Full-Scale Class A Biosolids Production by Two-Stage Continuous-Batch Thermophilic Anaerobic Digestion at the Hyperion Treatment Plant, Los Angeles, California

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ABSTRACT: The City of Los Angeles Hyperion Treatment Plant (HTP) (California) converted its anaerobic digesters to thermophilic operation to produce Class A biosolids. Phase IV tests demonstrated compliance of a two-stage, continuous-batch process with Alternative 1 of U.S. Environmental Protection Agency 40 *CFR* Part 503 (U.S. EPA, 1993), which defines the time–temperature requirement for batch treatment (T $\geq$ 56.3°C at 16-h holding). Fecal coliforms, *Salmonella* sp., viable helminth ova, and enteric viruses were not detected in biosolids in the postdigestion train, including the truck-loading facility and the farm for land application as the last points of plant control where compliance is to be demonstrated. The same results were achieved during Phase V tests, after lowering the second-stage holding temperature to 52.6°C to reduce the elevated methyl mercaptan production that was observed during Phase IV. Hence, the Phase V process complied with Alternative 3 of 40 *CFR* Part 503. Currently, HTP operates its digesters under the same conditions as tested in Phase V. In 2003, monthly monitoring of the biosolids at the truck-loading facility and the farm for land application demonstrated consistent compliance with Alternative 3. *Water Environ. Res.*, **78,** 2244 (2006).

KEYWORDS: thermophilic anaerobic digestion, disinfection, Class A biosolids, 40 *CFR* Part 503, Alternatives 1 and 3, postdigestion.
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Introduction

After the pioneering studies by Andrews and Pearson (1965), Garber et al. (1975), McCarty (1964), and Pohland and Bloodgood (1963), several plants have recently implemented processes for the thermophilic anaerobic digestion of wastewater treatment sludges (Schafer et al., 2003; Wilson and Dichtl, 1998; Wilson et al., 2002). A limited number of plants have also investigated the disinfection of biosolids (Volpe et al., 1993), generally by analysis of the digester outlet flows instead of the biosolids at the last point of plant control (truck-loading facility and/or farm for land application, which are the legally required sampling points). Useful information on disinfection by thermophilic anaerobic digestion is also available from bench- and pilot-scale studies (Ghosh, 1998; Huyard et al., 1998; Watanabe et al., 1997).

The City of Los Angeles has land-applied its biosolids in Kern County, California, since 1994. In response to a county ordinance banning the land application of Class B biosolids on January 1, 2003, the mesophilic anaerobic digesters of the City of Los Angeles Hyperion Treatment Plant (HTP) were converted to thermophilic operation to produce Class A biosolids. This paper describes the Phases IV and V certification tests that were conducted at HTP in October to December 2002. The Phases IV and V tests were preceded by the following full-scale tests and developments:

- During Phases I and II (October 2001 to March 2002), a battery of six digesters was converted to thermophilic operation as a two-stage continuous-batch process (Iranpour et al., 2006). This battery and its dedicated postdigestion train treated approximately 20% of the plant's feed sludge rate and were isolated from mesophilic plant operations (approximately 80% of the plant's feed sludge rate). *Salmonella* sp. were nondetectable in biosolids to the farm for land application. Fecal coliforms densities, however, increased in postdigestion biosolids, causing noncompliance at the truck-loading facility and the farm for land application. The fecal coliform recurrence was tentatively attributed to contamination of thermophilically digested biosolids by mesophilically digested biosolids and a large drop of the biosolids temperature after the dewatering centrifuges in the postdigestion train (Iranpour et al., 2006).
- Following the recommendations of Phases I and II, it was decided to proceed with the complete conversion to thermophilic operation, which would eliminate the possibility of contamination by mesophilically digested biosolids. In addition, the postdigestion train was insulated and electrically heat-traced to maintain a high biosolids temperature throughout postdigestion.
- The Phase III process was a two-stage continuous process, with 90% of the plant's feed sludge being digested at a thermophilic temperature (Iranpour et al., 2004a). This was a temporary process configuration, necessitated for completing the conversion of HTP to thermophilic operation. Mesophilically (10%) and thermophilically (90%) digested biosolids were mixed in the second stage; hence, this process was entirely thermophilic after the first stage. The biosolids at the truck-loading facility and the farm for land application complied with the Class A limit for fecal coliforms in over 95% of the samples. This indicates that the design modifications implemented after Phase 2 could prevent the recurrence of fecal coliforms in postdigestion.

