Vol. 2, No. 1, 84-107, 2009
ISSN 0718-378X

REVISTA AIDIS

de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica.

PRODUCTION OF EXCEPTIONAL QUALITY BIOSOLIDS (CLASS A +) AT CITY OF LOS ANGELES 'S WASTEWATER PLANTS

Reza. Iranpour
Hubertus H.J. Cox

Production of exceptional quality biosolids (class a +) at City of los Angeles's wastewater plants

ABSTRACT

This paper is in two parts. Part I discusses how the Hyperion Wastewater Treatment Plant (HTP) produced Exceptional Quality (EQ) Biosolids after 5 phases of full-scale studies from 1999 to 2003, trying several alternatives from 40 CFR Part 503. HTP got certification (permit) to operate Class A EQ since 2003 and has continued operations and land application of Class A EQ till present. Part II discusses how the Terminal Island Water Reclamation Treatment Plant (TITP) achieved similar biosolids in 3 phases between 1999 and 2004, trying Alternative 1 od 40 CFR Part 503. This plant has continued producing land applied Class A biosolids till present. During the presentation, we will discuss Class A EQ data for both plant up to the present. Research, operational and maintenance issues and future plans will also be discussed.

Keywords: Treatment Plant, Class A biosolids.

Contact City of Los Angeles Bureau of Sanitation, 12000 Vista del Mar, Playa del Rey, CA 90293; Corresponding author: *phone (213) 4850577 email Rezairanpo@aol.com

Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica. Vol. 2, No. 1, 84-107, 2009. ISSN 0718-378X

PRODUCTION OF EXCEPTIONAL QUALITY BIOSOLIDS (CLASS A +) AT CITY OF LOS ANGELES 'S WASTEWATER PLANTS

Reza. Iranpour
Hubertus H.J. Cox

Contact City of Los Angeles Bureau of Sanitation, 12000 Vista del Mar, Playa del Rey, CA 90293;
Corresponding author: *phone (213) 4850577 email Rezairanpo@aol.com

Resumo
Este trabalho apresenta duas partes. A parte I discute como a Estação de tratamento Hyperion produziu biossólidos de excepcional qualidade após 5 fases de estudo em plena escala de 1999 a 2003, tentando várias alternativas com base na regulamentação 40 CFR parte 503. A Estação de Hyperion obteve certificação para operar na classe A-EQ desde 2003 e tem operado com aplicação no solo (classe A-EQ) até o presente.

A parte II discute como a Estação de Tratamento e Recuperação da Água de Terminal Island obteve biossólidos similares em 3 fases entre 1999 e 2004, tentando a alternativa 1-40 da regulamentação CFR parte 503. Esta estação tem continuado a aplicação de biossólidos no solo, na classe A até o presente.

Durante a apresentação discutiremos dados da classe A-EQ para ambas as estações até o presente.

Aspectos de pesquisa, operação e manutenção serão também

Part I. Hyperion Treatment Plant (HTP)
Early investigations on thermophilic anaerobic digestion at the City of Los Angeles Hyperion Treatment Plant (HTP) date back to the work of Garber, who had the main objective of improving solids destruction and gas production by increasing the digester temperature (Garber, 1954; Garber et al., 1975). More recently, interest in thermophilic anaerobic digestion has been renewed by an ordinance in Kern County, California, which banned the land application of Class B biosolids as of January 1, 2003. In anticipation of this ordinance, the City of Los Angeles in 1999 initiated a program to investigate and implement thermophilic anaerobic digestion at its plants for the production of Exceptional Quality (EQ) biosolids (Iranpour et al., 2005a). Production and land application of biosolids in the U.S. is regulated by the U.S. EPA in 40 CFR 503, commonly referred to as the Part 503 Biosolids Rule (U.S. EPA, 1993). EQ biosolids

meet the Class A pathogen reduction requirements and can be land applied without site restrictions (U.S. EPA, 1994).

Pilot-scale tests at HTP (Phases I and II)

They demonstrated the reduction of fecal coliform and *Salmonella* sp. densities to below the Class A limits in a designated thermophilic battery of six digesters, which treated approximately 20% of the plant's feed sludge (Iranpour et al., 2004a; 2005a). The recurrence of fecal coliforms (Class A limit of 1000 MPN/g dry wt) in post-digestion biosolids during these pilot tests, however, caused non-compliance with the Class A pathogen reduction requirements in the Kern County ordinance. Fecal coliform recurrence was tentatively attributed to: a) contamination of thermophilically digested biosolids by mesophilically digested biosolids; b) a large drop of the biosolids temperature in the thermophilic post-digestion train, which could have facilitated the reactivation and/or growth of fecal coliforms (Iranpour et al., 2002a; 2004b). It was therefore decided to insulate and heat-trace HTP's post-digestion train between the digesters and silos at the Truck Loading Facility.

After completing the conversion of HTP to thermophilic operation and the insulation of the post-digestion train, several full-scale tests were conducted to demonstrate compliance with the local and federal standards for EQ biosolids. In this contribution, the following tests will be discussed:

Phase III: two-stage continuous process for compliance with Alternative 3 in 40 CFR 503.32.
Phase IV: two-stage continuous/batch process for compliance with Alternative 1.
Phase V: two-stage continuous/batch process for compliance with Alternative 3.

EPA Regulations

The general requirement for Class A biosolids is that either the fecal coliform (indicator) density needs to be less than 1000 MPN/g dry wt or the *Salmonella* sp. (pathogen) density needs to be less than 3 MPN/4 g dry wt. In addition, one of six Alternatives in 40 CFR 503 Section 32 should be used. These Alternatives specify treatment conditions or requirements for additional monitoring. Thermophilic anaerobic digestion may comply with Alternatives 1, 3, 4 or 6:

- Alternative 1 specifies the required time and temperature for disinfection of biosolids. Although not specifically defined in the regulations, it is usually understood that the time-temperature requirement needs to be met in a batch process to guarantee a certain holding time for all sludge particles.
- Alternative 3 can be used for continuous processes or other processes that do not meet the time-temperature requirement of Alternative 1. Alternative 3 requires additional monitoring of viable helminth ova and enteric viruses (non-bacterial pathogens) and monitoring of process parameters. If destruction of both non-bacterial pathogens to below their limit of detection has been demonstrated, the process is considered to be Class A as long as operation is in the parameter range during which complete destruction was achieved.

- Alternative 4 can be used for undefined processes. The requirement is that helminth ova and enteric viruses need to be non-detectable in each batch of biosolids leaving the plant. This alternative is not feasible for plants that produce and transport biosolids on a continuous basis.
- If a process has been demonstrated to achieve the Class A pathogen reduction requirements, Alternative 6 provides the opportunity of seeking equivalency as a Process to Further Reduce Pathogens (i.e., “recognized” Class A processes, which are included in Alternative 5) as decided by the Pathogen Equivalency Committee. This requires extensive testing to demonstrate the equivalency.

Materials and methods

Hyperion Treatment Plant (HTP) is the main wastewater treatment facility for the City of Los Angeles, servicing an area of about 1500 km^2 and a population of about 4 million. The treatment process consists of preliminary screening and enhanced primary treatment, a pure oxygen secondary activated sludge process, conventional and egg-shaped digesters, solid bowl centrifuges for sludge dewatering, and biosolids handling and storage. The average daily flowrate is 350 mgd. The plant produces approximately 700-800 wet tons of biosolids per day, the vast majority being land applied in Kern County. Post-digestion biosolids handling at HTP consists of screening, centrifuge dewatering, transport of digested sludge and concentrated biosolids through pipes with Able pumps, and biosolids storage in silos for a maximum of one day. Prior to the tests described herein, the entire post-digestion train between digesters and silos was insulated and provided with electrical heat-tracing to reduce heat losses during post-digestion biosolids handling.

Phase I and II Processes

These will be discussed briefly (1999 to 2002).

Phase III process: This process was tested in August/September, 2002, when the conversion of HTP to thermophilic operation still was in progress **(Figure 1).** The first stage contained 15 thermophilic digesters (90% of the plant’s total feed sludge) at an average temperature of 54.4^{0}C and a mean hydraulic retention time (HRT) of 10.9 days. Approximately 10% of the sludge was digested in 6 mesophilic digesters at an average temperature of 35.2^{0}C and a mean HRT of approximately 39 days. Digested biosolids from mesophilic and thermophilic digesters were mixed in two blending digesters at a mean HRT of 1.3 days and an average temperature of approximately 51.4^{0}C.

