United States Environmental Protection Agency
Research and Development

Risk Reduction Engineering Laboratory Cincinnati, OH 45268

EPA/600/S2-89/001 Aug. 1989

EPA

Project Summary

Comparative Evaluation of Mesophilic and Thermophilic Anaerobic Digestion

Irwin J. Kugelman and Vincent G. Guida

A study comparing anaerobic digestion at mesophilic and thermophilic temperature was conducted. In the first phase of the study, operation under temperature transition in 750-mL lab-scale digesters was studied. Systems seeded with domestic sewage sludge, but subsequently fed a synthetic sludge, were operated at 20- and 30-day detention times at 35°C. The temperature was raised to 55°C at rates varying from 0.25°C to 2.5°C per day in duplicate, parallel units. Regardless of temperature rise rate, as soon as the temperature exceeded 45°C methane production was retarded. The units were held at 45°C until recovery occurred. Once recovery of methane production ability occurred, transition to 55°C took place with little incident except for minor difficulty at 51°C. Data analysis indicated that rate of temperature rise had little effect on the total time required to obtain stable operation at 55°C; detention time had a minor effect with longer detention times yielding superior results.

The organisms that function under thermophilic conditions appear to be present in mesophilic sludge but are not active at low temperature. When thermophilic conditions are brought about, the thermophilic organisms will multiply and reach an adequate level in several weeks.

A temperature drop study was also conducted during the first phase of the project from 55°C to as low as 47.5°C. No adverse effect was observed until the temperature was reduced to less than 50°C. Washout of methane bacteria seemed to occur when the temperature was suddenly dropped below 50°C and the system detention time was less than 20 days. These data indicate that thermophilic digester failure due to a loss of thermal input should not be a problem, unless the heat source is not restored.

Comparison of operation at 55°C vs 35°C under steady state at detention times ranging from 7.5 to 30 days with the chemically defined feed indicated that based on effluent volatile acids level, mesophilic operation was superior and that this superiority was greater at the lower detention times.

In the second phase, steady-state operation was conducted in larger 75-L digesters on a feed of raw primary sludge. Long-term, steady-state performance data were obtained at 49.5°C and 35°C. Two hydraulic detention times, 25 and 15 days, were used. Attempts to operate at temperatures above 50°C resulted in poor performance (propionic acid levels well above 1,000 mg/L).

Operation of both the mesophilic and thermophilic units was within parameter ranges normally considered satisfactory. Mesophilic operation was slightly superior to thermophilic operation as indicated by total and volatile solids breakdown and by gas production. Mesophilic breakdown of carbohydrate and oil and grease was superior. Thermophilic breakdown of organic

nitrogen was superior. Dewaterability of sludge produced under mesophilic conditions was significantly better than sludge produced under thermophilic conditions.

The results obtained here indicate no advantage to operation of anaerobic digestion at thermophilic temperatures.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in two separate reports of the same main title, one on each phase of the project (see Project Report ordering information on back).

Introduction

The purpose of this study was to conduct a comparative evaluation of the performance of anaerobic digestion systems under different temperature regimes. The temperature regimes chosen were those most commonly used in field installations (i.e., mesophilic 35°C and thermophilic 50°C to 55°C). Evaluation of performance was in terms of a number of parameters including: stability of operation, degree of waste stabilization, dewaterability of the digested sludge.

The work has been divided into two phases. The first deals primarily with the operation of anaerobic digestion systems under situations of temperature transition. The second deals with differences between system performance at steady state in the two temperature regimes.

The primary reason for conducting temperature transition studies revolves around the question of how to startup a thermophilic digestion system. The most efficient procedure is to seed with sludge from an operational thermophilic system. However, this material may not be readily available. In such a case it will be necessary to convert a mesophilic anaerobic digestion system to a thermophilic system. Because methane forming microorganisms are known to be quite sensitive to all environmental conditions, it was felt that a rapid change in temperature may not yield positive results. On the other hand, if a very low rate of adjustment of temperature is used, the anaerobic treatment system may be out of operation for a long period of time. Consequently, an evaluation was made here into the effect of temperature rise rate when converting from mesophilic to thermophilic operation. Another question that was addressed in this phase of the study was the effect of temperature decreased on the performance of thermophilic systems. It is generally considered that thermophilic systems are more sensitive than mesophilic systems. Thus, small reductions in temperature may have severe consequences in thermophilic system performance. This part of Phase I of the study incorporated experiments in which the temperature was intentionally and rapidly reduced to determine the magnitude of the effect on the thermophilic anaerobic systems.