The HTP has been entirely thermophilic since October 2002, using a two-stage, continuous-batch process (Iranpour et al., 2004a). The first stage of this process contains 16 digesters that are operated in a continuous mode. Digested biosolids of first stage are transferred to the second stage, with four digesters for batch treatment. The specific objective of the Phase IV test was to demonstrate compliance with the Class A pathogen reduction requirements using the time–temperature requirement for batch treatment Alternative 1 (40 *CFR* Part 503 [U.S. EPA, 1993]; alternatives for biosolids disinfection by thermophilic anaerobic digestion are discussed in the next section). Although the Phase IV process achieved complete disinfection of the biosolids, the rapid increase of the digester temperature (required to meet a minimum temperature of 56.3°C) caused an elevated production of methyl mercaptan and a concomitant increase of odor complaints (Iranpour et al., 2005). This necessitated a reduction of the digester temperature to a level that was previously used in the Phases I and II tests (approximately 53 to 54°C). As the time–temperature requirement of Alternative 1 would not be met, Phase V testing became necessary to demonstrate compliance with Alternative 3. In this contribution, we present the results of the Phases IV and V tests and include the first year (2003) of compliance data after receiving Kern County's permit for land application of Class A biosolids. The latter data are included, as they will be used in the future as support for an application of the Phase V process as a Process to Further Reduce Pathogens (PFRP equivalency, Alternative 6).

Regulations for Biosolids Disinfection

Federal Regulations. Production and land application of biosolids is regulated in 40 *CFR* Part 503 (U.S. EPA, 1993, 1994). This rule specifies general requirements, pollutant limits, management practices, and operational standards to ensure safe biosolids land application. Whereas the majority of land-applied biosolids still is of Class B quality (Goldstein, 2000), concerns about the safety of biosolids, growing public opposition, and local regulations have caused a shift towards the production of Class A biosolids. Pathogen levels in these biosolids are below the detection limit, which allows for unrestricted biosolids land application.

The Class A pathogen reduction requirements include the general standard that either the fecal coliform density in biosolids shall be less than 1000 MPN/g dry weight (wt) or the *Salmonella* sp. density shall be less than 3 MPN/4 g dry wt (U.S. EPA, 1993). These must be met at the last point of plant control, which typically is the truck-loading facility and/or the farm for land application. In addition to this general requirement, 40 *CFR* Part 503 defines six alternatives for the production of Class A biosolids (U.S. EPA, 1993, 1994). Alternatives 1, 3, and 6 are the most relevant for plants that use thermophilic anaerobic digestion (Iranpour et al., 2004b).

- Alternative 1 can be used if the process uses one of four time–temperature regimes for pathogen reduction. The regimes vary with the solids content of biosolids and the size of biosolids particles. Although not specifically mentioned in 40 *CFR* Part 503, it is generally understood that the time–temperature requirement can only be met in a process containing a batch stage.
- Alternative 3 can be used for continuous processes and other processes that do not meet the time–temperature requirements of Alternative 1. This alternative requires comprehensive monitoring of viable helminth ova and enteric viruses until it has been shown that the process effectively reduces these pathogens to below their detection limits (1 ova/4 g dry wt and 1 plaque-forming units [PFU]/4 g dry wt, respectively).
- Alternative 6 provides the opportunity to demonstrate equivalency of a process as a Process to Further Reduce Pathogens (PFRP). This typically requires extensive monitoring of process conditions and analyses of the biosolids to demonstrate that the process consistently produces Class A biosolids. In addition, it must be demonstrated that the process can achieve a 2-log reduction of viable helminth ova and a 3-log reduction of enteric viruses.

Kern County Ordinance. The City of Los Angeles Class A Biosolids Program has been motivated by Chapter 8.05 of the Kern County Ordinance, California, which banned the land application of Class B biosolids by January 2003. This ordinance has a few additional requirements to the federal standards, an important one for this study being that both density limits for fecal coliforms and *Salmonella* sp. shall be met.

Materials and Methods

Hyperion Treatment Plant and Conversion to Thermophilic Operation. The HTP is a full secondary wastewater treatment plant servicing a population of 4 million in a surface area of approximately 1550 km^2 (600 sq mi). The average daily flow is 1.3×10^6 m^3/d (350 mgd), with a design peak wet-weather flow of 3.0×10^6 m^3/d (800 mgd). The HTP converted a battery of six digesters to thermophilic operation in June 2000 for initial investigations (Iranpour et al., 2006). The remaining 14 digesters were converted to thermophilic operation in July 2002. These conversions were done by rapidly increasing the digester temperature, while slowly increasing the sludge feed rate to achieve rapid adaptation and stable operation of thermophilic digesters.

Two-Stage, Continuous-Batch Thermophilic Anaerobic Digestion Process. The HTP digests, on average, 1.1×10^4 m^3/d (3 mgd) primary sludge and 3.0×10^3 m^3/d (0.8 mgd) thickened waste activated sludge in 20 egg-shaped digesters, each with a volume of 9500 m^3 (2.5×10^6 gallons) and equipped with an internal draft system for mixing. Figure 1 presents an overview of the two-stage, continuous-batch digestion process. The first stage contained 16 digesters in three batteries, which were all operated in a continuous mode, at an average hydraulic retention time of 11.6 ± 1.0 days. Primary sludge and thickened waste activated sludge were transported to the digesters through separate pipes. The flow of these sludges to the first-stage digesters were regulated by electrically operated valves that were opened and closed every few minutes to provide a nearly continuous feed to each digester. The digester outflows were combined and pumped to the second stage containing four batch digesters. These digesters were operated in cycles of feeding for 8 hours, holding for 16 hours, and withdrawing for 8 hours, as shown in Table 1. Heating of the wastewater treatment sludges was by steam injection to the feed lines and the top of the first-stage digesters. Additional steam was injected to the biosolids transfer lines from the first to the second stage. Temperatures were measured by two sensors in each digester, continuously monitored in HTP's control room and reported as daily averages.