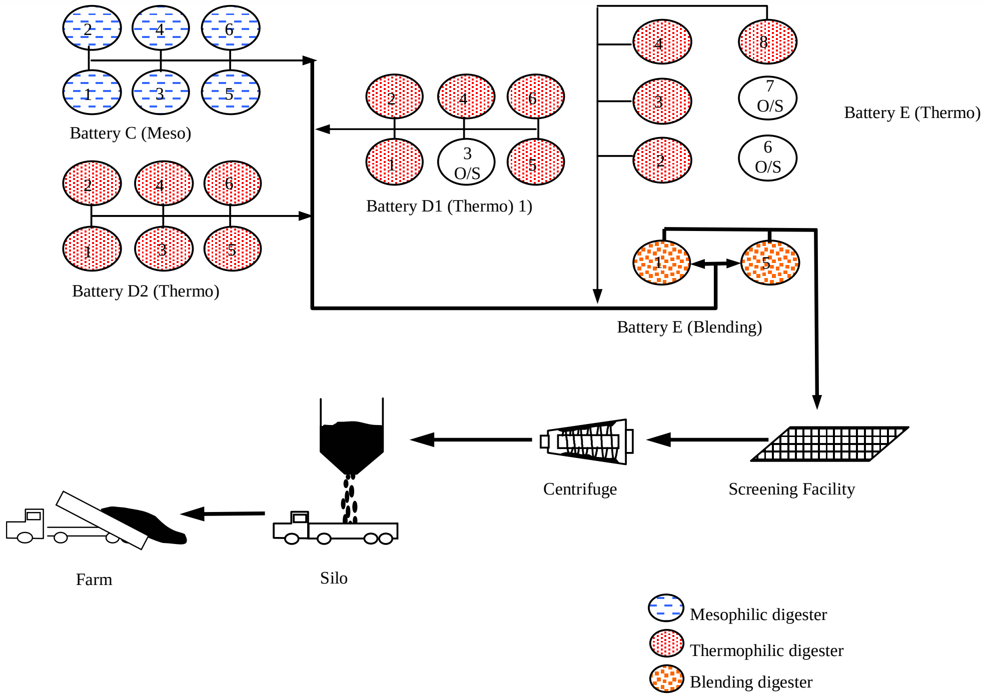

Figure 1. Phase III process diagram.

Phase IV process

The tests were conducted in October, 2002, after conversion of all egg-shaped digesters to thermophilic operation (Figure 2). The first stage contained 16 digesters that were operated in a continuous mode at an average temperature of 57.5^{0}C and a HRT of on average 10.5 days. The second stage contained four digesters that were operated in a batch mode to comply with the time-temperature requirement of Alternative 1. The guaranteed holding time was 16 hours, which required a temperature of at least 56.3^{0}C. Continuous measurements indicated that the minimum temperature in any of the batch digesters during the entire test period was 56.6^{0}C.

Phase V process

This process was the same as the one in Phase IV **(Figure 2)**, but the digester temperatures were lowered. As the time-temperature requirement of Alternative 1 would not be met, tests were conducted in November, 2002, to demonstrate compliance with Alternative 3. The average temperature in the first stage (16 digesters) was 52.7^{0}C at a HRT of 9.9 days. The holding time in the second stage was 16 hours, but at a holding temperature of 52.6^{0}C.

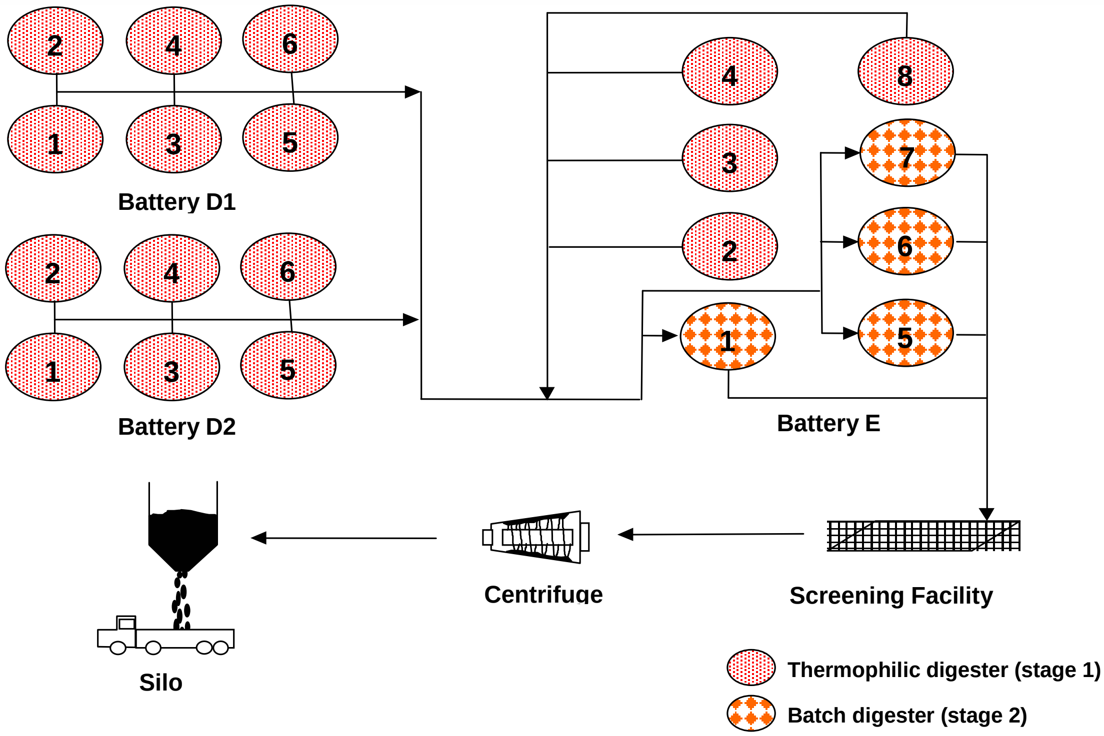

Figure 2. Phases IV and V process diagram.

Sampling procedures

Biosolids samples from the silos at the Truck Loading Facility (sampled just before loading onto the trucks) and at the farm (sampled immediately after unloading) were collected in sterile bottles. Sample collection and preservation were according to procedures as described in Part 9020 of *Standard Methods* (APHA et al., 1992) and by U.S. EPA (1999).

Analytical methods

Total solids and densities of fecal coliforms and *Salmonella* sp. in biosolids were determined according to Parts 2540G, 9260 and 9221E.2 of *Standard Methods* (APHA et al., 1992), respectively. Helminth ova and enteric viruses were determined according to the methods by U.S. EPA (1987) and ASTM (1992), respectively.

Results

Phase III

Preliminary testing of this Phase in August, 2002, demonstrated that the biosolids temperature at the silos was on average 50.4^{0}C. This was only 1^{0}C less than the average temperature in the second stage digesters, which can be attributed to insulation of the post-digestion train. Without insulation, during pilot-scale tests (Phases I and II) with a thermophilic battery and dedicated post-digestion train, the temperature in silo biosolids dropped by almost 12^{0}C as compared to the digester temperatures (Iranpour et al., 2004b; 2005a).

Additional tests were conducted in September, 2002, providing the following results:

- The Class A limit for fecal coliforms in biosolids at the silos and the farm was met in 95% (two exceedances) and 88% (one exceedance) of the samples, respectively. These exceedances can be related to a relatively low biosolids temperature **(Figure 3)**.
- The Class A limit for *Salmonella* sp. was met in all farm biosolids samples. It should be noted that *Salmonella* sp. never exceeded the Class A limit in any of the tests, nor was recurrence of *Salmonella* sp. ever observed during post-digestion.
- Helminth ova and enteric viruses were detected in primary sludge, but the densities of non-bacterial pathogens in farm were reduced to below Class A limits non-detect).