During Phase I, limited steady-state data on system performance were collected at 55°C and 35°C to compare performance at these two temperatures. In Phase I a chemically defined complex substrate synthetic sludge was used. Much more extensive steady-state data were collected during Phase II in which parallel steady-state operation was conducted over periods of several months on a feed of *raw primary sludge*. Evaluation of performance in Phase II was based on measurement of total gas production, methane production, COD destruction, grease destruction, carbohydrate destruction, organic nitrogen destruction, total and volatile solids destruction and sludge dewaterability. Two periods of steady-state operation were intensively monitored. One period lasted almost 6 months during which the hydraulic detention time was maintained at 25 days. After a short transition period of 2 weeks at a 20-day detention time, a second period of steady-state operation at a 15-day hydraulic detention was carried out for a 2-1/2-month period.

Procedures

Phase I

The major goal of this phase of the study was to determine the effect of rate of temperature change on system performance during conversion from mesophilic conditions to thermophilic conditions. The basic plan used was to set up a series of bench scale units at 35°C, operate them to a steady state and then raise the temperature at various rates while maintaining as long as possible a normal feeding pattern. Units were operated at more than one detention time to determine the effect of this parameter (20 and 30 days).

A series of 750-mL bench scale anaerobic digestion systems were set up using digested sewage sludge from the anaerobic digester at the Allentown, PA, Sewage Treatment Plant. The units operated on a batch feed and withdr basis such that the HRT and SRT in unit was identical.

A total of 20 units were set up, 1 each detention time used. In each s 10, units were operated in duplicate. provided for four pairs of replicate at each detention time in which temperature would be raised, plus pair as controls. The control units maintained at 35°C. The four rate temperature rise used were 1°C, 2 3.5°C, and 5°C per feeding period.

All of the units were set up i temperature-controlled room maintai at 35 ± 0.1°C. The units in which temperature was to be raised were addition immersed in temperatu controlled water baths. Before actu conducting the experiments detai below, the necessary settings on thermostats were manually calibrat Eight water baths were used; e contained a pair of bench scale anaero units.

As indicated above, these units w originally started with digested slud However, chemically defined comp feed was used in the studies. The fe chosen was a commercial prod "Carnation Instant Breakfast"* suspen in whole milk. It was chosen becau when mixed with whole milk in recommended proportion (1 envelop fluid oz of milk), it had a f carbohydrate, and protein content sim to that of raw sludge. In addition, contained most of the organic a inorganic nutrients required microorganisms. The feed was, addition, supplemented with seve inorganic materials for which metha fermenting organisms have a hi demand (Fe, Co, Ni). Prior to starting t study, the units were operated for seve months to ensure washout of the origi seed material.

After the washout period w complete, the temperature change peri was initiated. The volume of fe required for the detention times us corresponds to 25 mL/day at a 30-d HRT and 37.5 mL/day at a 20-day HRT. was felt that these volumes were t small to be fed accurately. Thus duri this study, the 30-day HRT units were f 50 mL once every 2 days and the 20-d HRT units were fed 75 mL once every days. It was indicated above that nomin temperature changes per feeding peri

*Mention of trade names or commercial produ does not constitute endorsement or recommendati for use.

ere to be used. Thus a feeding period epresents a period of 2 days.

In conducting the temperature rise study, the following procedure was used. At the beginning of a feeding period, the thermostat in the water bath of the appropriate units was adjusted based on the prior calibration and the normal once/2-day withdrawal and feed took place. At the end of the 2-day period, a comparison was made between the gas production of the units whose temperature was raised and that from the control units (those which were maintained at 35°C). If gas production was close to that of the control unit the temperature was again raised and the unit was given a normal feeding. If gas production was significantly less than in the control unit, the temperature was not raised and the units were not fed. The units were not fed again until gas production data indicated that most of the previous feed had been converted to methane and carbon dioxide. The temperature was not raised again until most or all of the feed added during the last feeding was consumed in the standard 2-day period. Each time a withdrawal was made from a unit, the digester mixed liquor was analyzed for H, alkalinity, and volatile acids. Daily as production was determined; and at the end of each feeding period, gas analysis for methane and carbon dioxide was conducted. Alkalinity, pH, and volatile acids were monitored by the procedures given in Standard Methods; gas analysis was conducted using a Fisher Gas Partioner.