Postdigestion Train. Postdigestion at HTP (Figure 1) consisted of screening, centrifuge dewatering, transfer of concentrated biosolids (30% total solids [TS]) through pipes with slip-injection of high-pressure effluent, and storage in silos to a maximum of one day. The transfer lines and silos in the postdigestion train were

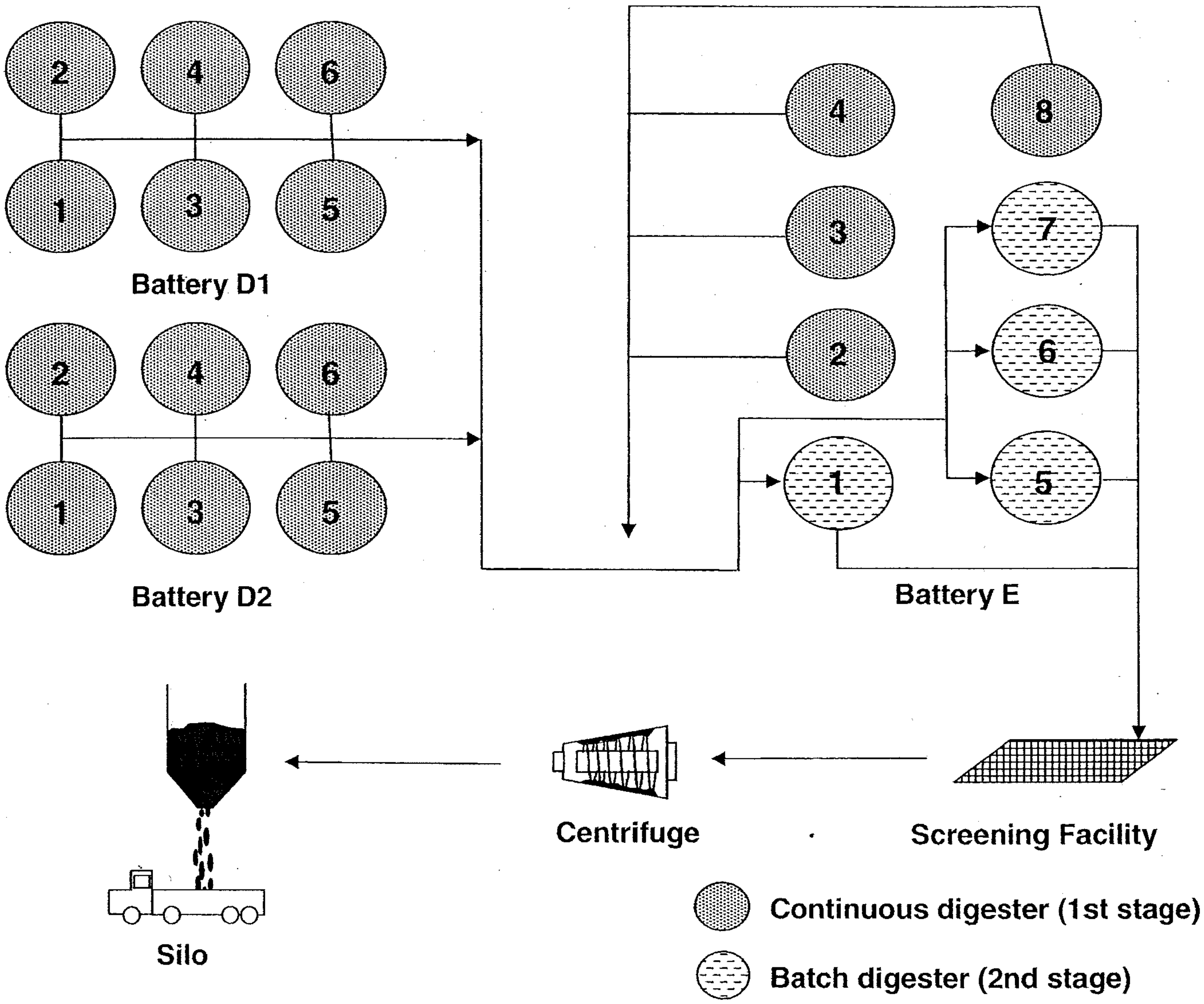

Figure 1—Two-stage, continuous-batch digestion and postdigestion at HTP.

insulated and electrically heat-traced to reduce the heat losses that were observed during the initial tests in Phases I and II.

Experimental Protocols. Testing consisted of sampling at seven locations in the postdigestion train (digester outflow, prescreening, postscreening, centrifuge inflow, centrifuge outflow, truck-loading facility, and farm for land application). The tests for the first five locations were limited in Phases IV and V, because these postdigestion locations were extensively evaluated during Phases I and II, which showed nondetectable levels everywhere in the postdigestion train, except the truck-loading facility and the farm (Iranpour et al., 2006). Therefore, Phases IV and V tests focused on pathogen monitoring in biosolids at the truck-loading facility and farm for land application as the last points of plant control.

