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Project Summary

Destruction and Stabilization of Sludge by Multiple-Stage Digestion and Thermal Treatment

Yeun C. Wu

A study was conducted to compare the performance of conventional single-stage anaerobic sludge digestion with three-stage anaerobic sludge digestion. The conventional digester and the first two stages of the multiple-stage system were operated at 35°C; the third stage was maintained at 49°C. The effluent sludges from both processes were further treated by wet air oxidation (WAO).

Study results indicated that multiple-stage digestion outperformed conventional single-stage digestion in terms of reducing chemical oxygen demand (COD) and volatile solids (VS) and producing methane. The multiple-stage system's first two stages alone achieved a greater degree of sludge stabilization, COD and VS destruction, and methane production than did the single-stage system. The WAO process achieved 86% VS reduction at 250°C.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Recent research on the anaerobic digestion of wastewater sludge has suggested that separation of the digestion process into stages can improve performance. Two methods of separation have been used: either a mesophilic stage followed by a thermophilic stage, or an acid-forming stage followed by a methane-forming stage. This project combined these two methods by using the following three stages: a hydrolyzing (mesophilic) stage, followed by an acid-forming (mesophilic) stage, followed by a methane-forming (thermophilic) stage.

Materials and Methods

The multiple-stage system consisted of three Plexiglas* digesters in series with effective volumes of 23, 114, and 68 L. The digesters were well mixed with mechanical stirrers and were heated to maintain temperatures of 35°, 35°, and 49°C, respectively. The feed rates to the multiple-stage system were 0.42, 0.57, and 0.95 L/hr over three operating periods, producing overall solids retention times (SRT's) of 20, 15, and 9 days. Chemical oxygen demand (COD) loadings ranged from 2.4 to 8.8 kg COD/m^3-day, and volatile solids (VS) loadings ranged from 1.3 to 4.0 kg VS/m^3-day.

A 102-L, single-stage, Plexiglas digester was also run at 35°C to act as a control. The feed rate to this digester was controlled to yield the same SRT and loadings as the overall multiple-stage system for each operating period.

The feed sludge for both the multiple-stage and control systems was a mixture of primary and secondary sludges from the Allegheny County Sanitary Authority in Pittsburgh, Pennsylvania (Table 1).

The digested sludges were further treated by a wet air oxidation (WAO) process. The WAO apparatus was a 3.78-L titanium unit supplied by an autoclave vendor. Tests were run at 1.4 x 10^7 pascal (Pa) (2100 psi) and at temperatures up to 300°C.

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use

Table 1. *Feed Sludge Characteristics*

Parameter	Mean
COD (mg/L)	68,000
Total solids (%)	5.1
Volatile solids (%)	3.2
Lipids (% of TS)	18
Carbohydrates (% of TS)	23
Protein (% of TS)	44
pH (range)	5.2 to 6.7
Alkalinity (mg/L as $CaCO_3$	250
NH_3-N (mg/L)	410
Organic-N (mg/L)	1800
Soluble-P (mg/L)	30
Volatile acids (mg/L)	2800
COD/N/P ratio	1000/6/0.5

Results

Reductions in COD, VS, lipids, carbohydrates, and protein are shown in Tables 2 through 6, respectively. The reductions shown are based on quantities entering the first stage. Mean coliform reductions were 1.3, 1.6, 2.0, and 4.9 logs for Stages 1, 2, 3, and the overall multiple-stage system, respectively. A 2.3-log coliform reduction was achieved in the control system. Metals (Cd, Cu, Mn, Ni, Pb, and Zn) partitioned to the sludge rather than the supernatant in the effluents from both systems.

Table 2. *COD Reduction (%)*

	SRT (days)		
Type of System	9	15	20
Three-Stage:			
Stage 1	9	13	20
Stage 2	28	38	27
Stage 3	6	8	7
Overall	44	59	54
Control	32	42	44
Sum of Stages 1 and 2	37	51	47

Table 3. *Volatile Solids Reduction (%)*

	SRT (days)		
Type of System	9	15	20
Three-Stage:			
Stage 1	12	17	25
Stage 2	41	40	27
Stage 3	8	10	8
Overall	60	67	59
Control	44	51	49
Sum of Stages 1 and 2	53	57	52

Table 4. *Lipid Reduction (%)*

	SRT (days)		
Type of System	9	15	20
Three-Stage:			
Stage 1	2	26	22
Stage 2	39	34	35
Stage 3	15	11	13
Overall	56	71	70
Control	45	57	61
Sum of Stages 1 and 2	41	60	57

Table 5. *Carbohydrate Reduction (%)*

	SRT (days)		
Type of System	9	15	20
Three-Stage:			
Stage 1	19	28	35
Stage 2	40	35	23
Stage 3	10	13	12
Overall	69	75	70
Control	42	43	34
Sum of Stages 1 and 2	59	63	58

Table 6. *Protein Reduction (%)*

	SRT (days)		
Type of System	9	15	20
Three-Stage:			
Stage 1	17	15	17
Stage 2	13	16	6
Stage 3	7	11	5
Overall	37	41	28
Control	20	25	21
Sum of Stages 1 and 2	30	31	23

Total methane yield and normalized methane production (i.e., rate per unit volume of the digester) are presented in Tables 7 and 8. The percentage of methane in the digester gas ranged from 22% to 46%, 69% to 71%, 65% to 69%, and 65% to 69% for the Stages 1, 2, 3, and control digesters, respectively.

