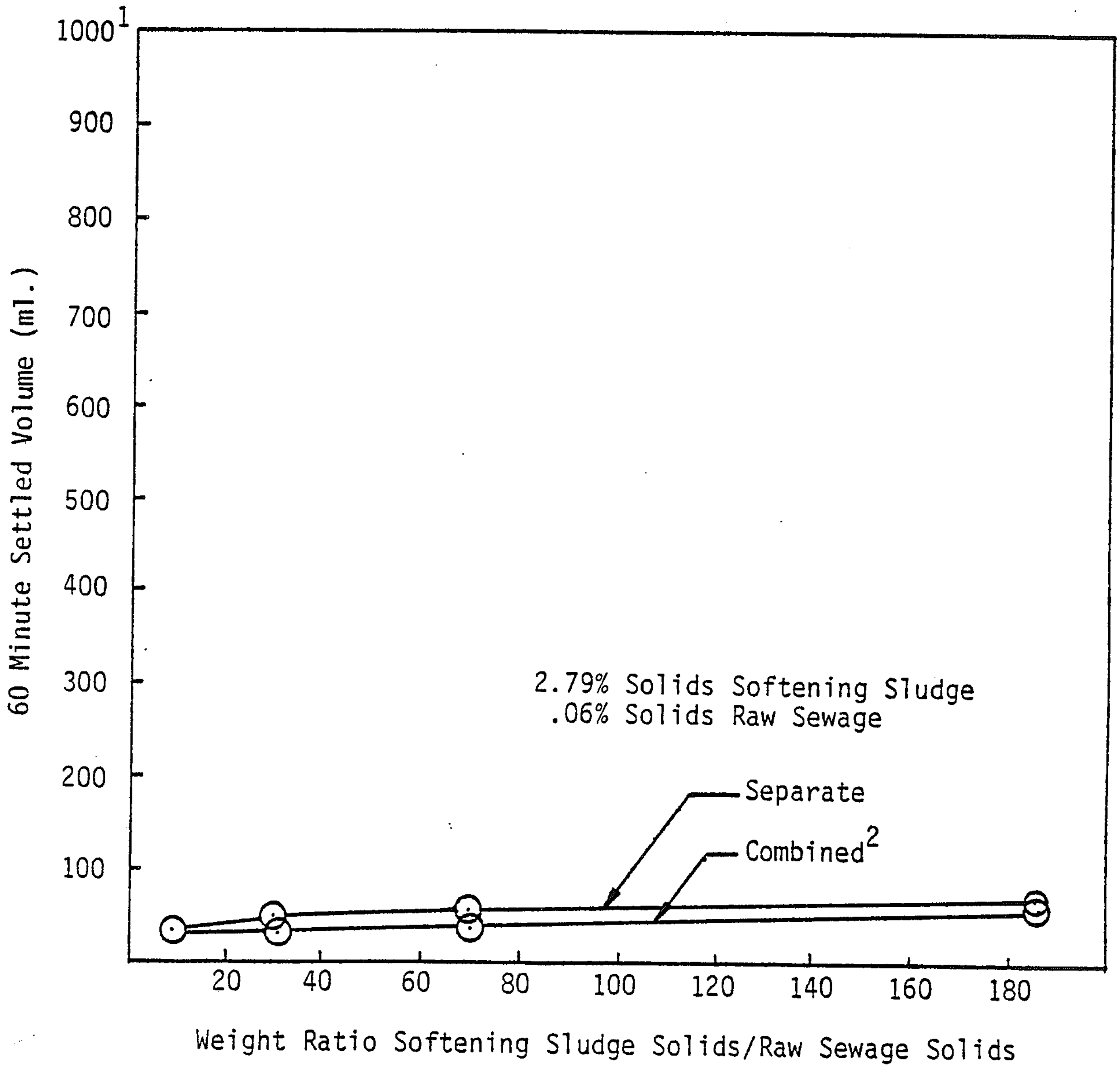


Figure 1. Combined Settling of Softening Sludge and Raw Sewage

[1]Initial Volume = 1000 ml.
[2]Net combined volume taking ratios into account - See Appendix B