During Phase IV tests (October 2002), the average holding temperature in the second-stage batch digesters was kept above 56.3°C to comply with the time–temperature requirement of Alternative 1 for a holding period of 16 hours. Primary sludge and farm biosolids were sampled on a daily basis for a period of 18 days (October 7 to 24, 2002) and analyzed for the densities of fecal coliforms, *Salmonella* sp., viable helminth ova, and enteric viruses. The farm biosolids were sampled immediately after delivery by designated trucks that were cleaned by steam.

During the Phase V tests (November 2002), the digester temperatures in the first and second stage were reduced to an average value of 52.6°C. The second-stage holding time was kept at 16 h. During a period of one week (November 5 to 12, 2002), farm

Table 1—Feed, hold, and withdraw cycles of second-stage batch digesters.

	8 hr				
Digester	**Sequence #1**	**Sequence #2**	**Sequence #3**	**Sequence #4**	**Sequence #1**
1E	Feed	Hold	Hold	Withdraw	Feed
5E	Withdraw	Feed	Hold	Hold	Withdraw
6E	Hold	Withdraw	Feed	Hold	Hold
7E	Hold	Hold	Withdraw	Feed	Hold

Table 2—Summary of thermophilic process data.

Phase/parameter	Mean ± standard deviation
Phase IV	
– TS in inflow (%)	3.8 ± 0.3
– VS in inflow (% of TS)	80.1 ± 1.2
– VS destruction (%)	58.3 ± 9.2
– pH	7.4 ± 0.34
– VFA (mg/L)	878 ± 223
– Alkalinity (mg/L)	3235 ± 154
– VFA/alkalinity ratio	0.274 ± 0.078
Phase V	
– TS in inflow (%)	4.2 ± 0.3
– VS in inflow (% of TS)	80.1 ± 0.9
– VS destruction (%)	58.4 ± 6.1
– pH	7.1 ± 0.75
– VFA (mg/L)	749 ± 85
– Alkalinity (mg/L)	3635 ± 91.6
– VFA/alkalinity ratio	0.206 ± 0.027
Post-Phase V (2003)	
– TS in inflow (%)	4.2 ± 0.4
– VS in inflow (% of TS)	80.4 ± 1.3
– VS destruction	60.0 ± 7.1
– pH	7.5 ± 0.1
– VFA (mg/L)	324 ± 141
– Alkalinity (mg/L)	4103 ± 337
– VFA/alkalinity ratio	0.081 ± 0.049

biosolids were daily sampled and analyzed for the densities of fecal coliforms and pathogens.

After completing the Phase V tests, operation of the two-stage, continuous-batch process was continued under conditions essentially the same as during the Phase V test. Compliance with Alternative 3 required monthly testing of biosolids in the silos at the truck-loading facility and quarterly testing of biosolids at the farm and monitoring of process conditions. The post-Phase V compliance tests include data during January to December, 2003.

Sampling Procedures. Primary sludge and biosolids from the truck-loading facility and the farm for land application were collected in sterile plastic bags or bottles (sample size 0.5 to 1 L). Samples collected at the plant were immediately transported to the laboratory for analysis and required no preservation. Farm biosolids were stored in cooled boxes and transported to the laboratory within five hours after collection. Samples for analyses of viable helminth ova and enteric viruses were stored at 4 and −18°C, respectively, until composition of these samples on the last sampling day of the Phases IV and V tests. Biosolids temperatures were measured with a digital thermometer in the total solids sample immediately after collection.

Analytical Procedures. All procedures were according to the requirements of 40 *CFR* Part 503 (U.S. EPA, 1993): fecal coliforms (Parts 9221-B and E1 of APHA et al., 1992); *Salmonella* sp. (Kenner and Clark, 1974); viable helminth ova (U.S. EPA, 1987); enteric viruses (ASTM, 1992); and total solids (Part 2540-G of APHA et al., 1992). Nonbacterial pathogens were analyzed by BioVir Laboratories (Benicia, California). Methyl mercaptan in digester gas was determined according to South Coast Air Quality Management District Method 307-91 (Diamond Bar, California), using gas chromatography with sulfur chemiluminescence detection, at a detection limit of 0.13 ppm_v. All other procedures were

Table 3—Digester temperatures.

Phase/stage	Temperature (°C) Mean ± standard deviation	Range
Phase IV		
– First stage	57.5 ± 0.9	55.0 to 60.3
– Second stage	57.4 ± 0.3	56.6 to 58.2
Phase V		
– First stage	52.7 ± 0.9	50.6 to 54.4
– Second stage	52.6 ± 0.6	51.9 to 53.7
Post-Phase V (2003)		
– First stage	53.5 ± 0.2	52.7 to 53.7
– Second stage	53.8 ± 0.3	53.0 to 55.0

performed by the City of Los Angeles Environmental Monitoring Division at HTP, according to *Standards Methods* (APHA et al., 1992), either on a daily basis (TS, volatile solids [VS], and pH) or twice per week (volatile fatty acids [VFAs] and alkalinity).