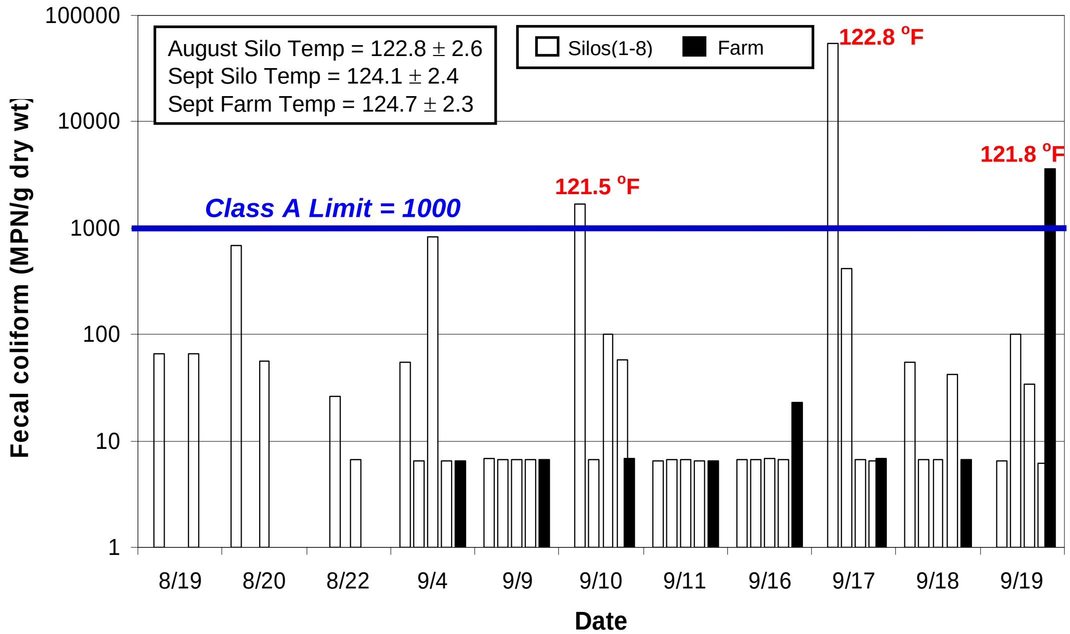

Figure 3. Phase III – Fecal coliform densities in silo and farm biosolids.

Phase IV

The Phase IV process was the configuration originally planned for HTP to demonstrate compliance with local and federal requirements for EQ biosolids. The biosolids at the farm were sampled daily over a period of 2 ½ weeks. These tests demonstrated that *Salmonella* sp. and fecal coliforms in farm biosolids consistently were below the Class A limit (non-detect) (Figures 4a and b). Helminth ova and enteric viruses were also below the Class A limit (non-detect) in composited samples of farm biosolids. Although compliance with the Kern County and federal regulations was demonstrated for the first time with HTP fully in thermophilic operation, a large increase of odorous emissions from thermophilic operations was observed when the digester temperature was rapidly raised to meet the time-temperature requirement of Alternative 1 at a holding time of 16 hours (Iranpour et al., 2005c). Analysis of the digester gas showed a sharp increase of the production of methyl mercaptan. Digester temperatures were subsequently reduced in order to prevent an increase of odorous air emissions.

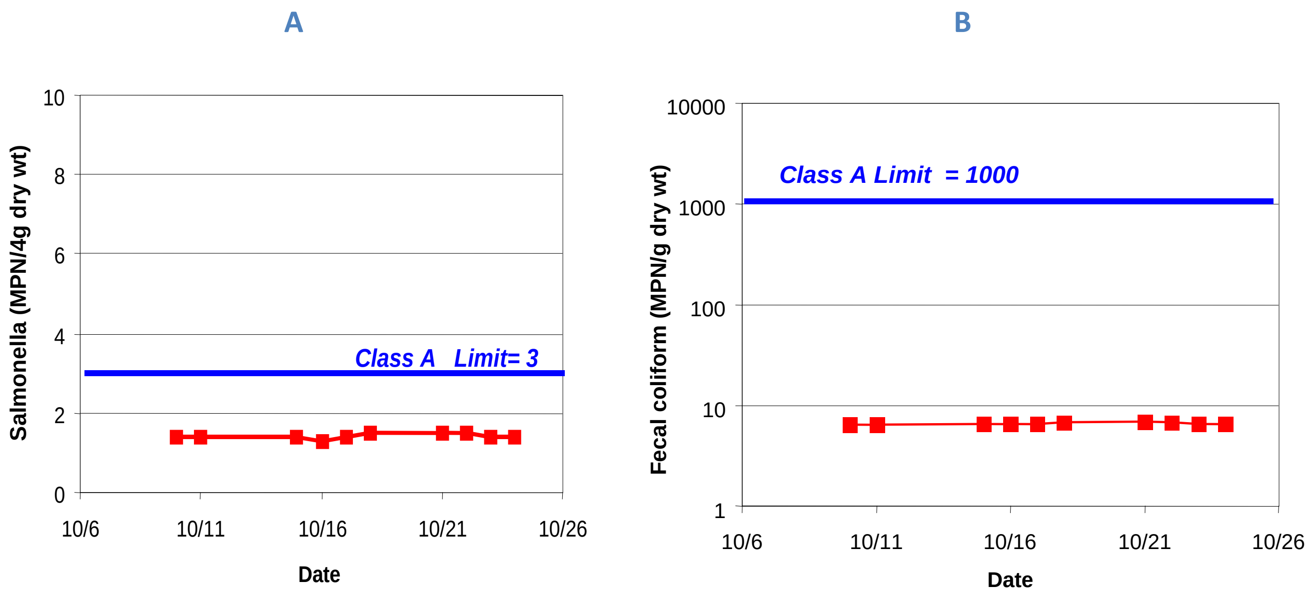

Figure 4. Phase IV – Densities of *Salmonella* sp. (A) and fecal coliforms (B) in farm biosolids.

Phase V

These tests were necessary because the time-temperature requirement of Alternative 1 would not be met after lowering the digester temperature, hence, demonstration of compliance with Alternative 3 was required. One week of daily testing in November, 2002, demonstrated that *Salmonella* sp. **(Figure 5a)** and fecal coliforms **(Figure 5b)** were below the Class A limit (non-detect) in biosolid samples taken at the farm. Likewise, viable helminth ova and enteric viruses were below the Class A limit (non-detect) in composited samples of farm biosolids.

Discussion and conclusions

Phase III

In general met the Class A pathogen requirements of Alternative 3 in the Part 503 Biosolids Rule. The one exceedance observed for the fecal coliform density in farm biosolids was considered not to be significant as an indicator of the disinfection efficiency because the Phase III achieved reduction of all pathogens (*Salmonella* sp., viable helminth ova, enteric viruses) to below the limits for Class A biosolids. These results are remarkable and better than at first expected from a continuous process that was operated below the target temperature of about 55^{0}C, received large amounts of fecal coliforms from the mesophilic digesters, and had a minimum average residence time in the digesters.

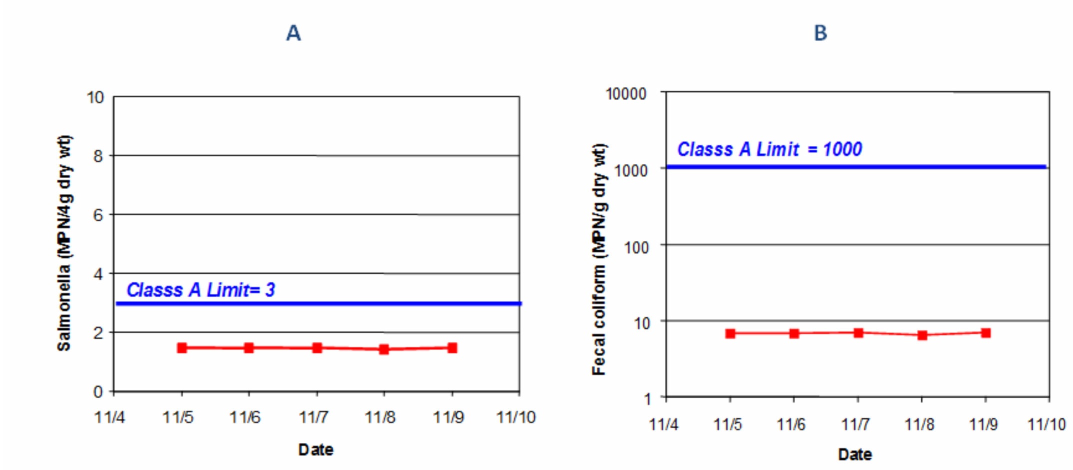

Figure 5. Phase V – Densities of *Salmonella* sp. (A) and fecal coliforms (B) in farm biosolids

Phase IV process

Complied with the time-temperature relation of Alternative 1 for batch treatment, therefore, meeting the Class A limits for fecal coliforms and pathogens by this process was expected. The elevated production of methyl mercaptan was a drawback, because it is a volatile sulfur compound with a low odor threshold (approximately 1 ppb). Minimization of odor emissions is a top priority for the City of Los Angeles and, in general, one of the major challenges in promoting public acceptance of production and land application of biosolids. Hence, it was decided to reduce the digester temperature with the rationale that the Phase III tests were conducted at a lower temperature, while still achieving the Class A pathogen reductions but without unacceptable odor emissions from thermophilic operations.