The WAO studies showed that little volatile solids destruction occurred below 180°C. Destruction rates increased rapidly for temperatures from 180° to 250°C, with little further increase in destruction above 250°C. A constant 86% VS destruction was achieved at 250°C. Dewatered sludge filter cake (>4% VS) was not destroyed as effectively as wet sludge, probably because of an oxygen-limiting condition.

Most of the metals in the WAO effluent were associated with the solids, but Cu was always found in the filtrate (≤= 11 mg/L). Mn (≤= 1.3 mg/L), Ni (≤= 2.0 mg/L), and Zn (≤= 8.5 mg/L) were occasionally found in the filtrate, but Cd and Pb never were.

Table 7. *Methane Yield (L/day)*

	SRT (days)		
Type of System	9	15	20
Three-Stage:			
Stage 1	3	9	17
Stage 2	196	160	103
Stage 3	47	37	21
Overall	247	206	141
Control	81	60	49
Sum of Stages 1 and 2	199	169	120

Table 8. *Methane Production Rate (L/day per L of digester)*

	SRT (days)		
Type of System	9	15	20
Three-Stage:			
Stage 1	0.1	0.3	0.8
Stage 2	1.7	1.5	0.9
Stage 3	0.7	0.4	0.3
Overall	1.2	1.0	0.7
Control	0.8	0.6	0.5

Conclusions

The multiple-stage system outperformed the single-stage system as the parameters in Tables 2 through 8 indicate. In fact, the first two stages of the multiple-stage system were together more efficient than the entire control system, even though the total retention time was 35% shorter.

Although the original intent was to maximize methane production in the third stage, the second stage of the multiple-stage system had a greater total methane yield and production rate than both the third stage and the control system. The retention time in the second-stage digester was only 55% that in the control digester.

The need for the third stage of the multiple-stage system was questionable. The third stage gave several benefits that would have to be weighed against the costs of adding a third stage: an additional 2.0-log reduction in coliforms, a 15% to 19% increase in methane, a 6% to 9% further reduction of COD, and an 8% to 11% further reduction of VS (percentage of reduction based on quantities entering the first stage).

Separation of the digestion process into stages did not create a need for chemical addition to control alkalinity and pH.

Although the digestion process was separated into stages, hydrolytic and liquefying reactions occurred in all three digesters of the multiple-stage system, as evidenced by reductions in lipids, proteins, and carbohydrates in all three digesters. Overall reduction of these compounds was greater in the multiple-stage system than in the control system.

At longer retention times in the first-stage digester, excessive foaming became a problem. Thus a first-stage retention time of about 1 day should be used.

Dewatering and settling characteristics of the multiple-stage digested sludge were only slightly better than those of the control digested sludge.

The principal products from the WAO of the digested sludge were volatile acids, nitrogen compounds, carbon dioxide, and water. Organic nitrogen was broken into ammonia nitrogen, nitrate, and nitrite, but some reformation of organic nitrogen compounds from these products and organic acids appeared to occur at higher temperatures. The effluent from the WAO was usually slightly basic.

If the multiple-stage system is used in conjunction with WAO, total VS destruction can be as high as 95.5%. However, use of a two-stage system should be considered if WAO is used, because the savings in digester volume, heating, and mixing may offset the costs of additional WAO capacity without sacrificing the efficiency of VS destruction.

The solids in the effluent of the integrated treatment system (three-stage digestion followed by WAO) possessed excellent settling characteristics, which improved with increasing temperature. Sludge volume index values of less than 18 mL/g were possible. The final effluent had a pH of about 7.5 and contained high levels of nutrients, such as ammonia, phosphorus, and organic nitrogen. However, since almost none of the original metal content was solubilized, the final sludge was highly contaminated with metals, and metal stabilization and detoxification could be required.

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Yeun C. Wu was with the University of Pittsburgh, Pittsburgh, PA 15261.

***Donald S. Brown** and **John N. English** are the EPA Project Officers (see below).*

The complete report, entitled "Destruction and Stabilization of Sludge by Multiple-Stage Digestion and Thermal Treatment," (Order No. PB 87-140 505/AS; Cost: $18.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

*For further information **Donald S. Brown** can be contacted at:*

Water Engineering Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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