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Project Summary

Determining the Stability of Treated Municipal Wastewater Sludges

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A study was conducted to determine the potential for further biological degradation of municipal wastewater sludges that may already have undergone some degree of treatment by a sludge stabilization process. A literature survey was carried out to determine the most fruitful study approaches, and laboratory-scale studies followed.

The literature survey comprehensively summarizes available information on the characteristics of sludges stabilized by anaerobic, aerobic, or thermal conditioning processes. The feed materials considered were raw primary sludge, activated sludge, and mixtures of the two. The sludges produced by treatment had a broad range of instability because design factors varied widely for the treatment processes that generated them. Many of the parameters considered useful in determining sludge stability were also reviewed in the literature survey.

The laboratory study built on methods described in the literature for evaluating sludge stability. Sludges studied included primary, trickling filter, and activated sludges, as well as sludges from full-scale anaerobic digesters, heat treatment processes, and aerobic digestion. Stability of these as-received sludges was evaluated by measuring their response to additional aerobic or anaerobic digestion, and by cumulative generation of hydrogen sulfide. Responses to aerobic digestion of the as-received sludges were generally similar and showed substantial reductions in parameters such as biological oxygen demand (BOD) and chemical oxygen demand (COD). Oxygen uptake eventually reached a low stable value for all sludges. The same kind of reduction in parameters occurred in the as-received sludges with anaerobic digestion. The hydrogen sulfide generation test generally showed well-defined points at which generation of the gas virtually ceased as sludge storage increased. With additional development, the test shows promise as a method for comparing sludges to determine their potential for further biological decomposition.

Though much has been learned about the response of various sludge stability parameters to further digestion, a simple measurement indicating sludge stability was not developed.

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

The major and most offensive byproduct of municipal wastewater treatment is sludge. Before ultimate disposal, municipal sludges undergo varying amounts of treatment by stabilization processes to reduce their odor and their potential for adverse environmental effects. The stability of these sludges varies with their origin and final treatment (if any) before disposal. This project analyzed municipal sludges originating from aerobic and anaerobic biological processes and from thermal processes.

A sludge should be stable before final disposal. Unfortunately, the term "stable" is not clearly defined with respect to municipal sludges. Before disposal, a sludge should be stabilized enough that no adverse environmental effect can be easily observed upon disposal. Sludges disposed of by means of land application should be sufficiently stable so that odor and health problems do not develop. Ocean disposal of sludges should not have adverse effects on the marine ecosystem. This report does not determine how stable a sludge should be before disposal; rather it defines stability of any given sludge with respect to equilibrium concentrations of various parameters achieved after long-term biological digestion.

The objects of this investigation were therefore (1) to review the literature for the best ideas on sludge stability and methods for measuring it, (2) to search experimentally for the most promising measures and to test them, and (3) to recommend the best methods or avenues for further research.

The primary experimental activity was concerned with anaerobic and aerobic digestion of sludges that had been stabilized at a municipal wastewater treatment plant. The object of the experimental program was to determine how much biological activity remained in the sludge and if possible, to relate this instability to some sludge parameters or group of parameters.

Literature Survey

The scope of the literature review was confined to the stabilization of municipal sludge originating from aerobic and anaerobic biological processes and from thermal processes. Primary objectives were to review the literature, gather information on sludge stability, make the data available to the scientific community, and provide ideas for the laboratory work.

To define the direction of the review, conclusions had to be drawn about what constitutes a stable sludge. Probably the best indicator of stability is the inability of the sludge to degrade further biologically. Consequently, the processes of anaerobic and aerobic digestion were carefully reviewed, and all parameters that might be related to stability were examined. For anaerobically digested sludge, parameters such as gas production, methane-to-carbon-dioxide ratio, volatile solids reduction, adenosine triphosphate (ATP) concentration, BOD, COD, and others may be important for measuring the potential for further biological degradation. Odor production potential could be very important in determining the stable state of a sludge. For example, a sludge digested for 30 days is less odorous than a sludge digested for 15 days. Potential appeared to exist for establishing a simplified method for measuring sludge odor and relating it with other parameters to obtain a sludge stability index.