Over a 3-month time period, the temperature of each unit except the controls was raised to 55°C. At that time it was decided to continue operation of these units at 55°C and 35°C, respectively, to establish a comparison between operation at these temperatures with this feed and at these two detention times.

Subsequent to this steady-state period, a study was conducted in which the temperature was suddenly dropped by various amounts while normal operation, i.e., feed and withdrawal, were maintained. This study ascertained the effect that a sudden loss of heat supply could have on the operation of a thermophilic digester.

Only some of the 16 units being maintained at 55°C were used in the temperature drop study. The remainder was used in a study in which the tention times of the 55°C and the 35°C units were reduced to as low as 7.5 days. The purpose of this study was again to obtain a comparison between operation of units in parallel at the two temperatures but at much lower detention time.

Thus, this study contained three separate periods:

- temperature rise rate study
- temperature drop study
- steady state at 55°C and 35°C at various detention times.

Phase II

Raw primary sludge was periodically collected from the Allentown, PA, Sewage Treatment Plant. This is a typical municipal treatment plant serving a large metropolitan area. The sludges at this plant are separated so that the primary sludge contains little or no secondary sludge. Sludge was collected as it was being pumped from the primary tanks to the sludge handling area.

Sludge collected once per week was transported to Lehigh University Environmental Studies Center and kept under refrigeration at 4°C until used. Upon being brought to the laboratory, the sludge was sampled for total solids analysis. It was decided early in the study to maintain a constant total solids concentration in the feed. The original target was 4%, but after 1 month of sludge feed to the units this value was changed to 3.5%.

Two identical anaerobic reactors were used in this study. Each reactor was fabricated of plexiglass in the shape of a rectangular parallelepiped. A false bottom sloped toward the outlet pipe eliminating dead spaces. The total volume of each reactor was 75 L. At 25-day detention time, the liquid volume was 50 L; at 15-day detention time, the volume was 45 L. Gas recirculation was used to keep the reactors mixed. Cumulative gas was recorded on a wet tip gas meter. Each reactor was kept in a walk-in temperature-controlled room (± 0.1°C). Feed of raw sludge and withdrawal of digested sludge was conducted once per day on a batch basis.

Periodically, digested sludge removed from each unit was analysed for pH, alkalinity, volatile acids, ammonia-N, organic-N, grease, COD, carbohydrate, and total and volatile solids, and capillary suction time (CST). Analysis was started within an hour after sample withdrawal, except for sludge dewatering tests that were carried out on sludge cooled to 25°C. All sludge samples, except those portions used for dewatering tests, were ground in a Waring blender to reduce errors from lumps when making dilutions. Gas samples were collected in 100-mL glass sampling bulbs connected to a reservoir containing acid-salt solution.

The reactors were initially filled with digested mesophilic sludge from the Allentown, PA, Sewage Treatment Plant. The thermophilic unit was seeded with sludge saved from Phase I and sludge from a thermophilic digester in New York City. Feed was first Carnation Instant Breakfast (which was used in the Phase I study), then glucose and whole milk, and finally raw sludge. Operation of the thermophilic unit was somewhat erratic until 25 mg/L of yeast extract was added. Subsequent to this addition, thermophilic operation was satisfactory. It was found necessary to add 25 mg/L of yeast extract to the thermophilic unit to ensure good operation. To ensure identical treatment, this quantity of yeast extract was added to the mesophilic unit as well; although it was not needed. When raw sludge feed was started, the mesophilic unit temperature was 35°C and the thermophilic unit was slightly above 50°C.