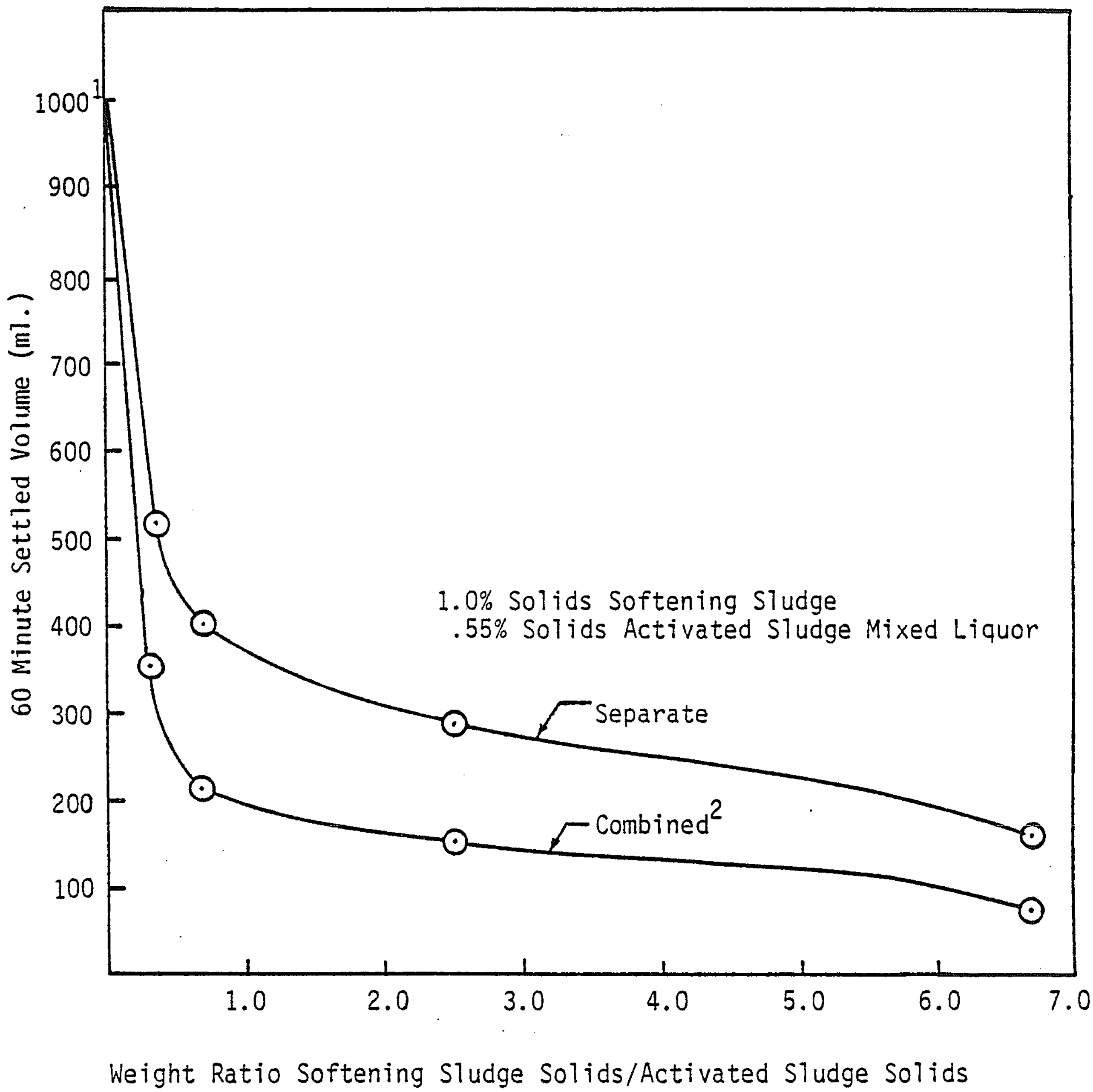


Figure 2. Combined Settling of Softening Sludge and Activated Sludge Mixed Liquor.