For aerobically digested sludges, operating parameters such as temperature, degree of mixing, organic loadings, solids retention time, and feed sludge characteristics affect the finished sludge's stability, but they are unlikely candidates as measures of stability. Parameters such as specific oxygen uptake rate, ATP, BOD, COD, organic nitrogen, ammonia nitrogen, nitrate, and others are better indicators of the sludge's biological activity.

The available literature on thermal treatment was reviewed primarily to examine how changes in severity of the thermal conditions (time and temperature) affect the chemical and dewatering properties of the sludge.

Experimental Procedures

Sludges were obtained from 11 municipal treatment plants in New York State and New Jersey. These sludges were primarily mixtures of primary and activated sludges that had been digested aerobically or anaerobically. They included the following:

- Extended aeration activated sludge
- Aerobically digested activated sludge
- Anaerobically digested primary sludge
- Anaerobically digested activated sludge
- Anaerobically digested primary and activated sludge
- Anaerobically digested primary and trickling filter sludge
- Thermally treated primary and activated sludges

The source and pretreatment of these sludges may be important in their initial instability. Brief descriptions of the treatment plants are included in the text of the full report.

Seven anaerobic sludges from five municipal wastewater treatment facilities were studied in this investigation. Sludge retention times in the digesters ranged from 13 to 37 days; volatile solids reductions ranged from 27 to 56 percent. Six different aerobic sludges were studied from six municipalities. Plant sizes ranged from 0.4 mgd flow for a small extended aeration plant to 85 mgd. Aerobic digestion times ranged from 6 to 21 days. One extended aeration plant did not digest its sludge.

The major portion of the anaerobic digestion work was carried out in 18-liter digesters that were continuously stirred and maintained at 35°C. Provision was made for monitoring gas production and composition and for periodic sampling. Some work was also carried out in 1.5-liter digesters that were mixed by hand once daily. Their only difference other than size was the manner of mixing.

Aerobic digesters were 19 liters in capacity and were mixed and provided with oxygen by a diffused air system. Temperatures ranged from 20° to 26°C. Evaporation losses were made up by addition of distilled water.

Special analytical procedures were used for ATP measurements and centrifuge button tests. The ATP tests, which might have produced interesting results, have not been reported because of difficulties with a new but faulty photometer. The centrifuge button test followed a procedure reported by Hartman et al. (Journal of the Water Pollution Control Federation, *51*, 2353, 1979). Hydrogen sulfide is generated from a button of sludge cake centrifuged from a 50-ml sample of sludge. The test measures the time it takes for the hydrogen sulfide to discolor 50 percent of a strip of lead acetate paper.

The objective of the experiments was to extend anaerobic or aerobic digestion far beyond its normal termination point to reach a stable condition. The various parameters used to follow the course of digestion (e.g., gas production for anaerobic digestion and oxygen uptake rate for aerobic digestion) were determined along with special measures such as the centrifuge button test and specific resistance to filtration. For both anaerobic and aerobic digestion, the residence time was infinite, that is, there was no daily feed. This batch digestion was continued for as long as 100 days to reach a stable condition.

Results and Discussion

The Search for Indicators of Stability

The data collected (1) permit a multitude of comparisons between sludges, (2) show the effects of digestion time on parameters indicating sludge quality or degree of stabilization, and (3) permit an assessment of these parameters as absolute or relative indicators of stability.

Table 1 describes the feed stocks for the anaerobic and aerobic digestion experiments by their source and stabilization history. The data collected require graphic presentation for best understanding. Examples in Figures 1, 2, and 3 illustrate the data comparisons that are possible. They are drawn from the aerobic digestion runs of the Phase 1 experiments.