Phase V process

Complied with the Class A requirements of Alternative 3 by achieving complete destruction of fecal coliforms, *Salmonella* sp. and enteric viruses, whereas helminth ova were non-detect in both the digester inflow and farm biosolids. Thus, this process met federal and local requirements for EQ biosolids and the City of Los Angeles received Kern County's permit for land application of HTP's EQ biosolids four days before the ban on Class B biosolids became effective.

Fecal coliform recurrence in post-digestion biosolids

Fecal coliform recurrence in biosolids, causing exceedance of the Class A limit, was observed during pilot-scale tests, Phases I and II (Iranpour *et al.*, 2004a; 2005a). This resulted in non-compliance with the Kern County ordinance, which is more strict than the federal regulations by requiring that the Class A limits for fecal coliforms and *Salmonella* sp. both be met. During these full-scale tests, fecal coliform densities in farm biosolids were either below the Class A limit (Phase III) or non-detectable (Phases IV and V). This can probably be attributed to complete conversion of HTP to thermophilic operation (elimination of contamination by mesophilically digested biosolids) and insulation and electrical heat-tracing of the post-digestion train (maintaining a biosolids temperature greater than 50^0C during post-digestion processing) (Iranpour *et al.*, 2004b, 2005b).

Part II. Terminal Island Treat. Plant (TITP)

In 1999, the City of Los Angeles initiated the Class A Biosolids Program, which entailed fthe conversion of Terminal Island Treatment Plant (TITP) from mesophilic to thermophilic anaerobic digestion, extensive testing and monitoring on lab and full-scale, process design modifications and final certification testing. Ad disused in Part I, HTP demonstrated compliance with the Class A standards of the U.S. EPA Part 503 Biosolids Rule in December 2002, which has allowed this plant to continue the land application of its biosolids in Kern County, California. The experiences at HTP have been described in detail by Iranpour et al. (2004, 2005a, b, c) and Wilson et al. (2004).

TITP recently demonstrated compliance with the Class A standards after testing several processes for the disinfection of biosolids. In this contribution, an overview of these investigations is presented with the following objectives:

- biosolids disinfection in a single-stage continuous process (Phase I);
- biosolids disinfection in two-stage continuous process (Phase II);
- biosolids disinfection in single-stage sequencing batch process (Phase III);
- fecal coliform recurrence in post-digestion solids handling (Phase III);
- final certification tests.

US EPA Requirements

The U.S. EPA Part 503 Biosolids Rule contains a general requirement with limits for pathogen densities and operational standards for treatment (U.S. EPA, 1993; Iranpour et al., 2004). The general requirement for Class A biosolids is that either the fecal coliform density should never exceed 1000 MPN/g dry wt, or the *Salmonella* sp. density should never exceed 3 MPN/4 g dry wt. These limits should be met in biosolids at the last point of control, which can be understood as the truck loading facility and/or the farm for land application. In addition to this general requirement, the biosolids must comply with one of six Alternatives containing operational standards. Thermophilic anaerobic digestion may comply with Alternatives 1, 3, 4 or 6. We only review Alternative 1 here. The rest are discussed in Part I.

- Alternative 1 specifies the time-temperature requirement during treatment for thermal inactivation. Although not specifically stated, it is usually understood that this time-temperature requirement must be met in a batch process that guarantees a certain holding time. The time-temperature requirement for sludges containing less than 7% TS is:

  $$D = 50{,}070{,}000/10^{0.14T}$$

  Where D is time (d) and T is temperature (^{0}C). The minimum temperature is 50^{0}C and the minimum time (at T>67^{0}C) is 30 min.

The City of Los Angeles has been land applying most of its biosolids in Kern County, California, since 1994. This county recently adopted an ordinance, by which since 2003 only the land application of Exceptional Quality (EQ) biosolids is allowed. EQ biosolids must comply with several requirements, including the Class A pathogen reduction requirements. Although the general requirement of the federal regulations can be satisfied by meeting either the fecal coliform or the *Salmonella* sp. Class A limit, the Kern County ordinance requires both limits to be met.

Materials and methods

TITP is located near Los Angeles Harbor, 20 miles south of downtown Los Angeles. The service area includes the residential community of San Pedro and the industrial areas surrounding the harbor. The plant receives an average flow of 15 mgd of which about 50% is from industrial contributions (primarily oil refining and food processing). The biosolids production is about 20,000 wet tons per year. TITP has four concrete egg-shaped digesters with volumes of 1.37 million gallon (Figure 1). The digesters can be operated in either a single-stage or a two-stage configuration and they have been designed to operate in an overflow mode. Mixing can be done by pumps (500 gpm) or by gas mixing (500 scfm). After the digesters, the biosolids are transported to centrifuges for dewatering. Until early 2004, concentrated biosolids were transported over conveyor belts to the silos in the truck loading facility. Recent modifications of post-digestion included the replacement of the conveyor belts by transport through pipes. The biosolids are usually stored for a maximum of one day prior to transport to the farm for land application.

Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica. Vol. 2, No. 1, 84-107, 2009. ISSN 0718-378X