Results

Biochemical Stability. The data summarized in Table 2 confirm that the performance of the digesters during the Phases IV and V tests was quite comparable to the average performance during 2003, when thermophilic process conditions were kept constant. It should be noted that initial operation in Phase IV caused a somewhat elevated VFA production, but the VFA-to-alkalinity ratio was only 0.27. This ratio further declined to 0.21 during Phase V operation in November 2002. Continuation of Phase V operation in 2003 showed even less VFA production, and the VFA-to-alkalinity ratio was close to 0.1.

Postdigestion Temperatures. Without insulation during the initial tests of Phases I and II, the biosolids temperature decreased from 52.6°C at the digesters to 41.0°C at the truck-loading facility (Iranpour et al., 2006). During these full-scale tests of Phases IV and V, insulation of the postdigestion train reduced the temperature drop between the digesters and the truck-loading facility to only 4°C.

Phase IV (Alternative 1). *Digester Temperatures.* The lowest temperature recorded in any of the second-stage digesters was 56.6°C (Table 3), which is above the minimum of 56.3°C, as required by Alternative 1 for a holding period of 16 h. Hence, the Phase IV process complied with the time–temperature requirement of Alternative 1. As illustrated in more detail in Figure 2, the temperatures in the batch digesters were relatively constant during holding. The batch digester typically cooled down by 0.2 to 0.3°C during holding, as there was only supply of steam when the biosolids were transferred from the first to the second stage. The temperature measurements in the batch digesters during feed and withdrawal periods showed large fluctuations, which do not reflect actual temperatures, because biosolids levels in these periods were below the temperature sensors.

Fecal Coliforms. Previous tests had shown that fecal coliform densities in primary sludge were consistently in the range of 10^7 to 10^8 MPN/g dry wt; however, fecal coliforms were not detected (<6.9 MPN/g dry wt) in farm biosolids in all 10 samples (Table 4).

Salmonella sp. Densities of *Salmonella* sp. in primary sludge varied between <1.9 and 7.7 MPN/4 g dry wt. *Salmonella* sp. in farm biosolids were consistently below the detection limit (Table 4).