The effect of additional aerobic digestion time on Stony Point aerobically digested sludge (Run 4A) is illustrated in Figure 1. The data indicate that it takes 30 to 40 days for the sludge to reach a state of equilibrium in which parameters are not changing. Parameters such as suspended solids (SS), volatile suspended solids (VSS), COD, and specific oxygen uptake rate (SOUR) level out after this time interval. Of these parameters, SS, VSS, and COD are not useful unless related to their initial values. At best, then, their absolute values are of no utility, but their percentage reductions might be relative indicators of stability. Experience indicates that the SOUR falls to approximately the same value for all aerobically digested sludges after prolonged digestion. The data in Figure 1 indicate that it reaches a steady value at about the same time as other parameters. Thus the absolute value for SOUR seems to be a good indicator of sludge stability.

Figure 2 presents the same type of data for aerobic digestion of a heat-treated sludge (Rockland County, Run 5A). A substantial seed of Stony Point sludge (see Table 1) was added to ensure that the original would digest aerobically. Note that SS, VSS, COD, and BOD fell substantially in the first 40 days, but SOUR remained constant. Clearly, the sludge was undergoing stabilization, but the SOUR did not indicate it. Thus although the SOUR might be useful as an indicator of stability for aerobically digested sludges, it does not appear to be useful for heat-treated sludges.

Figure 3 shows the change in specific resistance and the capillary suction test (CST) for the Stony Point and Musconetcong (Run 3A) aerobic sludges after additional aerobic digestion. Changes in these parameters did not follow the known increase in stability that takes place, so these parameters are not good indicators of stabilization.

The lead acetate test for detecting hydrogen sulfide emissions on Phase 1 sludges showed promise as a general indicator of stability for all types of sludges. Changes in the test during Phase 2 were intended to improve reliability. They included using a constant sludge mass and reducing the percent of blackened paper for a positive indication of hydrogen sulfide. The changes actually reduced reliability, however.

Table 1. *Sludge Charged to Digesters in Phase 1 and 2 Experiments*

Phase and Run	*% Seed*	*Sludge Being Tested: %*	*Sludge Being Tested: Plant*	*Sludge Being Tested: Type of Sludge from This Treatment Step(s)**	*Previous Stabilization*
Phase 1, anaerobic digestion:					
1	*75*	*25*	*Cedar Creek*	*P*	*None*
2	*75*	*25*	*Cedar Creek*	*SA*	*None*
3	*65*	*35*	*Stony Point*	*EA*	*aerobic digestion*
4	*100*	*+*	*Cedar Creek*	*P + SA*	*anaerobic digestion*
5	*75*	*25*	*Rockland County*	*P + SA*	*high pressure HT*
6	*75*	*25*	*Poughkeepsie*	*P + A*	*low pressure HT*
Phase 1, aerobic digestion:					
1A	*0*	*100*	*Beacon*	*A*	*aerobic digestion, 6 day*
2A	*0*	*100*	*Cold Springs*	*EA*	*None*
3A	*0*	*100*	*Musconetcong*	*CS*	*aerobic digestion, 21 day*
4A	*100*	*‡*	*Stony Point*	*EA*	*aerobic digestion, 14 day*
5A	*84*	*16*	*Rockland County*	*P + SA*	*high pressure HT*
6A	*98.4*	*1.6*	*Poughkeepsie*	*P + A*	*low pressure HT*
Phase 2, anaerobic digestion:					
7	*0*	*100*	*Stony Point*	*EA*	*aerobic digestion*
8	*0*	*100*	*26th Ward*	*P + SA*	*anaerobic digestion*
9	*0*	*100*	*Coney Island*	*A*	*anaerobic digestion*
10	*0*	*100*	*Cedar Creek*	*P + SA*	*anaerobic digestion*
11	*0*	*100*	*Oyster Bay*	*P + TF*	*anaerobic digestion*
12	*0*	*100*	*Yonkers*	*P*	*anaerobic digestion*
13	*0*	*100*	*Yonkers*	*SA*	*anaerobic digestion*
Phase 2, aerobic digestion:					
7A	*100*	*§*	*Stony Point*	*EA*	*aerobic digestion*
8A	*65*	*35*	*26th Ward*	*P + SA*	*anaerobic digestion*
9A	*65*	*35*	*Jamaica*	*P + A*	*anaerobic digestion*

****Abbreviations:** P, primary treatment; A, activated sludge; SA, step aeration; EA, extended aeration; CS, contact stabilization; TF, trickling filter; HT, heat treatment.*
+This sludge was the seed for Runs 1-6.
‡This sludge was the seed for Runs 4A-6A.
§This sludge was the seed for Runs 7A-9A.