[1]Initial Volume = 1000 ml.
[2]Net combined volume taking ratios into account

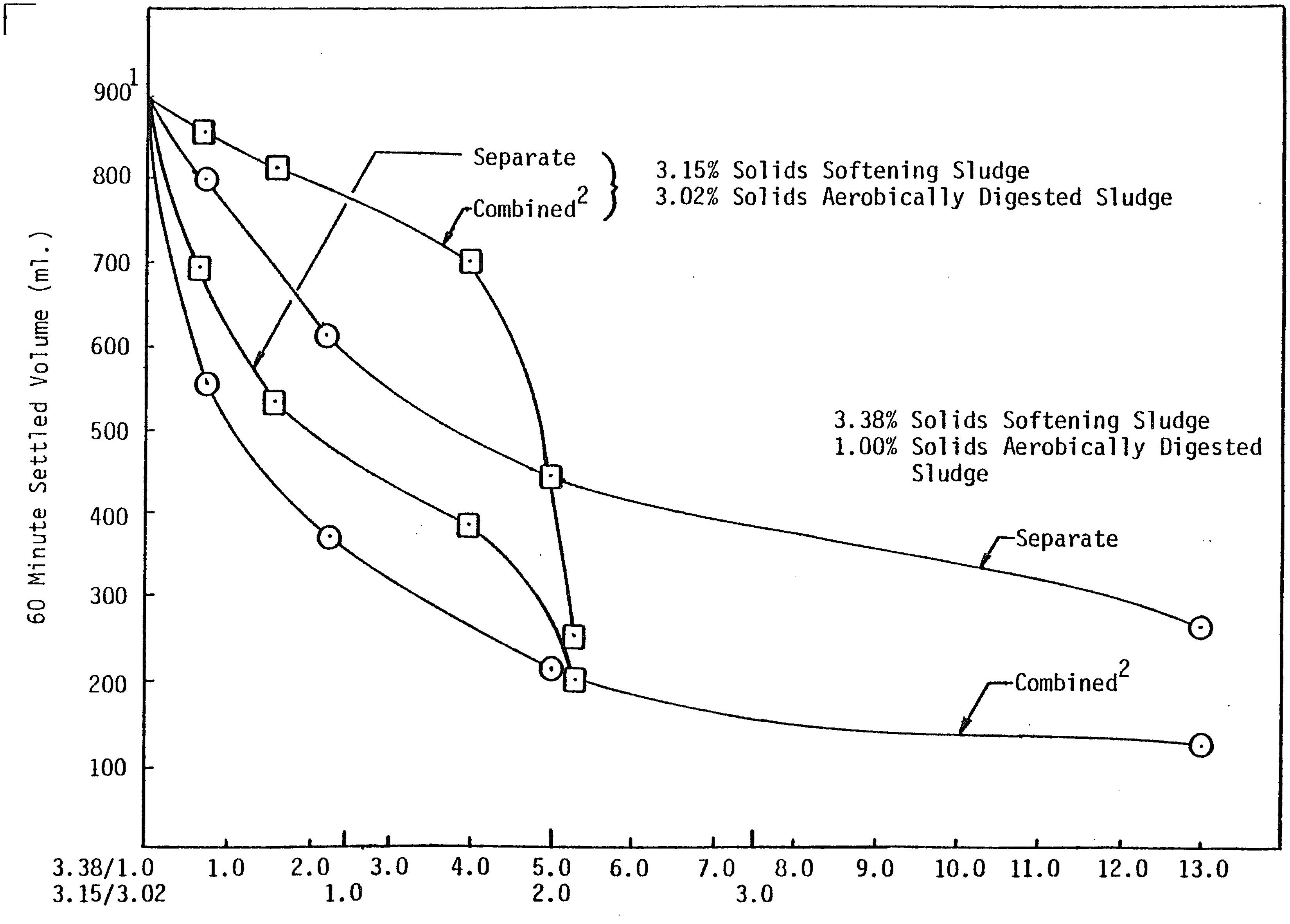


Figure 3. Combined Settling of Softening Sludge and Aerobically Digested Sludge

[1]Initial Volume = 900 ml.
[2]Net combined volume taking ratios into account

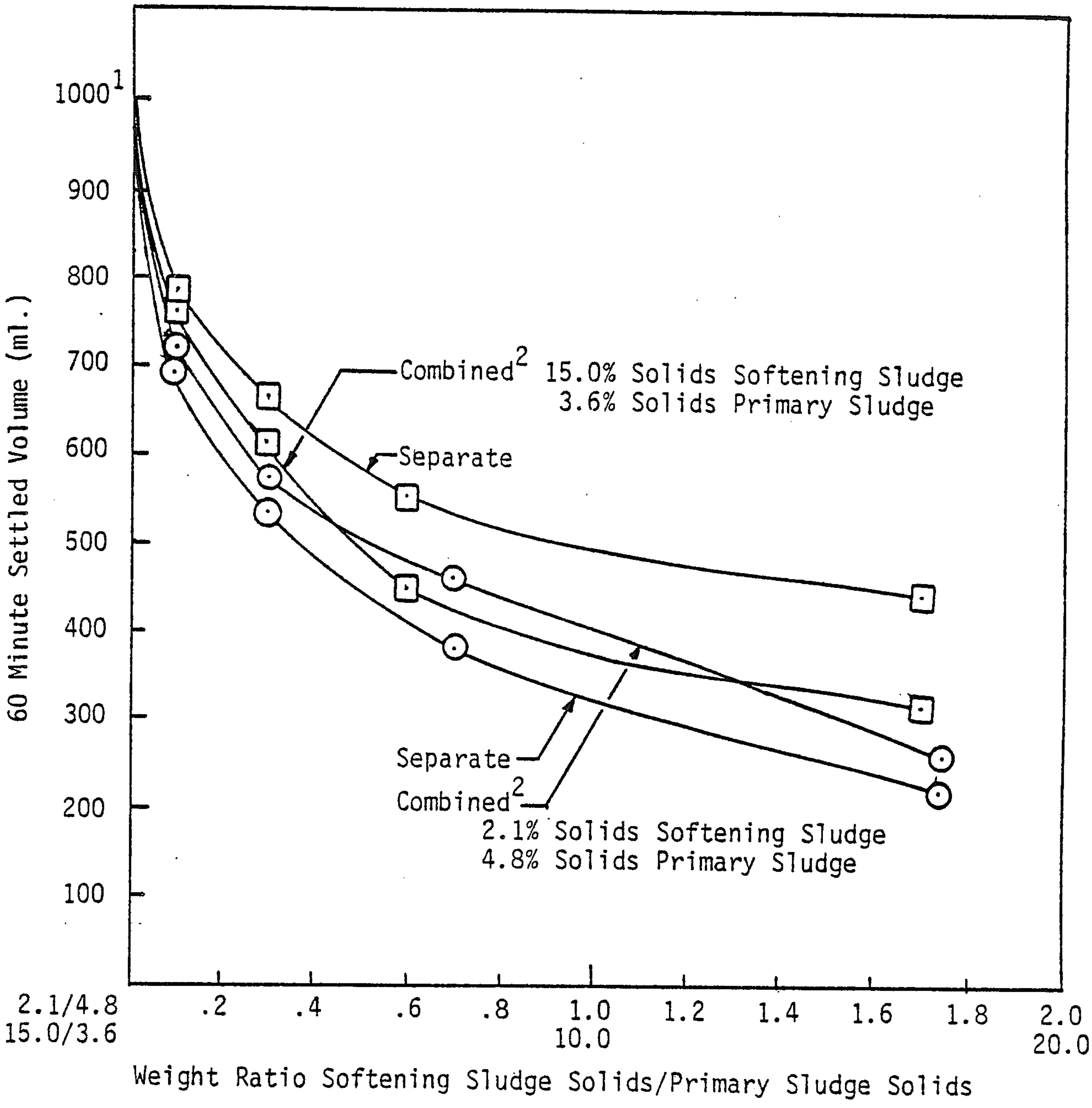


Figure 4. Combined Settling of Softening Sludge and Primary Sludge.

[1] Initial Volume = 1000 ml.
[2] Net combined volume taking ratios into account

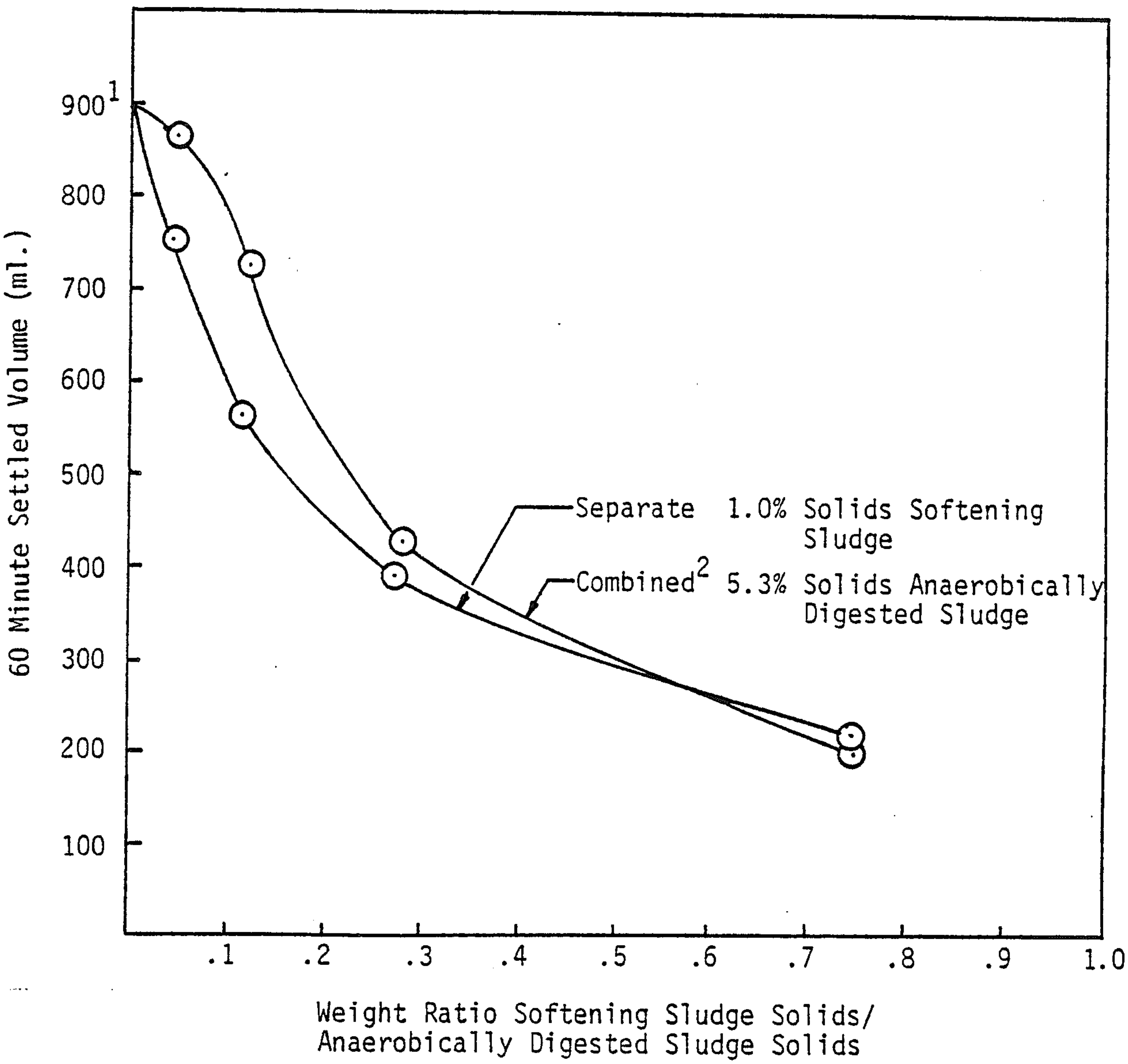


Figure 5. Combined Settling of Softening Sludge and Anaerobically Digested Sludge