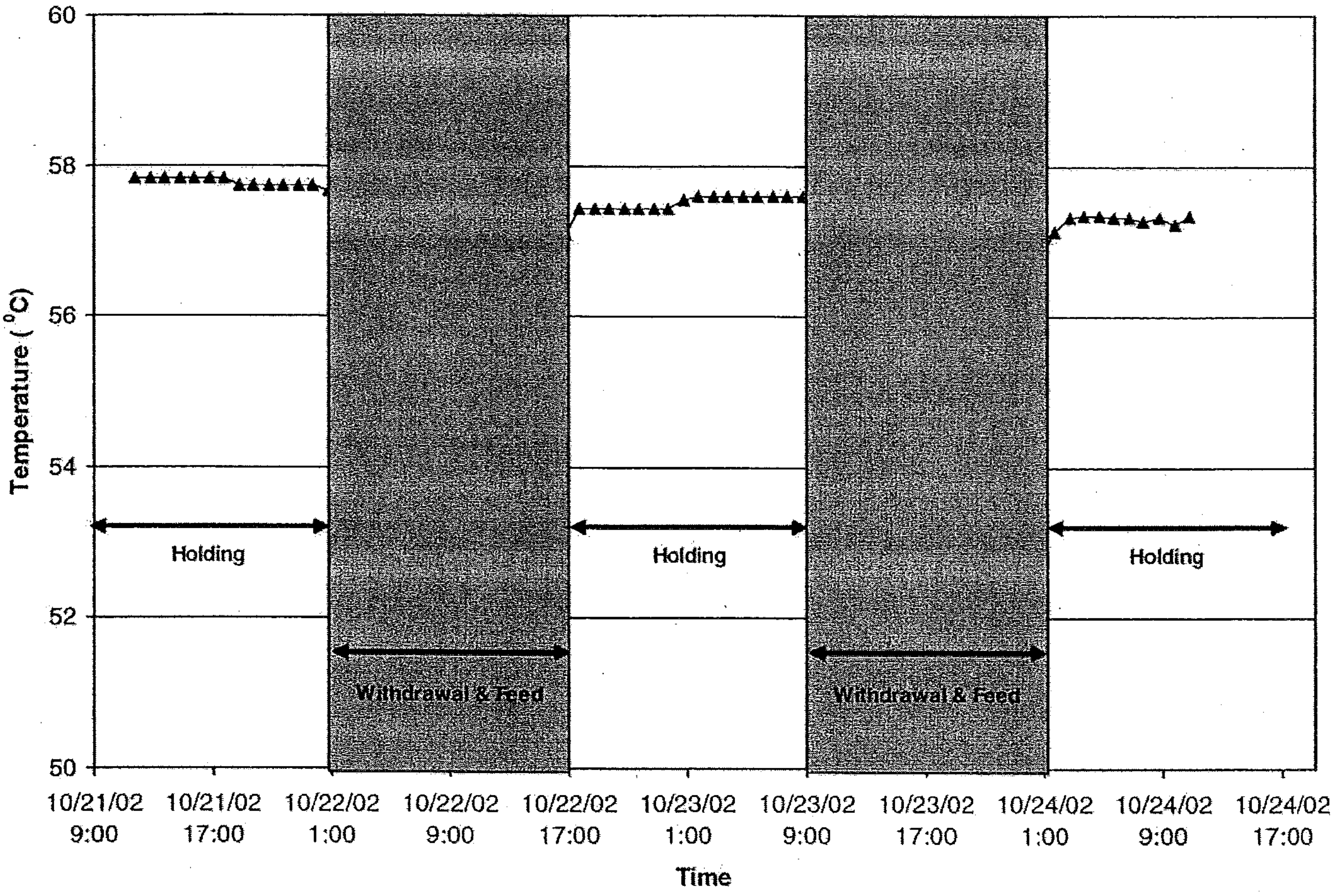

Figure 2—Phase IV: Example of continuous temperature measurements in second-stage batch digester 6E.

Nonbacterial Pathogens. Alternative 1 does not require the analysis of viable helminth ova and enteric viruses. Nevertheless, these analyses were done to compare the Phase IV process with the Phase V process. Viable helminth ova were not detected in either the digester inflow or in farm biosolids (Table 4). Enteric viruses were present in five-day composite samples of primary sludge at densities of 39 and 43 PFU/4 g dry wt, but they were not detected in farm biosolids (Table 4).

Other Sampling Locations. Confirming the comprehensive postdigestion tests in initial studies with similar setups in Phases I and II (Iranpour et al., 2006), fecal coliforms and *Salmonella* sp. were not detected in postdigestion biosolids between the digesters and the dewatering centrifuges (digester outflow, prescreening, postscreening, centrifuge inflow, and centrifuge outflow).

Phase V (Alternative 3). *Digester Temperatures.* The digester temperatures were lowered to reduce the increase of odor emissions in Phase IV that were probably caused by an elevated methyl mercaptan production, as shown in Figure 3. The average temperature in the second stage of the Phase V process was 52.6°C (Table 3). Tests conducted in Phases I, II, and III had shown that

Table 4—Results of fecal coliform and pathogen monitoring of Phase IV (October 2002).

PHASE IV			Week 1					Week 2				Week 3			
Sample	**Analysis**	**Unit**	**10/7 Mon**	**10/8 Tue**	**10/9 Wed**	**10/10 Thur**	**10/11 Fri**	**10/15 Tue**	**10/16 Wed**	**10/17 Thur**	**10/18 Fri**	**10/21 Mon**	**10/22 Tue**	**10/23 Wed**	**10/24 Thu**
Primary sludge	*Salmonella* sp.	MPN/4 g dry wt	4.2	7.7	15	4.7	< 1.9	2.1	4.3	2.1	< 2.0				
	Helminth ova	Ova/4 g dry wt			< 1 (composited)				< 1 (composited)						
	Enteric viruses	PFU/4 g dry wt			39 (composited)				43 (composited)						
Farm biosolids	Ambient temp.	°C				12.2	11.7	11.7	9.4	10.8	9.4	8.9	11.7	9.8	10.6
	Biosolids temp.	°C				53.2	54.6	54.4	54.4	53.3	55.3	53.6	53.7	54.3	53.4
	Fecal coliforms*	MPN/g dry wt				< 6.4	< 6.4	< 6.6	< 6.5	< 6.6	< 6.8	< 6.9	< 6.8	< 6.5	< 6.6
	Salmonella sp.*	MPN/4 g dry wt				< 1.4	< 1.4	< 1.4	< 1.3	< 1.4	< 1.5	< 1.5	< 1.5	< 1.4	< 1.4
	Helminth ova	Ova/4 g dry wt							< 1 (composited)				< 1 (composited)		
	Enteric viruses	PFU/4 g dry wt							< 1 (composited)				< 1 (composited)		

* Fecal coliforms and *Salmonella* sp. were not detected in biosolids sampled from five different locations between the digesters and the dewatering centrifuges (October 3, 2002), confirming extensive postdigestion testing in Phases I and II (Iranpour et al., 2004a).

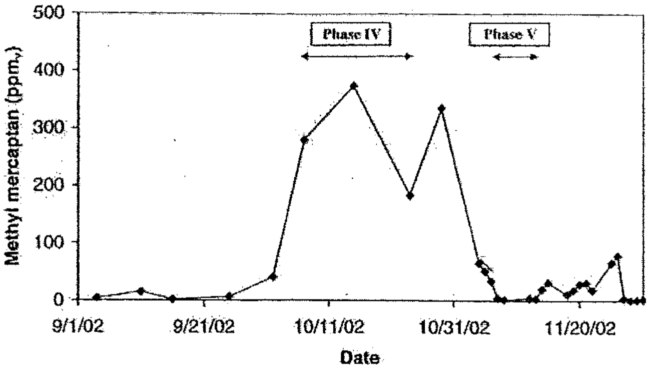

Figure 3—Production of methyl mercaptan in digester gas during Phase IV testing.

this temperature did not cause a significant increase of odor emissions. Because the holding time in the second stage was the same as during Phase IV (16 h), the time–temperature requirement of Alternative 1 was not met. Hence, the Phase V test was to demonstrate compliance with Alternative 3.