Parameter Changes Resulting from Long-Term Digestion

Aerobic Digestion of Aerobic Sludge— Five sludges that had been aerobically treated in the wastewater treatment plants were subjected to further aerobic digestion. Similar patterns of change in

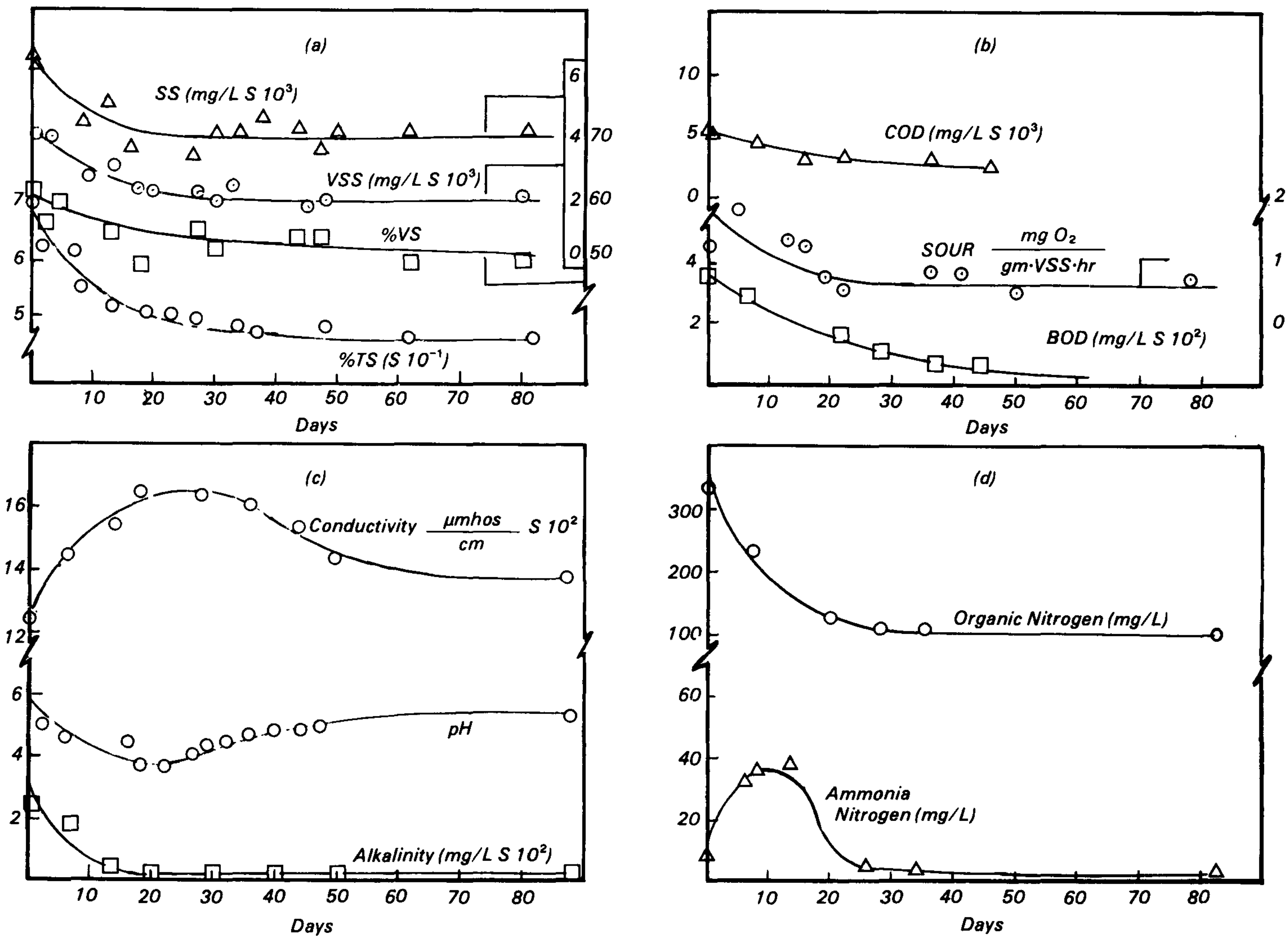

Figure 1. Aerobic stability parameters for aerobic sludge in Run 4A, Stony Point, New York (summer).

parameters were observed for all of the aerobic sludges (Beacon, Cold Springs, Musconetcong, Stony Point summer and Stony Point winter). In most cases, all forms of solids decreased relatively quickly over the first 20 to 30 days and rather slowly thereafter. Oxygen demand exhibited a similar pattern, with higher fractional decreases in BOD and SOUR than COD. Only one sludge showed anomalous results, and there seemed to be a reasonable explanation for this behavior.

All changes in pH, alkalinity, and conductivity were similar except for the anomalous sludge. Alkalinity rapidly decreased to very low levels in about 20 days. The pH first decreased to a minimum (usually into the range of 4 to 5) over the first 20 days and typically returned to the original value. Conductivity exhibited the reverse pattern, first rising and then falling. The conductivity peak occurred a few days after the pH minimum. The shift in conductivity is a response to the increased hydrogen ion concentration (low pH) because of the high specific conductance of this ion.

The nitrogen forms pattern was again similar for all units except for the anomalous sludge unit. Organic nitrogen decreased rapidly as a result of the endogenous metabolism of the cellular material. The nitrogen is released into the liquor in the form of ammonia, resulting in the initial increase of this nitrogen form. Ammonia removal takes place concurrently, primarily by nitrification and to a minor extent by stripping. Once the organic nitrogen breakdown is complete, no ammonia is fed to the system, so the ammonia level peaks and starts to decrease. Note that this ammonia peak correlates well with the stabilization of SOUR, BOD, organic nitrogen and (to a smaller degree) with alkalinity. Undoubtedly the pH changes observed are due to the changes in nitrogen forms and stripping of ammonia and carbon dioxide. The specific resistance and CST measurements did not generally indicate significant change as digestion proceeded, but there was a tendency for a rise and fall pattern.

In all cases, significant grease removal (greater than 50%) took place over the first 20 to 30 days for all sludges. This removal along with nitrate formation may account for the drop in pH observed during the initial period of stabilization.

Aerobic Digestion of Heat-Treated Sludges—The heat-treated sludges (Rockland and Poughkeepsie) that were further aerobically digested exhibited patterns of