[1]Initial Volume = 900 ml.
[2]Net combined volume taking ratios into account

sludges were settled separately. The curve labeled "combined" is the total volume of sludge produced when the sludges were mixed prior to settling. The curves were highly dependent upon the softening and wastewater solids concentration.

A 52% reduction was noted for softening sludge (3.4%) mixed with aerobically digested sludge (1.0%) at a 60/40(%) ratio (Table 2). This mixture provided the best volume reduction of the sludges tested. Figure 3 shows this graphically. The settling curves in Figure 1 for raw wastewater are nearly flat and horizontal due to the low amount of solids in the wastewater (0.06%). Visual observations of the mixing process revealed that the softening sludge and wastewater sludge particles appeared to agglomerate.

Sludge mixing did not reduce sludge volume when softening sludge and wastewater sludges were mixed with sludges greater than or equal to 3% solids content. The anaerobically digested sludge had a solids content of 5.3%. Digester upset made a more dilute anaerobically digested sludge unavailable as digesters were drained.

Dissolution and Precipitation

A total solids balance was performed on the sludge mixtures to determine whether solids were dissolving or precipitating. It was hypothesized that the softening sludge would dissolve in the wastewater sludge. If this occurred, there was the possibility of no-cost sludge disposal through dissolution. A statistical method utilizing a two sample "t" test with 95% confidence region was also used as part of the sensitivity analysis on the total solids balance (Appendix B). The overall solids balance showed no measurable dissolution or precipitation. The "t" test also indicated no measurable dissolution or precipitation except for the already thickened (3.02%) aerobically digested sludge mixed with (3.15%) softening sludge which indicated a slight precipitation of solids from the mixture (Table 3).

A more sensitive measure, the supernate hardness and alkalinity indicates a slight leaching of calcium carbonate into the supernate of the mixed softening and wastewater sludges (Table 4). Again dilution was taken into account in the calculation (Appendix B). The dissolution of the calcium carbonate was expected due to the biological treatment of wastewater sludge. Wastewater sludges generally contain acids in the waste, primarily carbonic acid, which is formed from the reaction of carbon dioxide and water. The chemical equation exemplifying this is: $CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2$. The dissolution of the $CaCO_3$ increases the water's alkalinity and hardness.

Another test indicating the dissolution potential is the Langelier Saturation Index, which deals with pH level as an indicator of water stability. In the Langelier test, a positive index indicates a tendency to precipitate $CaCO_3$, while a negative index indicates a tendency for $CaCO_3$ to dissolve. In the study of the various sludge mixtures, the pH of the mixed solution was between that of the control softening sludge and the control wastewater sludge. In the Langelier test (Table 5), it can be observed that the sludge mixtures were either at equilibrium or had a negative index, indicating a tendency to dissolve $CaCO_3$.

TABLE 3

Total Solids Balance and Two Sample "t" Test on Mixtures of Softening Sludge and Wastewater Sludges[1]

	Control Solids Content	Soft. Sludge / WW. Sludge	20% / 80%	40% / 60%	60% / 40%	80% / 20%	Ho: $u_1 - u_2 = 0$ Ha: $u_1 - u_2 \neq 0$ "t"	Sludge does not dissolve or precipitate Sludge does dissolve or precipitate "t" for rejection at 95% confidence level = 2.45
Softening Sludge Raw Sewage	2.79 0.06	Predicted Actual	0.606 0.38	1.15 1.00	1.69 1.76	2.24 3.4	-0.435	Accept Ho
Softening Sludge Activated Sludge	1.01	Predicted	0.64	0.73	0.83	0.92	-0.33	Accept Ho
Mixed Liquor	0.55	Actual	0.67	0.80	0.83	0.97		
Softening Sludge Aerobically Digested	3.15	Predicted	3.05	3.07	3.10	3.12	6.28	Reject Ho
Sludge	3.02	Actual	3.22	3.23	3.18	3.22		
Softening Sludge Primary Sludge	2.1 4.8	Predicted Actual	4.26 3.65	3.72 3.70	3.18 3.1	2.64 2.9	0.274	Accept Ho
Softening Sludge Anaerobic Digested	0.76	Predicted	4.39	3.48	2.58	1.7	0.06	Accept Ho
Sludge	5.3	Actual	4.0	3.3	2.7	2.0		

[1]All readings in % by weight.

TABLE 4

Typical Filtrate Characteristics for Waste Activated Sludge

Mixture	Control Soft. Sludge	Wastewater Sludge	Volume Ratio	Separate Thickening	Combined Thickened	% Hardness Gain
Total Hardness mg/l as $CaCO_3$						
Waste Activated Sludge	100	110	20/80	108	145	26.0
			40/60	106	120	12.0
			60/40	104	115	9.5
			80/20	102	105	3.0
Total Alkalinity mg/l as $CaCO_3$						
Waste Activated Sludge	125	176	20/80	166	174	4.7
			40/60	153	172	11.0
			60/40	145	161	10.0
			80/20	135	145	7.0