Fecal Coliforms. Densities of fecal coliforms in farm biosolids were below the detection limit in all of 6 samples (Table 5).

Salmonella sp. The density of *Salmonella* sp. in primary sludge varied from <1.7 to >13 MPN/4 g dry wt, but *Salmonella* sp. in farm biosolids were consistently not detected (Table 5).

Nonbacterial Pathogens. As in the Phase IV test, composited samples of primary sludge and farm biosolids did not contain viable helminth ova. Enteric viruses in primary sludge were present at a density of 71 PFU/4 g dry wt, but farm biosolids did not contain detectable enteric viruses (Table 5).

Other Sampling Locations. As in Phase IV and similar to the results in Phases I and II (Iranpour et al., 2006), fecal coliforms and *Salmonella* sp. were not detected in postdigestion biosolids between the digesters and the dewatering centrifuges (digester outflow, prescreening, postscreening, centrifuge inflow, and centrifuge outflow).

Post-Phase V (2003; Alternative 3). *Digester Temperatures.* The average first-stage digester temperature was 53.5°C, with very little variation over time and between individual digester temperatures (Table 3). Second-stage digester temperatures during holding were, on average, 53.8°C.

Fecal Coliforms. Fecal coliforms were typically not detected during monthly testing of biosolids at the truck-loading facility and quarterly testing of farm biosolids (Table 6). Only the samples from April and December 2003 contained fecal coliforms, but the densities were at least 20 times less than the Class A limit.

Salmonella sp. *Salmonella* sp. in primary sludge were present at a density in the range 3.6 to 18.2 MPN/4 g dry wt; however, biosolids from the truck-loading facility and the farm did not contain detectable *Salmonella* sp. (Table 6).

Nonbacterial Pathogens. Viable helminth ova were detected at a low density in 3 of 12 primary sludge samples, but they were never detected in biosolids from the truck-loading facility and farm biosolids (Table 6). Enteric viruses, present in primary sludge in a density of up to 51 PFU/4 g dry wt., were also not detected in biosolids from the truck-loading facility and farm biosolids.

Other Sampling Locations. Based on these results and in an effort to save costs, it was decided not to sample at locations other than the truck-loading facility and the farm.

Discussion and Conclusions

An important outcome of this study is that complete disinfection of biosolids at the last points of plant control (truck-loading facility and the farm for land application) can be achieved in a two-stage, continuous-batch process with a second batch stage operated under conditions less stringent than required by the time–temperature requirement of Alternative 1. One important aspect to consider is the importance of odor emissions from thermophilic operations for the public acceptance of biosolids land application (Goldstein, 2000; U.S. EPA, 1999). One possible option to reduce odor emissions is to use a process in which the thermophilic stage is followed by a mesophilic stage, such as temperature phased anaerobic digestion (TPAD) (Schafer et al., 2003). Although volatile solids and pathogen destruction by TPAD has been well-documented in laboratory- and pilot-scale tests (e.g., Bucher et al., 2001; Reusser and Zelinka, 2001; Sandino et al., 2002; Santha et al., 2003), and several plants have implemented TPAD on a full scale (Arant et al., 2003; Schafer et al., 2003; Wilson and Dichtl, 1998), the effect of polishing by a mesophilic stage on reducing odor emissions has not been well-established. We opted for reducing the digester temperature in Phase V to the lower end of the thermophilic range,

Table 5—Results of fecal coliform and pathogen monitoring of Phase V (November 2002).

			PHASE V					
Sample	**Analysis**	**Unit**	**11/5 Tue**	**11/6 Wed**	**11/7 Thur**	**11/8 Fri**	**11/9 Sat**	**11/12 Tue**
Primary sludge	*Salmonella* sp.	MPN/4 g dry wt	> 13	12	< 1.7	7.4	5.5	
	Helminth ova	Ova/4 g dry wt			< 1 (composited)			
	Enteric viruses	PFU/4 g dry wt			71 (composited)			
Farm biosolids	Ambient temp.	°C	5.6	5.6	13.3	17.8	16.1	16.7
	Biosolids temp.	°C	49.9	51.7	52.3	51.2	51.2	51.4
	Fecal coliforms*	MPN/g dry wt	< 6.8	< 6.8	< 6.9	< 6.5	< 6.9	< 6.9
	Salmonella sp.*	MPN/4 g dry wt	< 1.5	< 1.5	< 1.5	< 1.4	< 1.5	< 1.5
	Helminth ova	Ova/4 g dry wt			< 1 (composited)			< 1
	Enteric viruses	PFU/4 g dry wt			< 1 (composited)			< 1

* Fecal coliforms and *Salmonella* sp. were not detected in biosolids sampled from five different locations between the digesters and the dewatering centrifuges (November 1, 2002), confirming extensive postdigestion testing in Phases I and II (Iranpour et al., 2004a).

Table 6—Results of fecal coliform and pathogen monitoring of post-Phase V (2003).