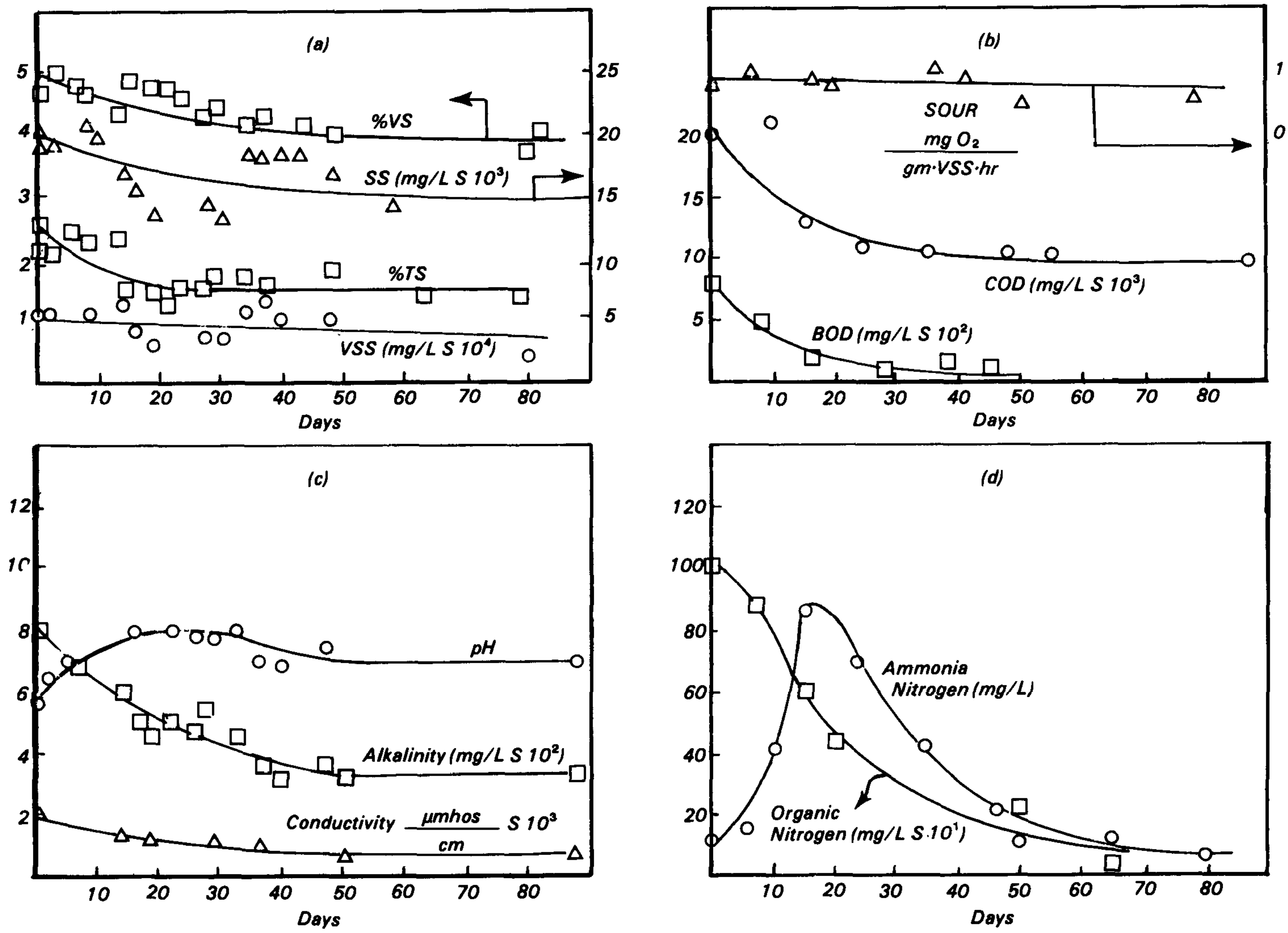

Figure 2. *Aerobic stability parameters for thermal sludges in Run 5A (compare with 4A), Rockland County, New York.*

change in solids, oxygen demand, nitrogen forms, and grease that were similar to those of the aerobic sludges discussed above. The pH pattern was different, however. For both heat-treated sludges, the pH first rose and then returned to near the original level. This rise and fall is the normal pattern expected in batch aeration of sludge, not the pattern observed previously with the aerobic sludge. As ammonia is released during protein breakdown, ammonium bicarbonate tends to be formed first, followed by nitric acid as nitrification of the ammonia occurs. In the five aerobic sludges, a large population of nitrifiers may have been present initially. Their presence would foster rapid initial nitrification with consequent fall in pH, whereas heat treatment would retard nitrifiers, delaying the onset of nitrification and allowing pH to rise. Specific resistance and CST showed no consistent trends.

Aerobic Digestion of Anaerobically Digested Sludges—Two anaerobically digested sludges were further aerobically digested. The pattern of parameter change with time of aeration was similar to that observed previously in aerobic stabilization. The main area of difference was in the pH-conductivity pattern and in the ammonia nitrogen pattern. The pH rapidly decreased and then remained constant, and conductivity rose as pH fell. The ammonia nitrogen at time zero was already at a high level because of protein breakdown under aerobic conditions with no possibility of nitrate formation. Both the organic and ammonia nitrogen decreased with time as aerobic stabilization converted ammonia to nitrate. Thus no ammonia peak was observed. The specific resistance rose, and the CST remained constant.

