Effects of transient temperature increases on odor production from thermophilic anaerobic digestion

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Abstract The City of Los Angeles, Bureau of Sanitation, has implemented thermophilic anaerobic sludge digestion at the Hyperion and Terminal Island Treatment Plants (HTP and TITP). A two-stage continuous-batch process was established at HTP, while a single-stage sequencing batch process was established at TITP. This was to evaluate compliance with the Class A pathogen reduction requirements of U.S. EPA 40 CFR Part 503. A rapid increase of the digester temperature at TITP from 57.5 to 65.5°C caused an increase of the volatile fatty acid to alkalinity ratio, a decline in digester performance, and an elevated production of methyl mercaptan and hydrogen sulfide. A rapid increase of the digester temperature at HTP from 54 to 58°C caused an elevated production of methyl mercaptan, but the effect on the volatile fatty acid to alkalinity ratio and digester performance was insignificant. It is likely that these effects observed at TITP and HTP were transient responses to rapid changes in temperature.

Keywords Biochemical stability; class A biosolids; thermophilic anaerobic digestion; volatile sulfur compounds

Introduction

Many activities on thermophilic anaerobic digestion are currently driven in the US by bans of Class B biosolids land applications and requirements of Class A disinfection standards for Exceptional Quality (EQ) biosolids in 40 CFR Part 503 (Iranpour *et al.*, 2004; U.S. EPA, 1993). In full-scale applications, thermophilic digester temperatures are usually in the lower end of the thermophilic temperature range (50–55°C). Anaerobic digestion above 60°C has been investigated mostly in lab-scale studies, focusing on process performance (Varel *et al.*, 1980; Nozhevnikova *et al.*, 1999), pathogen removal (Gabb *et al.*, 2000) and microbial populations dynamics (Ahring *et al.*, 2001), but it is usually recommended to keep the temperature below 60°C (Van Lier, 1996; Wilson *et al.*, 2004).

The City of Los Angeles Hyperion and Terminal Island Treatment Plants (HTP and TITP) have conducted series of full-scale disinfection tests to meet the Class A pathogen reduction requirements for producing EQ biosolids (Shao *et al.*, 2002; Iranpour *et al.*, 2003a, 2005a). HTP currently employs a two-stage continuous/batch process, while TITP has implemented a single-stage sequencing batch process. During thermophilic operation, the digesters were operated for short periods of time with increasing temperatures in the range of about 55–65°C. As the limited batch digester capacity at HTP allowed for a maximum holding time of 16 hours in the second stage, the objective to increase the temperature was to comply with the time-temperature relation of Alternative 1 in 40 CFR 503 by raising the temperature to a minimum of 56.3°C. The Alternative 1 time-temperature relation is met by TITP during standard operation of the single-stage sequencing batch process (24 hours holding, minimum temperature of 55°C). The objective to increase the digester temperature at this plant was to prevent the recurrence of fecal

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coliforms in the post-digestion biosolids that was observed during standard thermophilic operation.

This contribution presents full-scale data obtained during short-term episodes with rapidly increasing and decreasing digester temperatures at HTP and TITP. The results will be discussed with focus on the production of volatile sulfur compounds (VSC), biochemical stability of the process and digester performance.

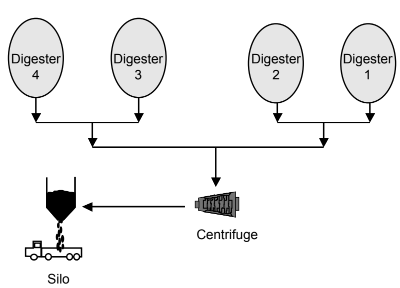
Materials and methods

Terminal Island Treatment Plant setup

TITP is located in San Pedro, California, USA, and has four 5,000 m^3 egg-shaped digesters (Figure 1). The digesters were fed with a mixture of primary sludge and thickened waste activated sludge (TWAS) at a total feed rate of 570 m^3/day. Digesters 1, 3, and 4 were operated in a single-stage sequencing batch process to meet the time-temperature requirement of Alternative 1 in 40 CFR 503, section 32, for Class A biosolids ($T \geq 55°C$ if holding for 24 hours). Each digester was operated on a 3-day cycle of sludge feeding, holding, and withdrawal (Figure 1). Approximately 11% of the digester volume was withdrawn/fed in each cycle, resulting in an average HRT of 26 days. In order to evaluate prevention of fecal coliform recurrence in the post-digestion train, the temperature of Digester 1 was rapidly increased from 57.5°C to 65.5°C and held constant for approximately one and a half week at 65.5°C. The digester temperature was then reduced to about 53°C.