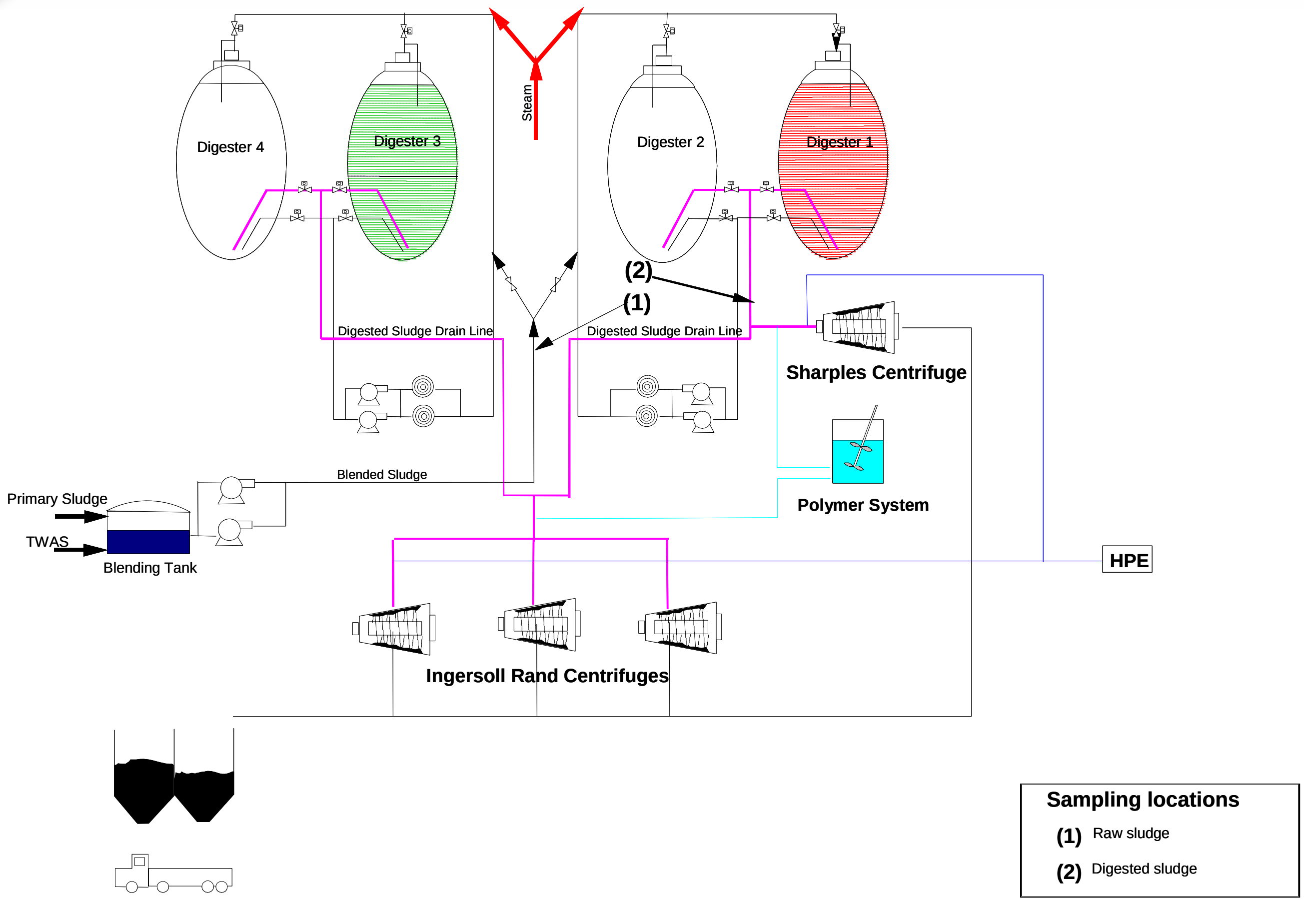

Figure 1. TITP digestion and post-digestion process.

Phase I - Single-stage continuous process

Phase I tests at TITP were done with Digester 1 from February to June 2000. In a period of 8 days without sludge feeding, the temperature of this digester was rapidly increased from 93°F to 130°F. Once at thermophilic temperature, the sludge feed rate was gradually increased over a period of two months in steps depending on the accumulation of volatile fatty acids (VFAs) in the digester. The final feed sludge rate was 0.081 mgd, corresponding to a hydraulic retention time (HRT) of 17 days. Further details on the conversion of Digester 1 to thermophilic operation have been provided by Iranpour et al. (2002) and Shao et al. (2002). Digested biosolids were daily sampled from the outflow of Digester 1 and analyzed for chemical and microbiological parameters.

Phase II -Two-stage continuous process

From July 2000 to April 2001, TITP used two thermophilic digesters in series, both operated in continuous mode. Digester 1 received the feed sludge and steam to maintain a temperature of 131°F. The biosolids from the first-stage digester were continuously transferred to Digester 2 as the second-stage. Because the digesters were well insulated, the second-stage digester could be maintained at 129°F without supplementary heat. The average total HRT initially was 25 days, but after one month in Phase II it was reduced to an average of 15 to 17 days. Biosolids sampling was conducted from October 2000 to April 2001.

Phase III Single-stage sequencing batch process

Operation of Digesters 1, 2 and 3 as sequencing batch reactors started in July 2001 with the objective of meeting the time temperature requirement of Alternative 1. At the end of August 2001, Digester 3 was taken out of service and replaced by Digester 4. Each digester was operated with the 3-day cycle of sludge feeding, holding and withdrawal illustrated in **Table 1.** The average HRT in each digester was 22 days. The guaranteed holding time was 24 h, which requires a treatment temperature of $\geq 131^0$F according to Alternative 1 time-temperature requirement. Over a period of 4 months (July – October, 2001), samples were aseptically collected from the digester inflow and outflows, as well as the in post-digestion train at the conveyor belt and the silos at the truck loading facility.

Table 1. Phase III – Cycles of feeding, holding and withdrawing for sequencing batch digesters.

Day	Day 1	Day 2	Day 3	Day 4
Hours 0	12 24	36 48	60 72	84 96
Digester 1	Feed (104 gpm)	Hold	Withdraw (104 gpm)	Feed (104 gpm)
Digester 2	Withdraw (104 gpm)	Feed (104 gpm)	Hold	Withdraw (104 gpm)
Digester 3	Hold	Withdraw (104 gpm)	Feed (104 gpm)	Hold

Post-digestion design modifications

Based on earlier experiences at HTP, several design modifications to the post-digestion train were implemented at TITP:

- Transport of dewatered biosolids on conveyor belts was replaced by transport through pipes and pumps.
- The top of the silos at the truck loading were covered.
- The post-digestion train was equipped with insulation and electrical heat-tracing between the digesters and the silos at the truck loading facility.

Certification tests

The certification tests were conducted in April-May 2004 after completion of the design modifications of the post-digestion train. The digesters were operated as sequencing batch digesters, in a manner similar as in Phase III. The average HRT was 31 days, and each digester was operated with a holding period of 24 hours. The temperature was maintained slightly above 131^{0}F to comply with time-temperature requirement for batch treatment in Alternative 1. Biosolids were sampled from the silos at the truck loading facility for a period of two weeks and analyzed for fecal coliforms and *Salmonella* sp.

Analytical procedures

Table 2 summarizes the procedures used for determining chemical and microbial parameters.

Table 2. Analytical procedures.

Parameter	Analytical method and/or reference
Digester temperature	resistance temperature detector in recirculation line
Total solids	Part 2540 B (APHA et al., 1992)
Total volatile solids	Part 2540 E (APHA et al., 1992)
pH	Part 4500-H^+ B (APHA et al., 1992)
Volatile fatty acids	Part 5560 C (APHA et al., 1992)
Alkalinity	Part 2320 B (APHA et al., 1992)
Fecal coliforms	Part 9221 E.2 (APHA et al., 1992)
Salmonella sp.	Kenner and Clark (1974)
Helminth ova	U.S. EPA (1987)
Enteric viruses	ASTM (1992)

Results and discussion

Phase I: Single-stage continuous process

The rapid increase of the temperature from the mesophilic to the thermophilic range followed by the gradual increase of the feed sludge rate proved successful in rapidly establishing a thermophilic digester with stable operation and performance. The pH was relatively constant (average of 7.3 $\pm$ 0.15) during Phase I. The VFA to alkalinity ratio increased to a maximum of 0.5 one week after raising the temperature to 130^{0}F. This coincided with a peak in the VFA concentration of 1525 mg/L. Both parameters rapidly declined thereafter, with typical ranges of 200-600 mg/L as acetic acid for VFAs and 0.07-0.2 for the VFA to alkalinity ratio. The alkalinity was relatively constant during the conversion (3300 $\pm$ 280 mg/L as $CaCO_3$).

Table 3 shows the results of fecal coliform sampling. It can be seen that on most days the fecal coliform density was well below the Class A limit of 1000 MPN/g dry wt. This limit was exceeded in 7 of a total of 46 samples (15%), most of these occurring in the first week after raising the temperature to 130^{0}F. Table 3 also demonstrates that gradually increasing the feed sludge rate did not have a significant effect on the disinfection of fecal coliforms. When the sludge feed rate to Digester 1 was increased to 0.081 mgd (HRT of 17 days), the fecal coliform density was usually less than 100 MPN/g dry wt. *Salmonella* were never detected in the additional samples taken on a few selected days.

Table 3. Phase I - Feed sludge rate to Digester 1 and fecal coliforms in digester outflow biosolids.

Date	Feed Flow (mgd)	Fecal coliforms (MPN/g dr wt)	Date	Feed flow (mgd)	Fecal coliforms (MPN/g dry wt)
2/23/00	0.002	<89	4/3/00	0.065	>6780
2/25/00	0.038	<72	4/4/00	0.065	<44
2/29/00	0.026	<100	4/5/00	0.065	46
3/1/00	0.000	9	4/6/00	0.065	<44
3/2/00	0.030	9	4/7/00	0.065	<94
3/3/00	0.033	9	4/10/00	0.065	17
3/6/00	0.030	4.2E+04	4/11/00	0.065	<90
3/7/00	0.023	6.2E+04	4/12/00	0.065	100
3/8/00	0.030	>6.2E+04	4/13/00	0.065	>6.7E+04
3/9/00	0.030	>6.3E+04	4/14/00	0.065	<89
3/10/00	0.030	58	4/17/00	0.065	<91
3/13/00	0.000	9	4/18/00	0.065	<93
3/14/00	0.036	101	4/19/00	0.065	<87
3/15/00	0.036	120	4/20/00	0.065	<90
3/16/00	0.036	103	4/21/00	0.065	<93
3/17/00	0.036	131	4/24/00	0.065	105
3/20/00	0.052	35	4/25/00	0.065	<89
3/21/00	0.047	18	4/26/00	0.081	<93
3/22/00	0.047	58	4/27/00	0.081	<91
3/23/00	0.047	101	4/28/00	0.081	<94
3/24/00	0.047	101			
3/27/00	0.047	>6250			
3/28/00	0.065	<9			
3/29/00	0.065	56			
3/30/00	0.065	55			
3/31/00	0.065	18			

The temperature increase from 90 to 130^{0}F was from Feb 15 to 23, 2000.