TABLE 5

Langelier Saturation Index Table for the Various Sludge Mixtures

		Control	Control	Mixture (%)			
		Soft. Sludge	Waste Sludge	20/80	40/60	60/40	80/20
Raw Wastewater	pH	9.0	8.0	8.4	8.3	8.3	8.7
	pHs	8.6	8.2	8.0	8.3	8.3	8.4
	(−,+)	+0.4	−0.2	+0.4	0.0	0.0	+0.3
Activated Sludge Mixed Liquor	pH	8.8	7.4	7.7	7.8	8.1	8.2
	pHs	8.6	8.2	8.2	8.2	8.2	8.3
	(−,+)	+0.2	−0.8	−0.5	−0.4	−0.1	−0.1
Aerobically Digested Sludge	pH	8.1	7.2	7.2	7.5	7.6	7.8
	pHs	8.2	7.7	7.8	7.9	7.8	8.0
	(−,+)	−0.1	−0.5	−0.6	−0.4	−0.2	−0.2
Primary Sludge	pH	9.0	6.9	7.2	7.4	7.5	7.7
	pHs	9.0	7.2	7.35	7.4	7.4	7.7
	(−,+)	0.0	−0.3	−0.15	0.0	+0.1	0.0

Supernate Quality

Mixing softening sludge and wastewater sludge improved the quality of supernate from thickening thereby reducing BOD_5 and suspended solids returning to the plant. Biochemical oxygen demand and suspended solids reductions ranged from 20-90% when comparing separate and concurrent treatment. Table 6 shows at optimum mix supernate improvements in the various mixtures of softening and wastewater sludges. Dilution was also taken into account in the calculation (Appendix B). The improvement in the supernate quality was due to improved solids capture of the organics and suspended solids in the mixture. This is in agreement with other studies done on the subject. (4) (8) (10) (14)

Belt Press Thickening

Belt press thickening of the mixed sludge without chemical addition was not successful on the media used for the experiment. This was also true for digested sludge without chemical addition. Cationic polyelectrolyte addition made thickening possible. A 4% increase in cake solids was observed when 20% by volume softening sludge was added to aerobically digested sludge with a 160 mg/l polymer dosage. Further softening sludge addition decreased the water content (Table 7). The dewatered sludge became sticky as more softening sludge was added to the mixture.

TABLE 6

Typical Supernate Characteristics of Mixed Sludges

Wastewater Sludge	Volume Ratio[1]	Control Soft. Sludge	Control WW. Sludge	Separate	Combined	Net Reduction (%)
Raw Wastewater						
BOD_5 (mg/l)	60/40	0.0	120.0	48.0	36.0	25.0
Suspended Solids (mg/l)		23.0	62.0	39.0	25.0	35.0
pH		8.6	8.2		8.4	
Waste Activated[3]						
BOD_5 (mg/l)	60/40	0.0	75.0	30.0	4.0	87.0
Suspended Solids (mg/l)		58.0	20.6	43.0	44.0	-2.3[4]
pH		8.8	7.6		8.2	
Aerobically Digeste						
BOD_5 (mg/l)	60/40	0.0	500.0	200.0	80.0	60.0
Suspended Solids (mg/l)[2]		194.0	22.0	127.2	27.0	78.0
pH		8.1	7.2		6.5	
Primary Sludge						
BOD_5 (mg/l)	60/40	0.0	1770.0	708.0	570.0	20.0
Suspended Solids (mg/l)		55.0	1339.0	569.0	108.0	81.0
pH		9.01	6.9		7.5	

[1]Gave maximum settled sludge volume reduction of softening sludge to wastewater sludge.
[2]Second test on aerobic digested. First test produced no supernate to compare.
[3]Obtained sample from sludge return pumps.
[4]% gain

TABLE 7

Dewatering of Mixed Sludges by 160 mg/1 Polymer Addition on Smith and Loveless Sludge Thickener

Ratio Softening Sludge to Aerobically Digested Sludge	Water Content %	Cake Solids %
Control (ADS) 40/60	92%	8%
20/80	88%	12%
40/60	90.4%	10%
60/40	76%	24%
80/20	66%	34%

ECONOMIC EVALUATION

Evaluation of Three Alternatives

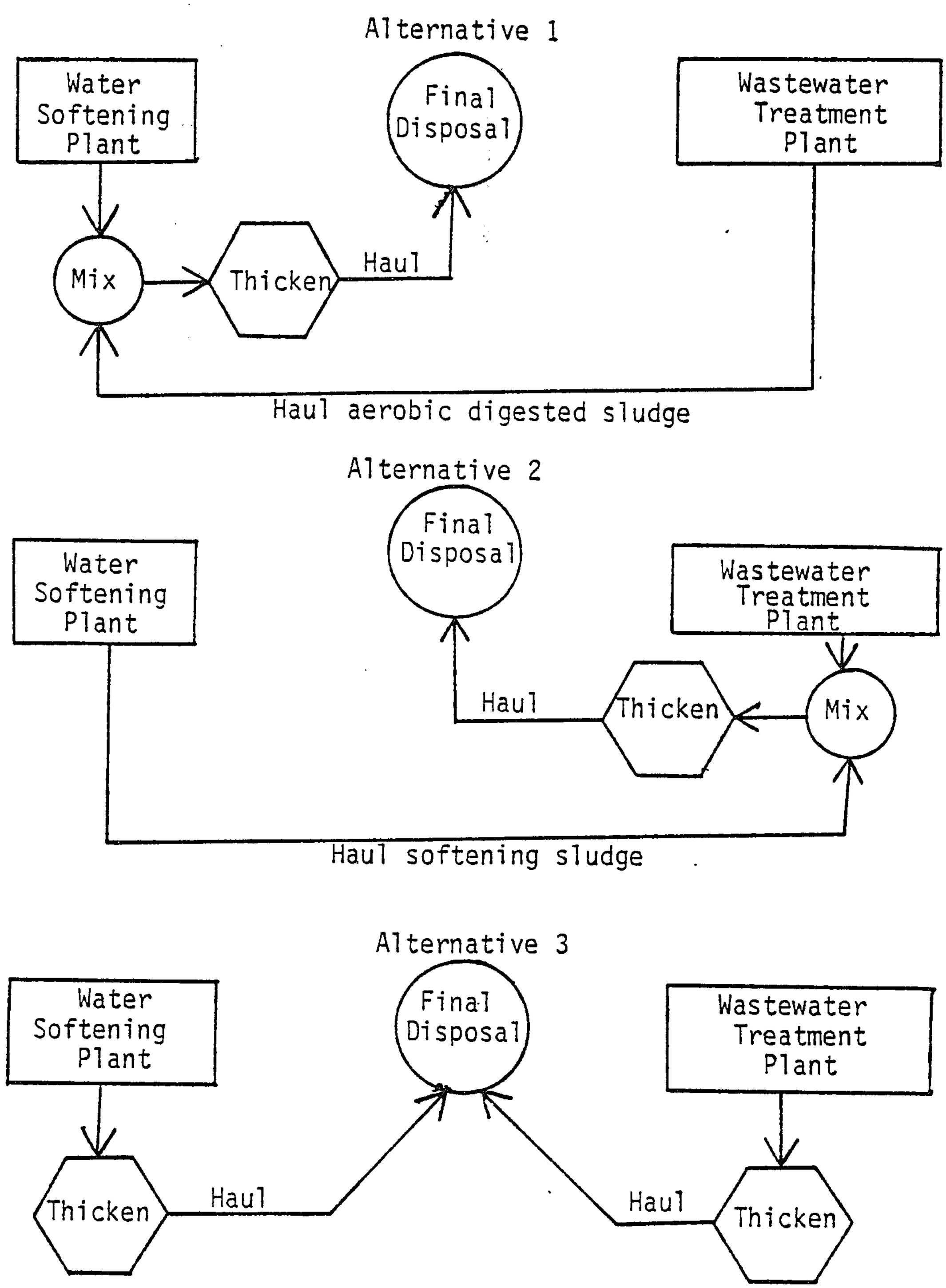
An economic analysis indicates that aerobically digested sludge (depending on total solids) should be mixed with softening sludge, thickened and transported to disposal facilities. At present, softening sludge and wastewater sludges are thickened and transported separately. Co-treatment would reduce haul volumes and eliminate capital equipment. Cost savings involved are dependent upon the distance between the water and wastewater plants. By mixing the sludge, thickening units at one of the plants could be eliminated. The following study is based upon the use of gravity sludge thickeners.