Results and Discussion

Phase I

Temperature Rise Rate

The data collected during the temperature rise rate study are much too extensive to be presented here; reference to the full report is recommended. It was found, however, that regardless of temperature rise rate and/or detention time, a similar pattern of results was obtained. System performance was satisfactory until the temperature was raised above 45°C, at which time severe retardation took place. The retardation was primarily in the methane fermentation but some inhibition of acid formation was observed. After a period of dormancy, gas production started and eventually reached normal levels. During this dormant period, feeding was restricted to prevent pH failure. After a normal level of gas production was achieved, the temperature increase was begun again. The temperature was raised to 55°C with little difficulty except for a minor discontinuity between 50°C and 52°C.

The major question explored in this part of the research effort was what is the best procedure for converting a mesophilic anaerobic digester to a thermophilic unit. Table 1 presents a summary of pertinent data that can be used to address this question. For each temperature rise rate and detention time, the following data are presented: time in days to first reach 55°C, time in days to achieve stable operation at 55°C, time in days to the first temperature inhibition, time in days to be able to return to a normal 2-day feed pattern after inhibition, time in days to the next temperature change after the first temperature inhibition, and the number of periods during which feeding took place until 55°C was achieved. The figures presented in the table except for the first and last columns represent days after the first change from 35°C. The following major points can be deduced from this table and other data in the full report.

1. The slower the temperature rise, the longer it takes to reach 55°C.
2. The rate of temperature rise, has only a minor effect on the time to reach stability at 55°C.
3. Regardless of the rate of temperature rise, a major retardation occurs whenever the temperature exceeds 45°C.
4. The effect of this retardation is lower at low temperature rise rates.
5. At high temperature rise rates, once acclimation to the thermophilic conditions occurs, few problems are manifest.
6. At low temperature rise rates, small periods of acclimation are needed as the unit proceeds from 45°C to 55°C.
7. At low temperature rise rates, the unit can be fed a high percentage of time during the transition procedure.
8. At high temperature rise rates, the unit can be fed only a small percentage of time during the transition period.
9. There seems to be a zone of minor retardation in the 50°C to 52°C range.
10. Temperature changes adversely affect the methane bacteria to a much greater extent than the acid formers.
11. Temperature effects are not instantaneous. During the first feed period after 45°C is exceeded, almost normal operation occurs. Retardation is manifest during the next feeding period.
12. Temperature effects are magnified at lower detention time.

Overall, it does not seem that the rate of temperature rise greatly affects the total time for conversion to thermophilic conditions. A decision on the rate to use will depend on another major factor, i.e., what can be done with the raw sludge during the conversion process. If there is no alternate sludge-handling procedure, the slow rate of rise should be used, as for the most part, feeding of the digester can continue. If an alternate sludge-handling procedure exists, the rapid rise method would achieve operation at 55°C in a somewhat shorter period of time. Since operation is satisfactory between 35°C and 45°C, perhaps a combination procedure would be best: a rapid rise to 45°C followed by a slow rise to 55°C.

As previously indicated, once all of the units reached 55°C, it was decided to maintain them at that temperature to use in the temperature drop study or for gathering steady-state operational data at thermophilic temperatures vs mesophilic temperatures. Consequently, the 16 units were maintained at 55°C, half at 30-day detention time and half at 20-day detention time for the next 3 months. This ensured that prior to any other studies using these units that they had been through at least three detention times of operation at 55°C. At the end of this period some of the units were used in a temperature drop study which is detailed below. The detention time in the other units was reduced to 15, 10, and 7.5 days. Simultaneously the temperatures in the 35°C units was lowered to the same detention times. This allowed for comparison of operation of units operating over a range of detection times at the two different temperatures.

Temperature Drop Study

To determine the effect of a temperature drop on the thermophilic system, the temperature was dropped from 55°C to the new setpoint over night and then maintained at the new setpoint. The normal feed and withdrawal pattern was maintained. The performance of these systems was then monitored for the next 25 days. Units with detention times of both 20 and 30 days were used. Temperatures were reduced to 52.5°C, 50°C, and 47.5°C. Controls were run with units maintained at 55°C and 35°C.