Phase II -Two-stage continuous process

The average values of various chemical parameters are summarized in Table 4**.** The VFA concentration was almost always higher in the first stage, whereas the total alkalinity was in general higher in the second stage. Consequently, the average VFA to alkalinity ratio was almost twice as high in the first stage as compared to the average ratio in the second stage. Although most volatile solids reduction occurred in the first stage, there was some additional digestion in the second stage because the contents of total solids and volatile solids were consistently lower

(1.9% TS, 58% volatile fraction) than in the first stage (2.1% TS, 60% volatile fraction). Overall volatile solids destruction over the two stages was on average 60%.

Table 4. Phase II - Average parameters of digestion in two-stage continuous digestion.

Parameter	Inflow	First stage	Second stage
Temperature		53.2 ± 1.9	52.2 ± 1.7
Total solids (%)	3.6 ± 0.3	2.13 ± 0.19	1.91 ± 0.26
Volatile solids (% of total solids)	76 ± 2.4	59.9 ± 2.2	57.6 ± 2.9
pH		7.12 ± 0.17	7.17 ± 0.14
VFAs (mg/L as acetic acid)		304 ± 172	191 ± 69
Alkalinity (mg/L as $CaCO_3$)		2613 ± 575	2961 ± 293
VFA to alkalinity ratio		0.116 ± 0.064	0.064 ± 0.029

Figure 2 shows the fecal coliform densities in the digester outflows from the first and second stage. Out of a total of 57 samples, first-stage digested biosolids exceeded the Class A limit in 30% of the samples. As expected, further reduction of coliforms was observed in the second stage, with only 10% of the samples exceeding the Class A limit.

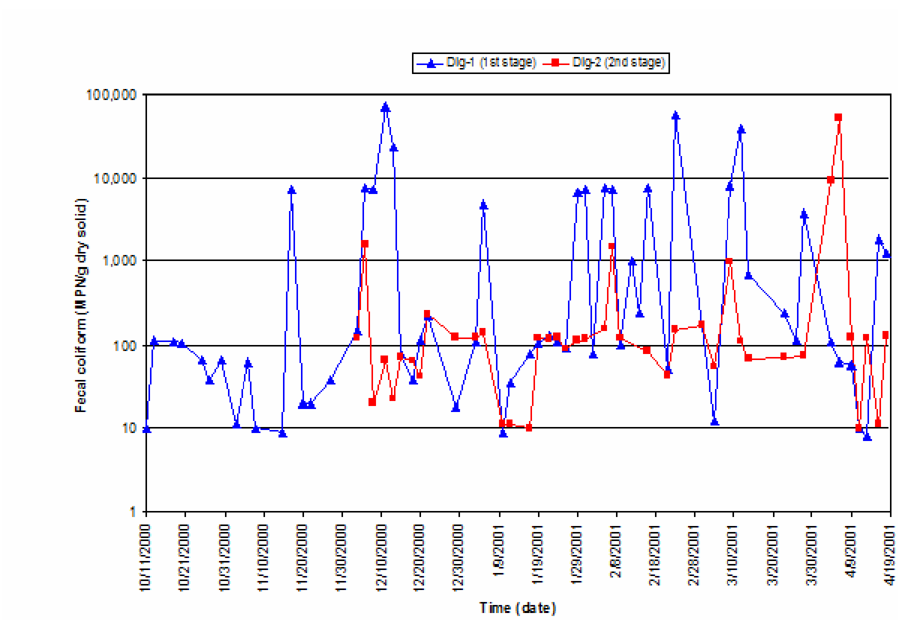

Figure 2. Phase II – Fecal densities in digester outflows, first and second stage.

Fecal coliform reductions in the first stage were less than observed in Digester 1 during Phase I when this digester was operated as a single-stage continuous digester. This can probably be attributed to the HRT in the first stage being reduced to 7.5 – 8.5 days, as compared to a minimum HRT in Digester 1 in Phase I of 17 days. The two-stage continuous process in Phase II with an overall HRT of 15 – 17 days showed fecal coliform reductions that were comparable to the single-stage digester in Phase I with a minimum HRT of 17 days.

Alternatives 3 and 4 of the regulations for Class A biosolids require complete destruction of helminth ova and enteric viruses. These pathogens were determined in composited samples of individual samples taken once every eight hours during several weeks in January and February, 2001. Helminth ova and enteric viruses were not detected in the outflow of the first-stage digester, as shown in Table 5.

Table 5. Phase II – Analysis of non-bacterial pathogens in the inflow and outflow of the first-stage digester.

Pathogen	Sampling location	Number of grab samples in composite sample	Density
Viable helminth ova	Digester 1 inflow	79	<1 ovum/4 g dry wt
	Digester 1 outflow	83	<1 ovum/4 g dry wt
Enteric viruses	Digester 1 inflow	41	8 PFU/4 g dry wt
	Digester 1 outflow	43	<1 PFU/4 g dry wt

Phase III - Single-stage sequencing batch process

Results from the period July – October, 2001, indicated that total and volatile solids destruction efficiencies, digester gas production and composition, pH, volatile fatty acids production and total alkalinity levels in the SBR digesters were similar to those observed during the operation of the digesters as a continuous single or two-stage process as described above.

Revista AIDIS de Ingeniería y Ciencias Ambientales:
2009. ISSN 0718-378X

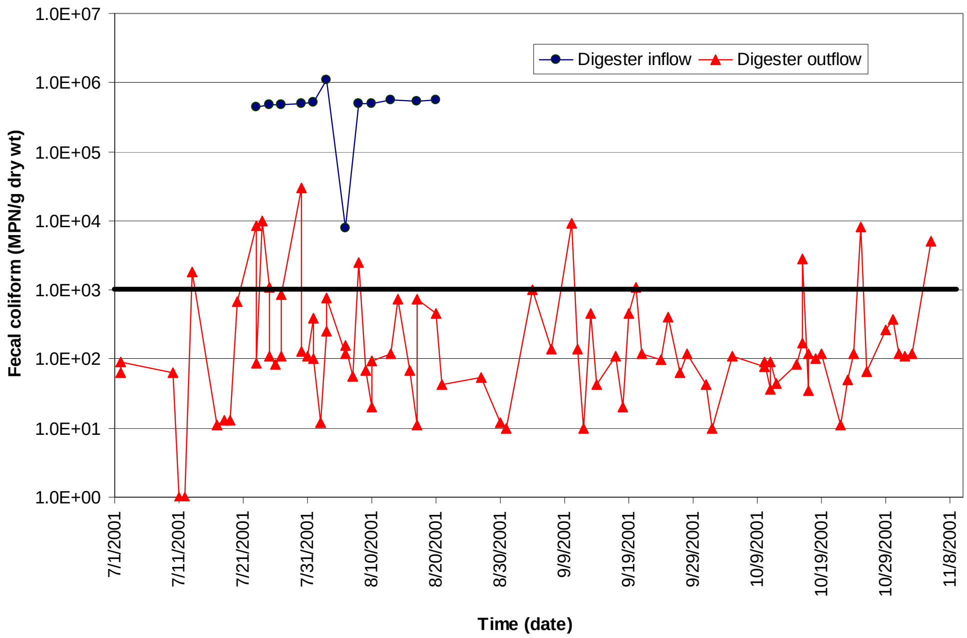

Figure 3. Phase III – Fecal densities in inflow and outflow of batch digesters.

The fecal coliform density in the feed was typically between 10^5 and 10^6 MPN/g dry wt. Operation as sequencing batch digesters usually reduced the fecal coliform density to the range of 10 to 100 MPN/g dry wt, but exceedance of the Class A limit was observed in 13% of the samples (Figure 3). This can most likely be attributed to the fact that digester temperatures did not always met the target value of 131^0C as required by Alternative 1 (Table 6). *Salmonella* sp. were never detected in the digester outflows (<2.2 MPN/4 g dry wt). Helminth ova and enteric virus analyses were performed on composited samples. The feed contained significant levels of enteric viruses but none were detected in the digester outflow (<1 PFU/4 g dry wt). Likewise, helminth ova were below the detection limit in the digester outflow (< I ova /4 g dry wt).