Three hypothetical alternatives were evaluated with cost figures from the city of Lafayette sludge hauling operations. The first two alternatives involve sludge mixing and are compared to a third alternative which considers gravity separate thickening and hauling. Figure 6 is a schematic of each alternative.

The first alternative involves trucking the aerobically digested sludge to the water softening plant which is presently equipped with a gravity sludge thickener. A holding tank would be required to facilitate sludge blending. The thickened mixed sludge would then be hauled by truck to final disposal. The supernate would be recycled into the waste treatment plant via the city sewers. This proposal eliminates thickening equipment at the wastewater treatment plant. The disadvantages of this proposal would be increased hydraulic loading to the

FIGURE 6

Schematic Diagram for Three Alternatives



wastewater treatment plant and the public health problem of transporting wastewater sludges to a city water treatment plant site where possible contamination of the treated water supplies might occur.

The second alternative entails trucking the water softening sludge to a thickener at the waste treatment plant. A holding tank would be needed to facilitate blending. The advantage of this alternative is the sludge could be handled at an existing waste treatment site. The supernate would not cause an overload on the organic and suspended solids loading, but increases in hydraulic loading would be expected.

The third alternative would involve separate gravity thickening and hauling of sludges to final disposal from the softening and waste treatment plant.

The economic analysis for the comparison of the three alternatives is shown in Table 8. For the city of Lafayette, the sludge production ratio is 1:4 softening to aerobic digested sludge. Therefore, the data on volume reduction for a 20:80 mix from Table 2 was used in the analysis. The first proposal indicated that it was not feasible to haul the aerobically digested sludge to the softening plant due to quantity of sludge to be hauled. The second alternative indicated that it was more economical to haul softening sludge to the wastewater treatment facility. The operation and maintenance savings resulting from the second proposal was 16% over the existing cases. A savings of approximately $50.00 per day would result by transporting the water softening sludge to the wastewater treatment plant for gravity thickening and final disposal instead of gravity thickening and final disposal of each sludge treated separately.

TABLE 8

Economic Comparison of Three Alternatives

	Separate Thickening Alternative 3		Concurrent Thickening			
	Softening Plant	Wastewater Plant	Alternative 1		Alternative 2	
Sludge/day						
Production (gal)	14,000.0	60,000.0				
Thickened Vol.[1] (gal)	5,950.0[2]	56,400.0[3]	44,400.0[4]		44,400.0	
Truck Size (gal)	2,800.0	2,800.0	2,800.0		2,800.0	
Haul Cost $/mile	.60	.60	.60	.60	.60	.60
Haul Distance Round Trip (miles)	20	20	10[5]	20	10	20
Trips/day	2	20	21	16	5	16
Total Cost/day	$24.00	$240.00	$126.00	$192.00	$30.00	$192.00
Total Combined Cost/day	$264.00		$318.00		$222.00	
% Savings/day			-20		16.0	

[1]Separate thickening from Table 2. 3.4% softening sludge and 1.0% aerobic digested sludge.
[2]Soften sludge settled 7% by volume. 14,000(7%) = 980 gallons use 8% minimum haulable 14,000(3.4)/8 = 5950 gallons
[3]Aerobically digested settled 94% by volume 94%(60,000) = 56,400 gallons
[4]Concurrent mixing 20:80 ratio softening to aerobic digested sludge reduced the volume of sludge by 40% (Table 2).
[5]Round trip distance between softening and waste treatment plant.
[6]Increase in cost/day over separate thickening.

CONCLUSION AND RECOMMENDATIONS

Conclusions

Co-treatment of sludges can benefit both the water softening plant and wastewater plant in sludge handling problems. It can turn a voluminous nuisance at the water softening plant into a tool in which wastewater treatment plants could employ to reduce their sludge volumes. In this study, the following conclusions can be made:

1. Softening sludge when mixed with wastewater sludges in nearly all cases reduced thickening sludge volumes in the range of 4 to 52%. The ratio of softening sludge solids to waste sludge solids was the key factor influencing volume reductions. Higher ratios provided higher volume reductions.

2. Visually, the sludges blended well and the softening sludge agglomerated the waste solids in the mixtures.

3. Total solids balances indicated negligible dissolution and precipitation. Slight increases in alkalinity and total hardness were observed in the supernate. This could be attributed to leaching of $CaCO_3$ into the solution as predicted by the Langelier Saturation Index.

4. Co-treatment of the softening sludge with the wastewater sludge significantly improved supernate characteristics when compared to separate settling. Five day biochemical oxygen demands and suspended solids in the mixed sludge supernate were reduced in the range of 20 to 90%. The improvement in the supernate quality was due to improved solids capture of the organics and suspended solids in the mixture. Less organic loading on the waste treatment facility would be expected if the supernatant water is recycled into the plant for treatment.

5. Belt press thickening was accomplished by the addition of a cationic polyelectrolyte to softening and aerobically digested sludge mixtures. A 4% increase in cake solids was observed when 20% by volume softening sludge was added to aerobically digested sludge with a 160 mg/l polymer dosage. Further increase in softening sludge addition increased cake solids and the stickiness of thickened sludge.