Hyperion Treatment Plant setup

HTP is located in Playa del Rey, California, USA, and has three batteries with 6 or 8 egg-shaped digesters with a capacity of 9,400 m^3 each (Figure 2). The plant's feed sludge was primary sludge and TWAS at approximate rates of 11,300 and 3,000 m^3/day, respectively. The digesters were operated in a two-stage process. The first stage contained 16 digesters operated in continuous mode with an average temperature of 54.4°C and an HRT of about 10 to 11 days. The second stage contained 4 digesters operated in a batch mode in 32-hour cycles of sludge feeding, holding, and withdrawal (Figure 2). The holding time was 16 hours (Alternative 1 in 40 CFR 503.32: $T \geq 56.2°C$). Each batch digester was withdrawn/fed up to 60–70% of its capacity during each cycle. In order to meet the Alternative 1 time-temperature requirement, the temperatures of the continuous and batch stages were rapidly increased to about 58°C and more than 56.2°C, respectively. Then, the temperatures of both stages were decreased to about 53°C.



Day	Day 1	Day 2	Day 3
Hours	0 24	48	72
Digester 1	F	H	W
Digester 3	W	F	H
Digester 4	H	W	F

F = feed, H = hold, W = withdraw

Figure 1 TITP–Thermophilic anaerobic digestion process and digester cycles for batch operation

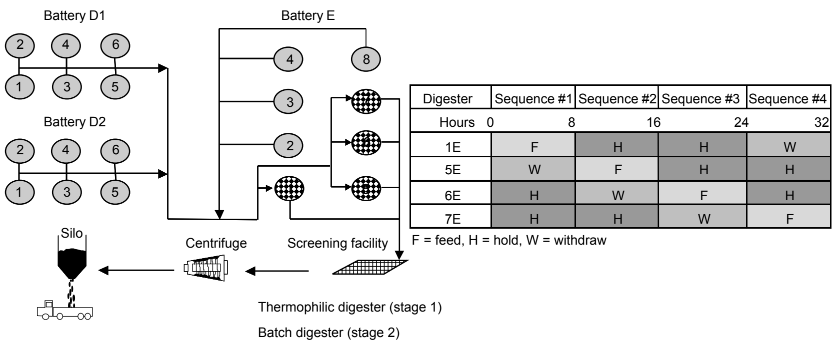


Figure 2 HTP–Thermophilic anaerobic digestion process and digester cycles for batch operation

Laboratory procedures

Digester gas composition (CH_4, CO_2) was measured with EPA Method 18. Total solids, volatile solids, total alkalinity, volatile fatty acids (VFA) and pH were measured as in *Standard Methods* (Parts 2540 B, 2540 E, 2320 B, 5560 C, 4500-H + B respectively) (APHA *et al.*, 1992). Volatile sulfur compounds (VSC) in digester gas were measured with South Coast Air Quality Management District method 307-91.

Results

Terminal Island Treatment Plant

Production of VSC. Methyl mercaptan, hydrogen sulfide and dimethyl sulfide were identified as the most important VSC in the digester gas. The highest concentrations of methyl mercaptan and hydrogen sulfide were found at 65.5°C (Figure 3). Reduction of the digester temperature to 60°C caused lower concentrations of both compounds. The dimethyl sulfide concentration was not affected by the digester temperature.

Biochemical stability. The VFA concentration in digester biosolids increased to approximately 1,000 mg/l after the digester temperature was increased to 65.5°C. The digester temperature did not significantly affect total alkalinity. These trends were