The results at 30-day detention time were that effluent volatile acids remained low in all units and were not distinguishable from the control values. There was some early tendency for the volatile acids to increase in the unit whose temperature was reduced to 47.5°C. However, this trend was soon reversed. The data for the 20-day detention time units exhibited a similar situation, except that both the 50°C and 47.5°C units exhibited an early tendency for volatile acids to rise. The trend reversed for the 50°C unit, but not fc 47.5°C unit. Figure 1 is a plot of the from the 20- and 30-day detention units in which the temperature dropped to 47.5°C. This plot cl shows the significant difference resulted. The pattern of rise in vo acids exhibited by the 20-day dete time unit is typical of a wash phenomenon. That is, the tempera reduction does not appear to inte with the microorganisms ability degrade the substrate, but for s reason their ability to reproduc impaired. It is possible that the 30 detention time unit would also go in failure mode if the run had b continued for a longer period of time.

Despite the problem when temperature was dropped to 47.5 these data indicate that operati problems from failure of the hea system of a thermophilic digester sh not be a major concern. The only adv situation which was manifest took sev weeks to develop. It is unlikely that heating system of a digester could no repaired in a few days. In addition, rate of temperature drop utilized h was extreme compared to what wc occur in the field. Field digestion syste are massive tanks with high h capacity. It is unlikely that the diges temperature would drop by more tl 1°C per day even if a complete failure the heating system occurred in middle of the winter.

Comparison of Mesophilic and Thermophilic Operation

Table 2 presents a summary of operation of the units referred to above detention times ranging from 30 days 7.5 days. Data presented are efflu volatile acids averaged over a minim of three detention times of operation can be seen that the performance similar at the longer detention times l that at shorter detention times t mesophilic systems were clearly super to the thermophilic units. It has oft been suggested that operation thermophilic temperatures will provi better breakdown of organics a consequently, more methane. The d here do not support this suppositic Performance of the mesophilic units w always superior to that of tl thermophilic units.

Phase II

The Phase I data had indicated th mesophilic operation seemed better th

Table 1. Summary of Performance During Temperature Transition from Mesophilic to Thermophilic Conditions

Temp. Change Detection Time	Time to Reach 55°C	Time to Reach Stability at 55°C	Time to First Major Inhibition	Time to Resume 2-day Feed Pattern	Time Till Next Temp. Change	No. of Feeding Periods to 55°C
5.0-30	52	52	6	38	52	13
5.0-20	56	72	6	48	56	13
3.5-30	54	54	10	44	48	13
3.5-20	48	56	8	34	46	14
2.0-30	54	62	14	26	42	23
2.0-20	60	68	12	48	52	21
1.0-30	64	64	24	36	42	30
1.0-20	74	74	22	48	50	27

thermophilic operation with a chemically defined complex substrate. In Phase II, reactors were fed sludge from an actual treatment plant to determine if any difference would be seen. For a 6-month period, the reactors were operated at a 25-day detention time. No change in the operation of the mesophilic digester was necessary during that period. However, a significant change in the operation of the thermophilic digester was made after 3-1/2 months of operation. At that time, the temperature was reduced from slightly above 50°C to slightly below 50°C. It was found that with the temperature above 50°C, the volatile acids were high (1,500 mg/L, 90% propionic); but when the temperature was dropped to 49.5°C, the volatile acids level was similar to that in the 35°C unit (200 mg/L). Gas production and COD data were in accordance with the high levels of volatile acids in the thermophilic unit; that is, when the thermophilic temperature was > 50°C, gas production was lower and COD was higher in the thermophilic vs the mesophilic unit.

Several times the temperature was cycled between 50.5°C and 49.5°C. Each time the rise in temperature retarded the thermophilic unit and the temperature reduction yielded better performance.

The operation at a 25-day detention time was maintained for 2-1/2 months after the temperature reduction. At that time the detention time was reduced to 20 days. After 2 weeks the detention time was converted to 15 days, which was maintained for the next 2-1/2 months. The results are discussed below in terms of the parameters measured.