6. The economic analysis indicated a 16% daily hauling savings of approximately $50.00 per day by transporting the water softening sludge to the wastewater treatment plant for gravity thickening and final disposal.

7. The softening sludge should be hauled to the waste treatment plant due to the differences in sludge quantities produced.

8. A major benefit which could result is the elimination of thickening units at one of the plants.

Recommendations

It is recommended that water softening and wastewater treatment plants be placed closer together in future planning. Transport systems should also be designed to facilitate the consolidation of the sludge treatment processes of the water softening and wastewater treatment plants. Feasibility studies should be performed on existing facilities to determine if with equipment renovation and future interest rates whether this study would be economically feasible. Another area which needs to be studied is the belt press operation on concurrent sludge mixing as a feasibility analysis on its collection and treatment.

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APPENDIX A

Thickening Tests of Various Sludge Mixtures

1. Thickening Characteristics of Raw Wastewater and Softening Sludge Mixtures (Average Values of Two Tests)

	Control		Mixture Ratios (%)			
	Softening Sludge	Raw Sewage	20/80	40/60	60/40	80/20
Settling Volume						
Initial (ml)	875.0	900.0	900.0	900.0	900.0	900.0
Final (ml)	70.0	25.0	35.0	40.0	45.0	60.0
pH	8.6	8.2	8.6	8.4	8.4	8.6
Total Alkalinity[1] (mg/l $CaCO_3$)	123.0	224.0	279.0	209.0	187.0	165.0
Total Hardness[1] (mg/l $CaCO_3$)	65.0	120.0	90.0	100.0	100.0	90.0
Turbidity (NTU)[2]	26.0	34.0	36.0	27.0	23.0	30.0
BOD_5 (mg/l)[2]	0.0	120.0	87.0	62.0	36.0	19.5
COD (mg/l)[2]	28.0	308.0	108.0	136.0	72.0	52.0
TSS (mg/l)[2]	23.0	62.0	52.0	32.0	25.0	54.0
Total Sludge Solids (%)	2.0	0.06	0.38	1.0	1.8	3.4

[1]Filtered supernate of settled samples
[2]Unfiltered supernate of settled samples

2. Thickening Characteristics of Primary Sludge and Softening Sludge Mixtures (Average Values of Two Tests)

	Control		Mixture Ratios (%)			
	Softening Sludge	Primary Sludge	20/80	40/60	60/40	80/20
Settling Volume						
Initial (ml)	880.0	900.0	900.0	900.0	925.0	950.0
Final (ml)	60.0	850.0	715.0	575.0	460.0	260.0
pH	9.0	6.9	7.2	7.4	7.5	7.7
Total Alkalinity[1] (mg/l $CaCO_3$)	110.0	550.0	550.0	476.0	472.0	312.0
Total Hardness[1] (mg/l $CaCO_3$)	120.0	500.0	500.0	420.0	400.0	260.0
Turbidity (NTU)[2]	13.0	——[3]	93.0	86.0	65.0	36.0
BOD_5 (mg/l)[2]	0.0	1770.0	1065.0	645.0	570.0	276.0
COD (mg/l)[2]	27.0	4410.0	2508.0	1710.0	1444.0	760.0
TSS (mg/l)[2]	55.0	1339.0	348.0	137.0	108.0	40.0
Total Sludges Solids (%)	2.1	4.8	3.65	3.7	3.1	2.9

[1]Filtered supernate of settled samples
[2]Unfiltered supernate of settled samples
[3]No supernate available for testing.

3. Thickening Characteristics of Anaerobically Digested Sludge and Softening Sludge Mixtures (One Test)

	Control		Mixtures Ratios (%)			
	Softening Sludge	Anaerobic Dig. Sludge	20/80	40/60	60/40	80/20
Settling Volume						
Initial (ml)	900.0	1000.0	925.0	915.0	915.0	900.0
Final (ml)	40.0	1000.0	870.0	725.0	430.0	195.0
pH	8.2	5.2	5.1	6.1	7.2	6.2
Total Alkalinity[1] (unfiltered) (mg/l $CaCO_3$)	300.0	880.0	1210.0	1116.0	623.0	1173.0
BOD_5 (mg/l)[2]	0.0	190.0	169.0	174.0	168.0	174.0
Total Sludge Solids (%)	0.76	6.3	4.0	3.3	2.7	2.0

[1]Supernate of settled sample
[2]Unfiltered supernate of settled sample

4. Thickening Characteristics of Activated Sludge Mixed Liquor and Softening Sludge Mixtures (Average of Two Tests)

	Control		Mixture Ratios (%)			
	Softening Sludge	Act. Sludge Mixed Liq.	20/80	40/60	60/40	80/20
Settling Volume						
Initial (ml)	1000.0	1000.0	850.0	850.0	900.0	875.0
Final (ml)	45.0	750.0	350.0	215.0	150.0	85.0
pH	8.8	7.7	7.7	7.9	8.2	8.4
Total Alkalinity[1] (mg/l $CaCO_3$)	125.0	176.0	174.0	172.0	161.0	125.0
Total Hardness[1] (mg/l)($CaCO_3$)	100.0	110.0	145.0	120.0	115.0	105.0
Turbidity (NTU)[2]	26.0	4.0	6.0	7.0	9.0	17.0
BOD_5 (mg/l)[2]	5.0	75.0	11.0	9.0	4.0	4.0
COD (mg/l)[2]	0.0	58.2	20.0	15.5	15.5	11.6
TSS (mg/l)[2]	58.0	21.0	23.0	34.0	44.0	53.0
Total Sludge Solids (%)	1.0	0.6	0.7	0.8	0.83	0.97

[1]Filtered supernate of settled samples
[2]Unfiltered supernate of settled samples

5. Thickening Characteristics of Aerobically Digested Sludge and Softening Sludge Mixtures (Average of Two Tests)

	Control		Mixture Ratios (%)			
	Softening Sludge	Aero. Dig. Sludge	20/80	40/60	60/40	80/20
Settling Volume						
Initial (ml)	700.0	1000.0	850.0	850.0	875.0	780.0
Final (ml)	50.0	1000.0	845.0	815.0	700.0	250.0
pH	8.1	7.25	7.2	7.5	7.6	7.8
Total Alkalinity[1] (mg/l $CaCO_3$)	124.0	330.0	220.0	240.0	233.0	194.0
Total Hardness[1] (mg/l $CaCO_3$)	100.0	200.0	165.0	165.0	180.0	148.0
Turbidity (NTU)[2]	27.0	——[3]	——[3]	28.0	13.0	7.0
BOD_5 (mg/l)[2]	0.0	500.0	219.0	172.0	80.0	36.0
COD (mg/l)[2]	27.0	314.0	287.0	210.0	136.0	70.0
TSS (1) (mg/l)[2]	751.0	——[3]	——[3]	2001.0	763.0	748.0
TSS (2) (mg/l)[2]	194.0	22.0	5.0	15.0	27.0	22.0
Total Sludge Solids (%) (1)	3.15	3.02	3.22	3.23	3.18	3.22

[1]Filtered supernate of settled samples
[2]Unfiltered supernate of settled samples
[3]No supernate available for testing.