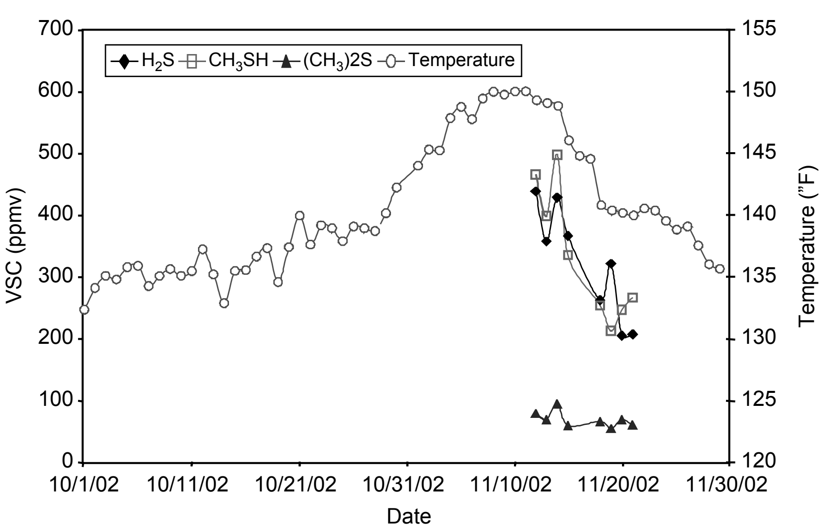


Figure 3 TITP–Volatile sulfur compounds versus digester temperature

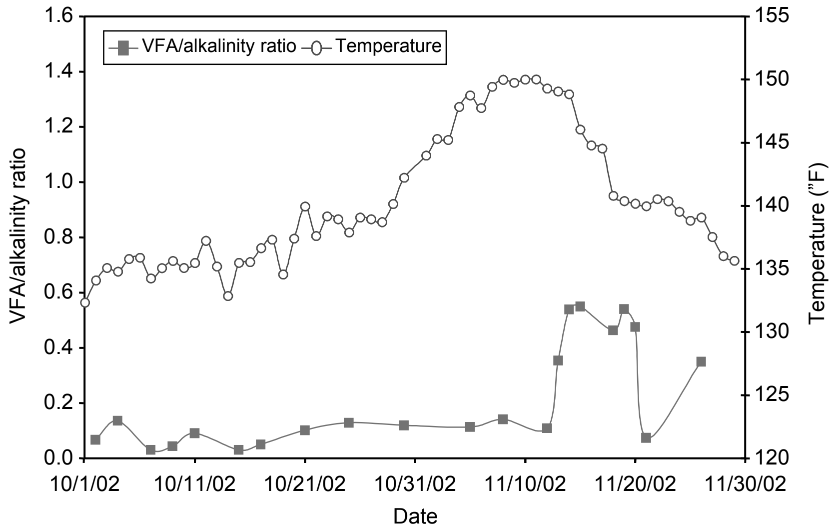


Figure 4 TITP–Volatile fatty acid to alkalinity ratio versus digester temperature

reflected in an abrupt increase in the VFA/total alkalinity ratio when the digester temperature was increased to 65.5°C (Figure 4).

Digester performance. The methane concentration in digester gas showed large fluctuations while increasing the temperature, indicating digester instability. Volatile solids destruction also decreased at higher digester temperatures, but the ammonia concentration and the pH were not affected (not shown).

Hyperion Treatment Plant

Production of VSC. A large increase of the methyl mercaptan concentration (up to 375 ppm_v) and an increase of the dimethyl sulfide concentration to around 40 ppm_v were observed when the digester temperatures was raised to 58°C (Figure 5). Both concentrations sharply dropped when the temperature of the digesters was reduced to 53°C.

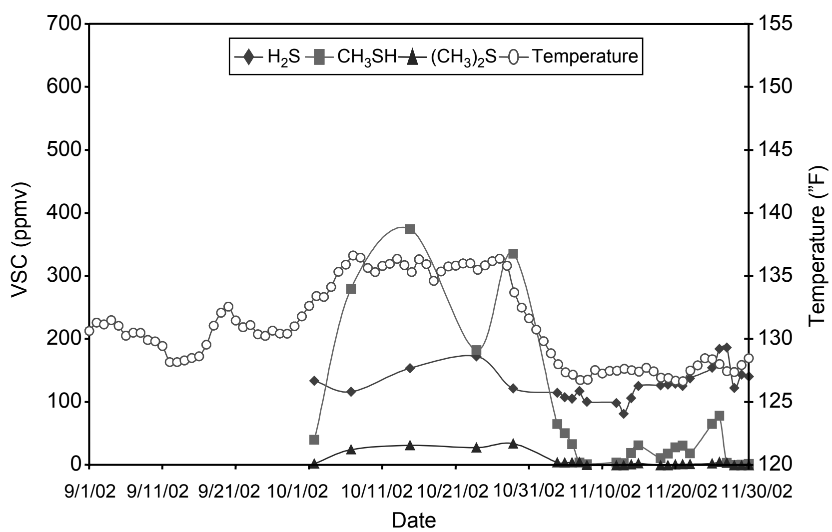


Figure 5 HTP–Volatile sulfur compounds versus digester temperature

Biochemical stability. The VFA concentration was somewhat higher at 58°C than at 54.4°C, while the total alkalinity remained relatively constant in this temperature range. Consequently, the increase of the digester temperature caused a small increase of the VFA/total alkalinity ratio (Figure 6), but not as pronounced as at TITP.