Table 6. Phase III – Temperatures of sequencing batch digesters

	Digester 1	Digester 2	Digester 3
Average	129.1	131.4	131.1
Standard deviation	3.4	1.9	4.4
Lowest temperature	123.0	125.7	116.9

Additional sampling was conducted in the post-digestion train during Phase III. This was motivated by the requirement that the Class A limits need to be met at the last point of plant control. Biosolids were taken at the silos in the truck loading facility and at the dewatering centrifuge outlet. *Salmonella* sp. were not detected at either location (Table 7). However, a small increase of the fecal coliform density was observed at the centrifuge outlet, whereas silo biosolids contained fecal coliforms in densities that exceeded the Class A limit by a factor of 10 to 100 (Table 7). This observation indicated the possibilities of contamination of biosolids with fecal coliforms, the reactivation and growth of fecal coliforms during post-digestion, or a combination of both (Cox et al., 2005). Plant surveys indicated the accumulation of residual biosolids on conveyor belts, which could potentially contaminate the biosolids during transport from the dewatering centrifuges to the silos in the truck loading facility. A contributing factor to the reactivation and growth of fecal coliforms could have been the large drop of biosolids temperature during transport of the biosolids on the conveyor belt (Table 8), which caused the temperature at the silos to decline to below the maximum temperature for growth of fecal coliforms.

Table 7. Phase III – *Salmonella* sp. and fecal coliforms in post-digestion biosolids.

Date	*Salmonella* sp. (MPN/4 g dry wt)		Fecal coliforms (MPN/g dry wt)	
	Centrifuge	Silo	Centrifuge	Silo
07/23/01			$\geq$ 62,000	
07/25/01			140	$\geq 8.8 \times 10^4$
07/27/01			< 140	$\geq 1.1 \times 10^6$
07/30/01	< 2.2	< 2.2	920	$\geq 7.4 \times 10^4$
08/01/01			< 11	
08/02/01	< 2.2			
08/03/01			15,000	$\geq 6.9 \times 10^4$
08/06/01			53	$\geq 8.9 \times 10^4$
08/08/01	< 1.6	< 1.8	130	$\geq 7.7 \times 10^4$
08/10/01				6.9×10^4
08/13/01			69	7.6×10^4
08/14/01	< 2.2			
08/15/01	< 2.2	< 2.2		
08/16/01	< 2.2	< 2.2		
08/17/01			1,100	7.4×10^5
08/20/01			12	8.1×10^4
10/02/01			< 6,800	6.2×10^7
10/05/01			500	8.9×10^4
10/10/01			< 100	$\geq 8.0 \times 10^5$
10/11/01			1,300	$\geq 8.0 \times 10^5$
10/16/01			< 120	5.1×10^5
10/17/01		< .19	470	4.4×10^4

Table 8. Phase III – Post-digestion biosolids temperatures.

Biosolids sampling location	Temperature (^{0}F)
Digester outflow	128.3
Centrifuge outlet	123.6
Halfway on conveyor belt	119.1
End conveyor belt and silo	109.6

Certification tests

After completion of the post-digestion modifications to prevent fecal coliform recurrence, certification tests were conducted to demonstrate compliance with the general requirement for Class A biosolids and the time-temperature requirement of Alternative 1. Continuous measurements of the digester temperatures indicated that the lowest temperature recorded during these certification tests was 132.0^{0}F, which implies compliance with the time-temperature requirement of Alternative 1 (T>131.0^{0}F at 24 hours holding). Densities of fecal coliforms and *Salmonella* sp. in biosolids sampled from the silos at the truck loading facility are shown in Figures 4 and 5, respectively. *Salmonella* sp. were never detected. Fecal coliforms were also often not detected and if they were present, their density was at least 10 times below the Class A limit of 1000 MPN/g dry wt. In addition, fecal coliform densities in biosolids after three hours of transport by truck (to simulate future sampling at the farm for land application) were comparable to those found in biosolids at the truck loading facility.

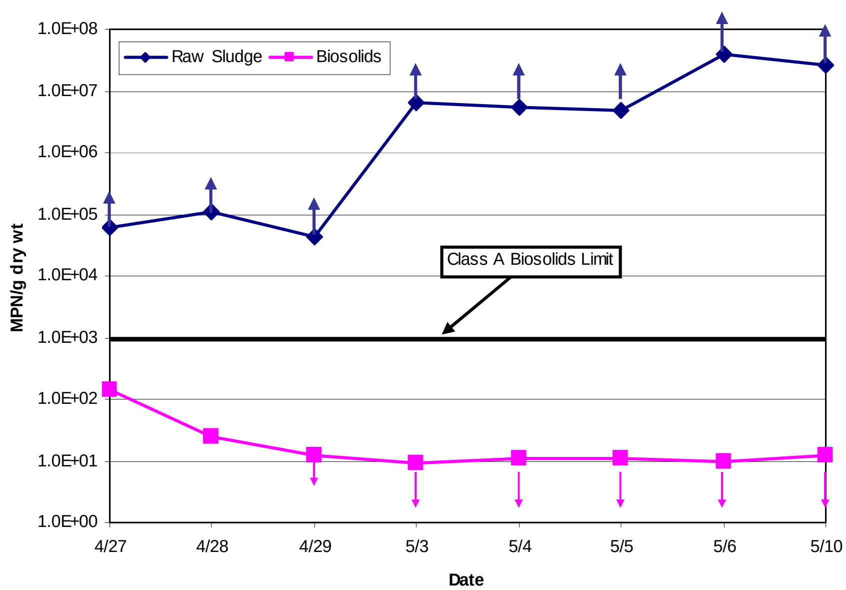

Figure 4. Certification tests – Fecal coliforms densities in raw sludge and silo biosolids at truck loading facility.

Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica. Vol. 2, No. 1, 84-107, 2009. ISSN 0718-378X

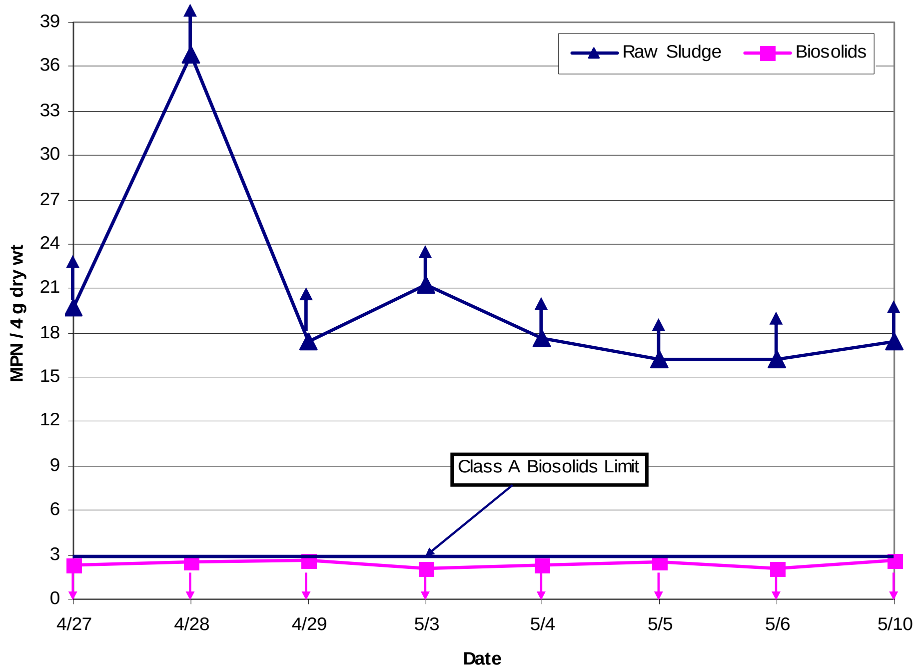

Figure 5. Certification tests – *Salmonella* sp. densities in raw sludge and silo biosolids at truck loading facility.

Conclusions

We conclude the following.