Anaerobic Digestion of Sludges—Thirteen sludges were subjected to prolonged anaerobic stabilization. These included raw sludges, mixtures of raw sludge and waste-activated or trickling filter sludge, waste-activated sludge alone, heat-treated sludge, sludge that had already been anaerobically digested, and sludge that had already been aerobically digested. A similar pattern of changes in measured parameters was observed for all of these units, regardless of the source of the sludge. Some departures from the general patterns occurred, but these were probably due to experimental difficulties rather than to basic differences in the pattern of stabilization. Quantitative differences between units can be traced to differences in the degree of stabilization

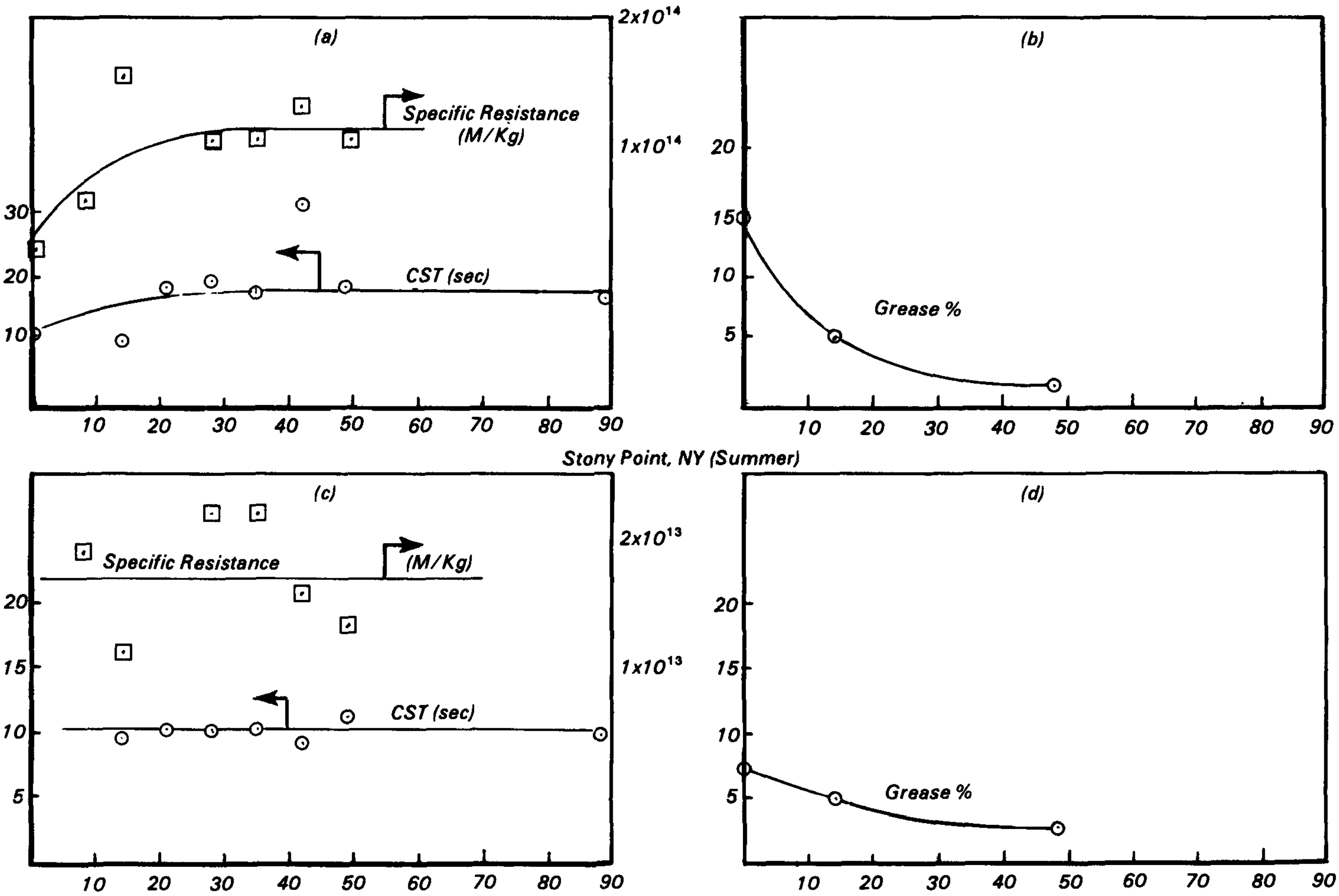

Figure 3. Aerobic stability parameters for aerobic sludges in Runs 3A and 4A, Musconetcong, New Jersey, and Stony Point, New York.

that had taken place in these sludges before they were charged to the test units.

The basic pattern includes the following items:

1. Modest continuous decreases in both total and volatile solids. In some cases, a rapid initial decrease was followed by a slow, gradual decrease.
2. Significant reductions in BOD and COD in a 20- to 30-day period, with the BOD generally decreasing more rapidly than the COD.
3. A rapid decrease in volatile acids occurring concurrently with gas production. Gas production ended when the volatile acids fell. The pH exhibited little change.
4. An organic nitrogen decrease that was almost exactly balanced by an ammonia nitrogen increase. This result is anticipated because under anaerobic conditions, all nitrogen released from organic breakdown must be in the ammonium ion form. The rate of change in these parameters decreased as the run progressed until steady state was achieved.
5. As indicated previously, essentially no change in sludge filterability took place. Grease was typically reduced by more than 50%.

Conclusions

1. Primary sludge, activated sludge, and trickling filter sludges that were subjected to aerobic digestion, extended aeration, thermal treatment or anaerobic digestion were not stable with respect to most parameters measured.
2. No single or combined parameter was found to be a standard that would indicate sludge stability. Most sludges reached steady state for most parameters studied within 20 to 40 days.