			POST-PHASE V (2003)											
Sample	**Analysis**	**Unit**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Primary sludge	*Salmonella* sp.	MPN/4 g dry wt	7.8	3.6	6.4	4.1	11.2	11.8	12.3	12.8	2.2	18.2	16.8	14.9
	Helminth ova	Ova/4 g dry wt	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	2	2	< 1	2
	Enteric viruses	PFU/4 g dry wt	10	10	15	9	13.0	34	51	48	36	19	40	18
Truck loading facility biosolids	Fecal coliforms	MPN/g dry wt	< 6.5	< 6.5	< 6.8		< 6.6	< 6.7		< 7.8	< 6.7		< 6.6	44.8
	Salmonella sp.	MPN/4 g dry wt	< 1.4	< 1.4	< 1.4		< 1.4	< 1.4		< 1.7	< 1.0		< 1.2	< 1.5
	Helminth ova	Ova/4 g dry wt	< 1	< 1	< 1		< 1	< 1		< 1	< 1		< 1	< 1
	Enteric viruses	PFU/4 g dry wt	< 1	< 1	< 1		< 1	< 1		< 1	< 1		< 1	< 1
Farm biosolids	Fecal coliforms	MPN/g dry wt				22			< 6.5			< 6.8		
	Salmonella sp.	MPN/4 g dry wt				< 1.4			< 1.4			< 1.2		
	Helminth ova	Ova/4 g dry wt				< 1			< 1			< 1		
	Enteric viruses	PFU/4 g dry wt				< 1			< 1			< 1		

to maintain disinfecting conditions, while reducing odor emissions. In addition, the implementation of a final mesophilic stage would result in a relatively low postdigestion biosolids temperature, which could be a factor contributing to fecal coliform recurrence in postdigestion (Iranpour et al., 2003, 2004c).

The reduction of the temperature in Phase V would imply elimination of the possibility of operation under Alternative 1, as the time–temperature requirement for batch disinfection was not met. Operation under Alternative 3 has the drawback of the requirement for monitoring of viable helminth ova and enteric viruses. However, this is more than offset by reduction of the energy costs because of the digester operations at lower thermophilic temperatures.

Most studies have evaluated the disinfection of biosolids only at the digester outlet flows, thereby not including the possibility of reactivation and/or growth of fecal coliforms and pathogens during postdigestion processing and storage of biosolids. It is noteworthy that, in this study, the Class A limits were met in biosolids at the truck-loading facility and the farm for land application, which are the last points of plant control where compliance needs to be demonstrated. In addition, preliminary tests with farm biosolids have demonstrated that fecal coliforms remained nondetectable when the biosolids were stored for over one week at an ambient temperature (Figure 4). Hence, it can tentatively be concluded that the disinfection at HTP's thermophilic process achieved destruction of fecal coliforms rather than inactivation of these microorganisms. This is an important finding, because inactivated cells may be nonculturable during analysis (Gibbs et al., 1997; National Research Council, 2002) and hence be nondetectable, but still cause noncompliance with the Class A requirements after reactivation. Other factors that may potentially contribute to preventing the recurrence of fecal coliforms in postdigestion biosolids are the production of ammonia, VFAs, and possibly other compounds, such as proteases and antibiotics, by the indigenous thermophilic culture (Kato et al., 2001; Traub et al., 1986; Ward and Ashley, 1977; Ward et al., 1999).

The results obtained in 2003 confirm the results of the Phase V test, by demonstrating nearly complete disinfection of biosolids over 12 months of operation. The consistency of disinfection with the ability of operating the first- and second-stage digesters within narrow ranges of holding time and temperature holds promise regarding future plans of the City of Los Angeles to seek equivalency of HTP's two-stage, continuous-batch process as a PFRP (Alternative 6). In addition, it will need to be demonstrated that the process conditions will achieve a 2-log reduction of viable helminth and a 3-log reduction of enteric viruses. If approved PFRP equivalency would be granted, this would provide a backup to operation of HTP's process under Alternative 3 and reduce the monitoring requirements for helminth ova and enteric viruses.

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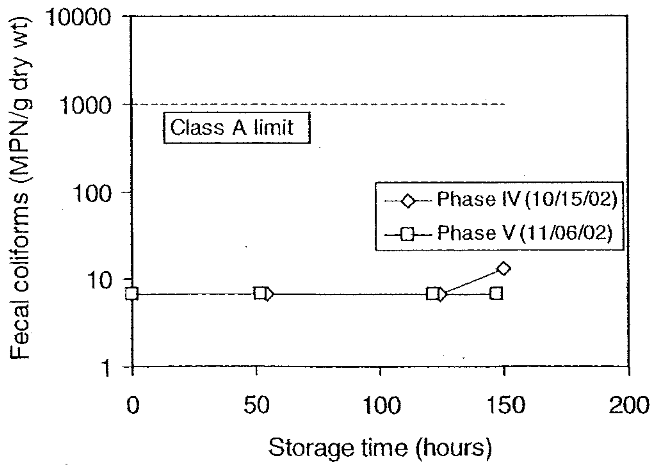

Figure 4—Fecal coliforms in farm biosolids during storage at 22°C.

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