Digester performance. Digester performance was not significantly affected by the increase of the digester temperature to 58°C. Methane and carbon dioxide concentrations in the digester gas, volatile solids destruction and the ammonia concentration remained approximately the same between 54.4 and 58°C.

Discussion

Elevated production of methyl mercaptan and to a lesser extent hydrogen sulfide was correlated with the rapid increase of the digester temperature at both plants. Since both compounds have odor thresholds in the lower ppb range, it is likely that they were important components in the odor emissions that were reported from HTP's full-scale thermophilic operations during these periods of rapidly increasing temperatures.

Recent investigations have suggested a complex mechanism for the formation and degradation of VSC by microbial populations in anaerobic digesters, in which methanogens are suspected to catalyze the demethylation of methylated sulfur compounds (Higgins *et al.*, 2003). Thus, it may be postulated that the elevated VSC production at increasing digester temperatures is a consequence of biochemical instability and an imbalance between VSC production and degradation processes. Application of molecular methods may provide further insight into microbial populations and their activities in relation to temperature changes (Iranpour *et al.*, 2003b). A reduction of the methanogenic activity during episodes of increasing temperature could potentially cause two effects:

- Less production of methane from VFA, thereby causing accumulation of VFA in the digester.
- Reduced demethylation of VSC, thereby causing accumulation of methyl mercaptan and dimethyl sulfide in digester gas.

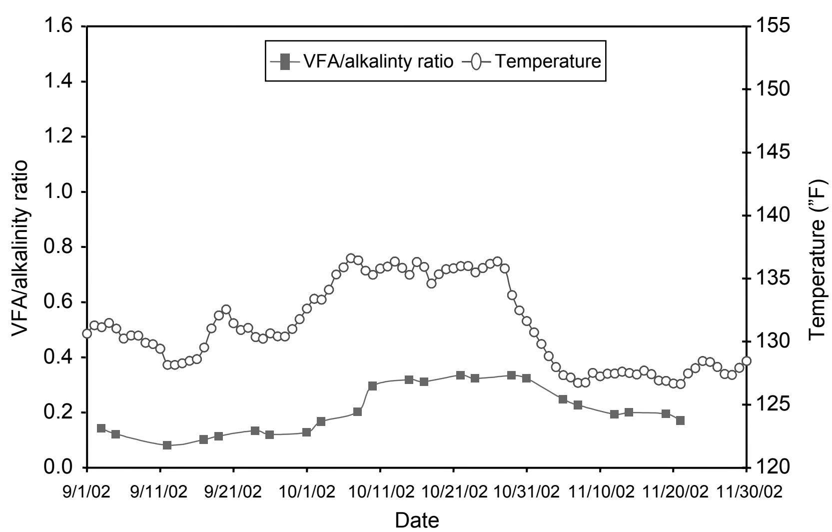


Figure 6 HTP–Volatile fatty acid to alkalinity ratio versus digester temperature

The increase of the VFA to total alkalinity ratio in the digesters at HTP and TITP confirms that rapidly increasing the digester temperature may have caused digester instability. At TITP, an effect on methane production and volatile solids destruction was also observed. Digester performance at HTP was not significantly affected, perhaps because the temperature increase was less at HTP than at TITP. It should be noted that the rapid changes in temperature during full-scale operations may not have allowed microbial populations to adapt to higher temperatures. Therefore, the observed impacts on full-scale operations were likely to be transient responses to increases of the temperature. This is substantiated by the observation that stable digester performance was observed soon after reducing the digester temperature. Hence, the microbial imbalances observed during the full-scale operations were reversible. Additional studies have been conducted at HTP using one dedicated first-stage digester to study the effect of high temperature on performance, biochemical stability and VSC production under steady-state conditions. The temperature of this digester was increased by approximately 0.5°C per month from 53 to 58°C. These tests demonstrated it was possible to operate HTP's digesters with no significant production of methyl mercaptan and other VSC at a temperature higher than 53°C if small increments in temperature and enough time are allowed for microbial populations to adapt to the higher temperature (Iranpour *et al.*, 2005b).

Conclusions

The rapid digester temperature increase at TITP from 57.5 to 65.5°C caused a higher VFA/alkalinity ratio, elevated production of H_2S and methyl mercaptan, and a minor decline in digester performance.

The rapid digester temperature increase at HTP from 54 to 58°C caused an elevated production of methyl mercaptan, but the VFA/alkalinity ratio and digester performance were not significantly affected.

These effects observed during full-scale operations were probably a result of microbial imbalances caused by rapidly increasing the temperature, which were reversed by reducing the temperature to the previous level.

The increase in odor complaints at HTP during transient high temperature digestion was probably associated with elevated production of methyl mercaptan.

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