APPENDIX B

SAMPLE CALCULATIONS

Introduction

Throughout this study, comparisons were made between tests on separate and combined sludge samples. For example, it was of interest to compare the sludge produced from separate thickening of water and wastewater sludges with the sludge volume produced by the thickened mixture of the two sludges. Results from such a test are listed below:

Sample	Sample Volume (ml)	Sludge Volume (ml)
Waste Activated Sludge	1000	50
Water Softening Sludge	1000	200
40/60 Mix WAS/WSS	1000	150

From this raw data, it is not directly observable whether the sludge produced from separate thickening is greater than or less than that from combined settling. The appropriate question is, "If equal volumes of sludge are thickened both mixed and combined, how does the total sludge production compare?" From the data, 1000 ml of a 40/60 mix of waste activated sludge and water softening sludge produced 150 ml or 15% by volume of sludge while 400 ml of WAS and 600 ml of WSS produced (0.4)(50) = 20 ml and (0.6)(200) = 120 ml respectively, or a total of 140 ml per 1000 ml of sludge thickened separately or 14% sludge production. In tabular form, the data would be presented as follows:

Sample	Sample Volume (ml)	Sludge Volume (ml)	% Sludge Production	Sludge Ratio	Net Sludge Production Comparison (%)
(Separate) Waste Act. Sludge	1000	50	5.0	40%	2.0
(Separate) Water Soft. Sldg.	1000	200	20.0	60%	12.0
			Separate Settling of the Sludges =		14.0
(Combined) 40/60 Mix WAS/WSS	1000	150	15.0		15.0

The comparison shows that 14.0% of the sludge would be produced for separate thickening and 15.0% from combined thickening of 40/60 mixes of Waste Activated Sludge and Water Softening Sludge. This test would result in a gain in sludge volume by approximately 7%. This represents a valid comparison. Similar reasoning was used for other characteristics such as alkalinity, hardness, solids concentrations, etc.

1. Percent Sludge Volume Reductions or Gains

Softening Sludge to Raw Sewage Ratio = 20/80

Control Sludge Volume Reductions

Softening Sludge = 8.0%

Raw Waste Water = 2.8%

Calculations

900 ml (.20)(8.0%)	=	14.4 ml
900 ml (.80)(2.3%)	=	20.2 ml
Separate thickening	=	34.6 ml
Combined thickening	=	35.0 ml

$$\% \text{ Volume Reduction} = \frac{34.6 - 35}{35}$$

$$= -0.0114$$

or 1.14% increase in volume

2. Percent Supernate Characteristics Reduction or Gain

Softening Sludge to Waste Activated Sludge = 20/80

Typical Hardness or Other Supernate Characteristic

Control Sludge Hardness

Softening Sludge = 100 mg/l as $CaCO_3$
Waste Activated Sludge = 110 mg/l as $CaCO_3$

Calculations

.20(100) =	20 mg/l
.80(110) =	88 mg/l
Separate Thickening =	108 mg/l
Combined Thickening =	145 mg/l

$$\text{\% Hardness Reduction or Gain} = \frac{108 - 145}{145} = -26\%$$

or 26% Gain

3. Total Solids Balance

Softening Sludge to Waste Activated Sludge Ratio = 20/80

Control Sludge Solids Content (%)

Softening Sludge	=	1.01%
Waste Activated Sludge	=	0.55%

Calculations:

1.01(.20)	=	0.202%
0.55(.80)	=	0.440%
Separate Thickening	=	0.642%
Combined Thickening	=	0.670%

4. Two Sample "t" Test

Data:

	Control Solids Content (%)
Softening Sludge	2.79
Raw Sewage	0.06

Solids Balance Data

Softening Sludge	20%	40%	60%	80%	"t"	Accept or Reject
W. W. Sludge	80%	60%	40%	20%		Hypothesis
Predicted	0.606	1.15	1.69	2.24	-0.435	Accept
Actual	0.380	1.00	1.76	3.40		

Calculations

Predicted: $\Sigma X_1 = 0.606 + 1.15 + 1.69 + 2.24 = 5.086$, $\quad \overline{X}_1 = 5.086/4 = 1.27$
$\Sigma(X_1)^2 = 0.367 + 1.322 + 2.856 + 5.011 = 9.56$, $\quad (S_1)^2 = 1.03$

Actual: $\Sigma X_2 = 0.38 + 1.00 + 1.76 + 3.4 = 6.54$, $\quad \overline{X}_2 = 6.54/4 = 1.63$
$\Sigma(X_2)^2 = 0.144 + 1.00 + 3.09 + 11.56 = 15.79$, $\quad (S_2)^2 = 1.70$

$t = 1.27 - 1.63/[(4 - 1)(1.03) + (4 - 1)(1.70)/(4 + 4 - 2)(1/4 + 1/4)]^{1/2}$
$t = -0.435$
at an x = .05 degrees of freedom = 6
"t" for rejection is equal to 2.45
$-0.435 < 2.45$ Accept Ho: There is no dissolution or precipitation $(u_1 - u_2 = 0)$

Hypothesis:

Ho: There is no dissolution or precipitation $(u_1 - u_2 = 0)$
Ha: There is dissolution or precipitation $(u_1 - u_2 \pm 0)$

Formulas used:

1) $\overline{X} = \Sigma X/n$

2) $S^2 = \dfrac{\Sigma X^2 - (\Sigma X)^2/n}{n-1}$

3) $t = \dfrac{\overline{X}_1 - \overline{X}_2}{[(n_1 - 1)(S_1^2) + (n_2 - 1)(S_2^2)/(n_1 + n_2 - 2)](1/n_1 + 1/n_2)}$