pH, Alkalinity, Volatile Acids, and Gas Production

Raw sludge pH ranged from 5.4 to 5.8, alkalinity from 600 mg/L to 2,100 mg/L, and volatile acids from 1,000 mg/L to 3,000 mg/L, which are typical values. Thermophilic sludge pH was 7.3 to 7.5, while mesophilic sludge pH was 7.0 to 7.2. Thermophilic alkalinity was also slightly higher than mesophilic alkalinity, 4,300 to 5,100 mg/L vs 3,800 to 4,600 mg/L. When the thermophilic temperature was greater than 50°C (discussed above), thermophilic sludge volatile acids were high; however, they were almost always <300 mg/L once the temperature was below 50°C. During the conversion from 25-day detention time to the 15-day detention time, thermophilic volatile acids rose to 550 mg/L for a few days but soon dropped again. The mesophilic volatile acids were always in the range of 100 to 200 mg/L. Gas production was always similiar in the two units, with mesophilic production only slightly higher (0% to 5%) than thermophilic production. Methane fraction in each unit averaged close to 60%, ranging from 57.5% to 64.5%. The operation of both units based on these traditional parameters was normal except for the period when the thermophilic temperature was above 50°C.

Total and Volatile Solids - Digested Sludge

Total and volatile solids were always slightly higher in the thermophilic unit than the mesophilic unit. The differences were most pronounced during the period when the thermophilic unit was at a temperature above 50°C. Indeed, near the end of each steady-state period, solids levels in both units were almost the same. Overall volatile solids destruction was higher in the mesophilic unit than the thermophilic unit.

COD

Prior to lowering the thermophilic temperature below 50°C, the total COD of the thermophilic unit was consistently higher than that of the mesophilic unit. After the temperature reduction (at 25-day detention time), the COD of both units was similar. After reduction of the detention time, the COD of the thermophilic sludge was initially higher than that of the mesophilic sludge. Much of this difference was eliminated by the end of the 15-day detention time operation.

The soluble COD data indicate that the thermophilic unit had a soluble COD from 1,400 to 1,700 mg/L higher than in the mesophilic unit. The difference was greater when the thermophilic unit was operated at temperatures above 50°C. Even under the best of thermophilic operation, a defined difference in soluble COD was observed.

Nitrogen

The ammonia-N was always higher and the organic nitrogen was always lower in the thermophilic unit. Since the TKN of both units was the same, these data indicate superior organic nitrogen conversion to ammonia-N in the thermophilic unit. The difference was higher at 25-day detention time then at 15-day detention time. As indicated previously, because of the higher degree of conversion of organic nitrogen to