3. Routine measurement of a stability parameter (e.g., SOUR, ultimate methane production, etc.), while not providing complete information on stability, would permit monitoring of process performance and comparison with other sludges.
4. A SOUR rate of 0.4 to 1.0 mg O_2/g VSS-hr may be a good indicator of stabilized aerobically digested sludge. This measurement is not applicable to anaerobic sludges.
5. CST's and specific resistance measurements for dewaterability were inconsistent and are not satisfactory as stability indicators.

6. The centrifuge button test appears to be a reasonable indicator of potential for hydrogen sulfide odor formation and is generally completed in 15 to 30 days for most sludges.
7. TS, VS, BOD, and COD continuously decreased for all sludges until steady state was typically reached in 20 to 40 days. These measurements are not particularly sensitive indicators of stabilization.
8. Alkalinity, pH, and conductivity did not generally appear useful as stability indicators; but they may serve as such in conjunction with nitrification and nitrate formation.
9. During anaerobic treatment of anaerobic sludges, the rate of gas formation and the concentration of volatile acids decrease rapidly in 5 to 10 days, but their relationship to stability is not evident.

Recommendations

1. Continue testing the most promising indicators of sludge stability using various municipal sludges to confirm their effectiveness.
2. Extend testing to include sludges from rotating biological contactors, trickling filters, and solids from composting operations.
3. Develop and extend the applications of the centrifuge button technique for predicting potential for hydrogen sulfide, odor generation, especially in conjunction with treatment plant operation.
4. Continue the development of the ATP and crude fiber analyses.
5. Confirm the use of the SOUR analyses as a stability indicator for aerobically treated sludges.
6. Develop stability and drainability relationships using the CST.

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***R. V. Villiers** was the EPA Project Officer (see below).*
The complete report, entitled "Determining the Stability of Treated Municipal Wastewater Sludges," (Order No. PB 85-147 189/AS; Cost: $19.00, subject to change) will be available only from:
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