1. All tests showed consistent elimination of *Salmonella* sp., enteric viruses and helminth ova to levels that were below the detection limits. The main challenge of producing Class A biosolids is therefore to meet the Class A limit for fecal coliforms.
2. The Phase I single-stage continuous process significant reduced the fecal coliform density in digester outflow biosolids at a HRT of 17 days and longer, but exceedances of the Class A limit were sometimes observed.
3. Reduction of fecal coliforms in the Phase II two-stage continuous process was more stable by the addition of the second-stage.
4. The Class A limit for fecal coliforms was sometimes exceeded in digester outflow biosolids from the Phase III single-stage sequencing batch process. This was probably caused by relatively low digester temperatures during Phase III that not always met the time-temperature requirement for batch treatment, Alternative 1 of the Part 503 Biosolids Rule.
5. Fecal coliform densities in post-digestion during Phase III increased after the dewatering centrifuges. This caused exceedance of the Class A limit in biosolids at the truck loading facility as a last point of plant control.
6. Design modifications of the post-digestion train solved the problem of fecal coliform recurrence.

7. Certification tests demonstrated consistent compliance with the time-temperature requirement for batch treatment in Alternative 1 and the Class A limits for fecal coliforms and Salmonella sp. in biosolids at the truck loading facility and after 3 hours of transport in trucks (equivalent to future sampling at farm for land application) as the last points of plant control.

References

Part I

Apha, Awwa and WEF (1992). *Standard Methods for the Examination of Water and Wastewater.* American Public Health Association/American Water Works Association/Water Environment Federation, 18th edition, Washington, D.C.

ASTM (1992). *Standard Practice for recovery of viruses from wastewater sludges.* Annual Book of ASTM Standards: Section 11 – Water and Environment Technology, ASTM, Philadelphia, PA.

Garber, W. (1954). Plant-scale studies of thermophilic digestion at Los Angeles. *Sew. Ind. Wastes* 26, 1202.

Garber, W., Ohara, G.T., Colbaugh, J.E., Haksit, S.K. (1975). Thermophilic digestion at Hyperion Treatment Plant. *J. Water Pollut. Contr. Fed.* 47, 950.

Iranpour, R., Oh, S., Cox, H.H.J., Samar, P., Taylor, D., Mohamed, F., Hagekhalil, A., Kearney, R.J. (2002a). Effects of dewatering on bacteria inactivation: Centrifuge simulation and field tests at the Hyperion Treatment Plant. *Proceedings Water Environment Federation 75th Annual Technical Exhibition and Conference*; Sep 28 – Oct 2, 2002, Chicago, Illinois; Water Environment Fed., Alexandria, Virginia.

Iranpour, R., Cox, H.H.J., Alatriste-Mondragon, F., Starr, M. (2004a). Pilot-scale tests on disinfection of biosolids by thermophilic anaerobic digestion at Hyperion Treatment Plant. *Proceedings 10th World Congress on Anaerobic Digestion*; Aug 29 – Sep 2, Montreal, Canada; International Water Association: London, UK.

Iranpour, R., Cox, H.H.J., Fan, S., Abkian, V., Kearney, R.J. (2004b). Solving fecal coliform growth/reactivation in biosolids during full-scale post-digestion processes. *Proceedings 10th World Congress on Anaerobic Digestion*; Aug 29 – Sep 2, Montreal, Canada; International Water Association: London, UK.

Iranpour, R., Cox, H.H.J., Fan, S., Abkian, V., Kearney, R.J., Haug, R.T. (2005). Short-term and long-term effects of increasing temperatures on the stability and the production of volatile sulfur compounds in full-scale thermophilic anaerobic digesters. *Biotechnol. Bioeng.* 91: 199-212.

Iranpour, R., Cox, H.H.J., Oh, S., Fan, S., Kearney, R.J., Abkian, V., Haug, R.T. (2006). Thermophilic anaerobic digestion to produce Class A biosolids; initial full-scale studies at Hyperion Treatment Plant. *Water Environ. Res.* 78: 170-180.

Iranpour, R., Cox, H.H.J., Fan, S., Abkian, V., Minamide, T., Kearney, R.J., Haug, R.T. (2006). Full-scale Class A biosolids production by two-stage continuous-batch thermophilic anaerobic digestion at Hyperion Treatment Plant, Los Angeles, California. *Water Environ. Res.* 78: 2244-2252.

Iranpour, R., Cox, H.H.J. (2006). Recurrence of fecal coliforms and Salmonella species in biosolids following thermophilic anaerobic digestion. *Water Environ. Res.* 78: 1005-1012.

Iranpour, R., Cox, H.H.J. (2007). Evaluation of thermophilic anaerobic digestion processes for full-scale Class A biosolids disinfection at Hyperion Treatment Plant. *Biotechnol. Bioeng.* 97, 19-39.

U.S. EPA (1987). *Occurrence of pathogens in distribution and marketing municipal sludges.* EPA 600/1-87-014.

U.S. EPA (1993). 40 CFR Part 503: The standards for the use and disposal of sewage sludge. *Federal Register* 58: 9248-9404.

U.S. EPA (1994). *Plain English Guide to the EPA Part 503 Biosolids Rule*. EPA/832/R-93/003.

U.S. EPA (1999). *Environmental Regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge*. EPA/625/R92/013.

Part II

American Public Health Association; American Water Works Association; Water Environment Federation (1992). *Standards Methods for the Examination of Water and Wastewater*, 18th ed.: American Public Health Association: Washington, D.C.

ASTM (1992). D 4994-89. Standard Practice for Recovery of Viruses from Wastewater Sludge. *Annu. Book ASTM Standards.* Section 11. Water and Environment Technology; Philadelphia, Pennsylvania.

Cox, H.H.J., Iranpour, R., Kearney, R.J., Haug, R.T. (2005). Reactivation/growth of fecal coliforms and *Salmonella* sp. in biosolids following thermophilic anaerobic digestion. *Water Environ. Res.* (accepted).

Iranpour, R., Oh, S., Cox, H.H.J., Shao, Y.J, Kearney, R.J., Deshusses, M.A., Ahring, B.K. (2002). Changing mesophilic wastewater sludge digestion into thermophilic operation at Terminal Island Treatment Plant. *Water Environ. Res.* 74: 494-507.

Iranpour, R., Cox, H.H.J., Kearney, R.J., Clark, J.H., Pincince, A.B., Daigger, G.T. (2004). Regulations for biosolids land application in U.S. and European Union. *J. Res. Sci. Technol.* 1: 209-222.

Iranpour, R., Cox, H.H.J., Fan, S., Abkian, V., Kearney, R.J., Haug, R.T. (2005). Short-term and long-term effects of increasing temperatures on the stability and the production of volatile sulfur compounds in full-scale thermophilic anaerobic digesters. *Biotechnol. Bioeng.* 91: 199-212.

Iranpour, R., Cox, H.H.J., Oh, S., Fan, S., Kearney, R.J., Abkian, V., Haug, R.T. (2006a). Thermophilic anaerobic digestion to produce Class A biosolids; initial full-scale studies at Hyperion Treatment Plant. *Water Environ. Res.* 78: 170-180.

Iranpour, R., Cox, H.H.J., Fan, S., Abkian, V., Minamide, T., Kearney, R.J., Haug, R.T. (2006b). Full-scale Class A biosolids production by two-stage continuous-batch thermophilic anaerobic digestion at Hyperion Treatment Plant, Los Angeles, California. *Water Environ. Res.* 78: 2244-2252.

Kenner, B.A.; Clark, H.P. (1974) Detection and enumeration of *Salmonella* and *Pseudomonas aeruginosa*. *J. Water Pollution Control Federation*, 46, 2163.

Shao, Y.J., Kim, H.S., Oh, S., Iranpour, R., Jenkins, D. (2002). Full-scale sequencing batch thermophilic anaerobic digestion to meet EPA Class A biosolids requirements. In *Proceedings Water Environment federation 75th Annual Technical Exhibition and Conference*; Sep 28-Oct 2, Chicago, Illinois; Water Environment Federation: Alexandria, Virginia.

U.S. EPA (1987). *Occurrence of Pathogens in Distribution and Marketing Municipal Sludges*.EPA 600/1-87-014.

U.S. EPA (1993) 40 CFR Part 503: The Standards for the Use and Disposal of Sewage Sludge. *Federal Register* 58, 9248-9404.

Wilson, T.E., Iranpour, R., Windau, T.D. (2004). Thermophilic anaerobic digestion in the US: Selected case histories. In *Proceedings 9th European Biosolids and Biowaste Conference*, Nov 14-17, Wakefield, UK.