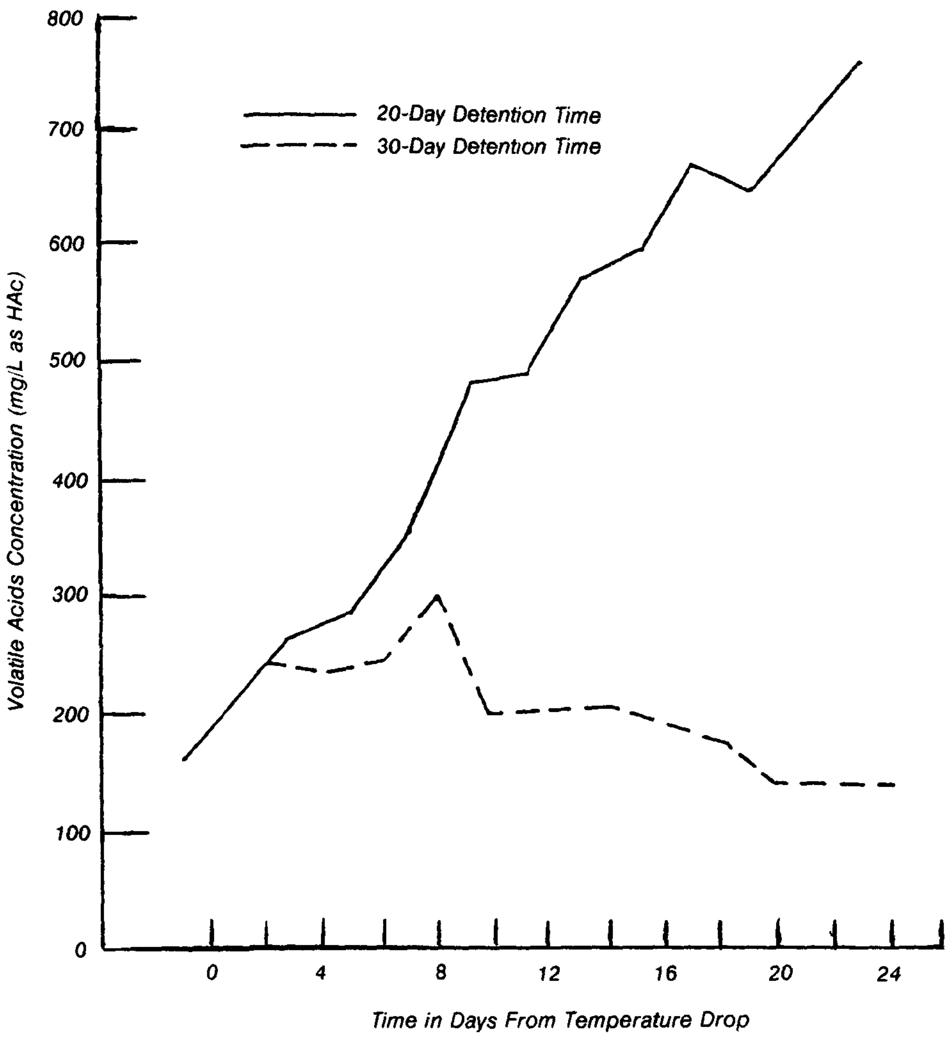

Figure 1. *Comparison of mean volatile acids concentration in units at 20- and 30-day detention times subjected to temperature drops from 55°C to 47.5°C.*

Table 2. *Steady State Performance of Thermophilic and Mesophilic Anaerobic Treatment Systems*

	Effluent Volatile Acids, mg/L	
HRT	55°C	35°C
30	100- 150	50-100
20	150- 250	75-100
15	200- 300	100-150
10	300- 600	100-200
7.5	1000-1200	200-300

ammonia-N, the pH and alkalinity were always higher in the thermophilic than in the mesophilic unit.

Oil and Grease

The reduction of oil and grease was higher in the mesophilic unit than in the thermophilic unit. This difference was especially pronounced when the thermophilic unit was operated above 50°C, because volatile acids are measured as grease and oil in this particular analytical test. There was little change in the difference between the units that could be ascribed to the reduction of the detention time to 15 days.

Carbohydrate

Sludge carbohydrate measurements were only conducted during the 15-day detention time operation. Total carbohydrate reduction was higher in the mesophilic unit than in the thermophilic unit. The difference ranged from 500 to 1,200 mg/L.

Sludge Dewaterability

Throughout most of the study, measurements were made on the dewaterability of the effluent from each unit. Preliminary tests were performed using three methods of dewatering: the

CST test, the Buchner funnel filtration test, and a batch centrifugation test. It was found that the latter two tests were very difficult to run unless the sludge was conditioned with a coagulant. The CST test, however, gave reasonable measurements with and without the addition of coagulants. Thus, the CST test was used to characterize the difference between both types of sludge. The results indicate that the thermophilic sludge was more difficult to dewater in an unconditioned state than the mesophilic sludge. CST for mesophilic sludge (unconditioned) was 350 to 450 sec, while values for unconditioned thermophilic sludge were 500 to 800 sec. Visual observation of the sludge clearly indicated better separation under gravity conditions for the mesophilic sludge. In addition, the sludge supernatant was more turbid for the thermophilic sludge, indicating that the size of digested sludge particles in the thermophilic sludge was smaller than in the mesophilic sludge. When the sludge was subjected to centrifugation without conditioners present, the thermophilic centrate was more turbid than that from the mesophilic sludge, although the depth of the solids pool was almost the same for both sludges.

In addition to the unconditioned tests, some tests were conducted in which sludge was conditioned with ferric chloride and/or lime. Ferric chloride conditioning had a significant affect on the CST values of both sludges. The addition of lime to a sludge already conditioned with ferric chloride had little effect as did the use of lime alone. The dose of ferric chloride required to reduce the CST to below 50 sec for mesophilic sludge was 20% less than that required for thermophilic sludge.

A summary of the steady-state results in terms of volatile solids destruction, COD destruction (direct measurement and methane production), organic nitrogen destruction, grease and oil destruction, and carbohydrate destruction is given in Table 3. Somewhat better performance was achieved at both detention times by the mesophilic unit except for nitrogen breakdown.

Overall Conclusions

1. Rate of temperature change had little effect on the total time required to reach stable operation at 55°C during conversion from mesophilic to thermophilic conditions.
2. The transition from mesophilic to thermophilic conditions seems to occur at 45°C, as operation was interrupted (methane production retarded) for one to several weeks when this temperature was reached.
3. Eventual recovery occurs indicating that thermophilic organisms exist in mesophilic sludge but are dormant at low temperature.
4. At longer detention time, operation temperature transition effects are not as severe.
5. When the temperature is rapidly reduced from 55°C, no effect on operation is manifest until the temperature is reduced below 50°C and the detention time below is 20 days.
6. The temperature drop effect is not a reduction in the ability of the methane bacteria to process substrate but in the ability to reproduce.
7. Based on effluent volatile acids, steady-state operation at 35°C was slightly superior to operation at 55°C at long detention times and clearly superior at short detention times, with a chemically defined complex substrate as the feed.
8. With a raw sludge substrate, steady-state operation above 50°C was characterized by poor performance. Volatile acids, especially propionic acid, were above 1,000 mg/L. Breakdown of various sludge components was less than under mesophilic conditions. Consequently, long-term steady-state data collection was obtained at 49.5°C in the thermophilic region.
9. In terms of pH, alkalinity, volatile acids, and methane production the long-term steady-state performance at 49.5°C and 35°C was satisfactory at 25- and 15-day HRT.
10. Under all conditions the performance of the mesophilic system was slightly superior to the thermophilic system.
11. At detention times of 15 and 25 days, significantly higher breakdown of carbohydrate and oil and grease were achieved in the mesophilic unit.
12. At both those detention times, significantly higher breakdown of organic nitrogen occurred under thermophilic conditions.
13. At both those detention times, slightly higher destruction of total and volatile solids and COD occurred under mesophilic conditions.
14. Performance of both systems was also better, in terms of breakdown of raw sludge components, at 25-day detention time.
15. The soluble COD of the thermophilic sludge was always at least 1,000 mg/L higher than for the mesophilic sludge.
16. At both detention times with the 50-L digesters, sludge dewaterability was significantly better, as measured by the CST test, under mesophilic conditions.
17. Sludge dewaterability for both temperature systems could be significantly improved by conditioning with ferric chloride. Higher doses were required for the thermophilic sludge.
18. Lime, both alone and with ferric chloride, had little effect on sludge dewaterability.
19. Detention time had little effect on sludge dewaterability.
20. Thermophilic sludge odor was more disagreeable than that from mesophilic sludge, even when volatile acids were low.
21. Thermophilic operation at temperatures above 50°C was better with chemically defined substrate than with raw primary sludge, but mesophilic operation was better than thermophilic operation regardless of feed.
22. These data indicate that operation of anaerobic digestion at thermophilic conditions has no advantage over operation at mesophilic conditions.

A report on each phase was submitted in fulfillment of Cooperative Agreement CR811022 by Lehigh University under the sponsorship of the U.S. Environmental Protection Agency.

Table 3. Summary of Performance of Mesophilic and Thermophilic Digesters

		% Removal					
Detention Time	Unit	Volatile Solids	COD D.M.	COD Gas	Organic Nitrogen	Grease & Oil	Carbohydrate
25	Thermo.	51.7	52.6	53.2	59.4	65.0	-
25	Meso.	57.2	52.9	63.1	50.2	71.2	-
15	Thermo.	44.7	44.2	53.3	44.9	59.3	56.2
15	Meso.	47.0	49.9	56.8	27.2	67.4	68.8

Irwin J. Kugelman and Vincent G. Guida are with Lehigh University, Bethlehem, PA 18015.
***Harry E. Bostian** is the EPA Project Officer (see below).*
The complete report consists of two volumes, entitled "Comparative Evaluation of Mesophilic and Thermophilic Anaerobic Digestion:"
Phase I. Temperature Transition Studies," (Order No. PB 89-151 393/AS; Cost: $15.95, subject to change).
Phase II. Steady State Studies," (Order No. PB 89-151 401/AS; Cost: $15.95, subject to change).
The above reports will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States Environmental Protection Agency
Center for Environmental Research Information
Cincinnati OH 45268

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35

Official Business
Penalty for Private Use $300

EPA/600/S2-89/001