PRODUCTION OF EQ BIOSOLIDS AT HYPERION TREATMENT PLANT: PROBLEMS AND SOLUTIONS FOR REACTIVATION/GROWTH OF FECAL COLIFORMS

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ABSTRACT

The City of Los Angeles Hyperion Treatment Plant (HTP) has conducted a multiphase study of thermophilic anaerobic digestion to meet federal (Part 503 Biosolids Rule) and local (Kern County ordinance) requirements for Exceptional Quality Class A biosolids. The study consisted of five Phases of full-scale testing.

A designated battery of six thermophilic digesters for digestion of 20% of HTP's sludge was used in Phases I and II (October 2001 – March 2002). The tests demonstrated compliance with the Class A limits for fecal coliforms and *Salmonella* in a two-stage batch process. However, fecal coliform densities in biosolids increased during post-digestion, causing non-compliance with local regulations. Potential causes for fecal coliform recurrence in thermophilic biosolids were: a) contamination by mesophilic biosolids; b) a large drop of the biosolids temperature which would allow reactivation/growth of fecal coliforms.

The Phase III process (August – September 2002) was a continuous process with 90% of the plant in thermophilic operation and the post-digestion train insulated between the digesters and silos to maintain a high biosolids temperature. This process almost fully complied with the Class A pathogen requirements for biosolids at the silos and the farm. Recurrence of fecal coliforms during post-digestion did not occur.

The Phase IV process (October 2002) was a two-stage batch process that complied with the time-temperature relation in Alternative 1 of the Part 503 Biosolids Rule. Complete disinfection of fecal coliforms and *Salmonella* was achieved and both groups of bacteria were non-detect in farm biosolids. Relatively high digestion temperatures, however, caused unacceptable emissions of odors.

To reduce odor emissions from thermophilic operations, the digester temperatures in the Phase IV process were lowered, which then became Phase V testing. The Phase V process (November 2002) produced farm biosolids with non-detect levels of fecal coliforms, *Salmonella*, helminth ova and enteric viruses. This process, therefore, complied with Alternative 3 of the Part 503 Biosolids Rule.

The City of Los Angeles received the permit to land apply HTP's Exceptional Quality biosolids at its farm in Kern County on December 27, 2002, four days before the ban on Class B biosolids became effective. Monthly testing in 2003 confirms that the standards for Exceptional Quality biosolids are consistently being met.

KEYWORDS

Exceptional Quality biosolids, Hyperion Treatment Plant, Thermophilic Anaerobic Digestion, Full-scale

INTRODUCTION

The City of Los Angeles Hyperion Treatment Plant (HTP) has converted its digesters to thermophilic anaerobic digestion for Exceptional Quality (EQ) Class A biosolids production. This was motivated by a recent ordinance in Kern County that banned the land application of Class B biosolids since January 2003. The objective, therefore, was to implement a thermophilic anaerobic digestion process at HTP that would comply with the federal regulations for Class A biosolids as well as with the regulations in Kern County where the City of Los Angeles applies it biosolids.

The federal Part 503 Biosolids Rule specifies general and treatment-specific requirements for compliance of biosolids with the Class A pathogen standards (U.S. EPA, 1993, 1994). The general requirement for all treatments is reduction of fecal coliforms to 1000 MPN/g dry wt or *Salmonella* sp. to 3 MPN/4 g dry wt. Treatment-specific requirements are specified in six Alternatives. Alternative 1 contains time-temperature relationships for batch treatment that specify the required holding time as a function of temperature. Such holding periods, however, can not be guaranteed in continuous processes, as small portions leave the digester much earlier than the hydraulic retention time. Continuous processes can satisfy Alternatives 3 or 4, which require demonstration of complete disinfection of non-bacterial pathogens (helminth ova, enteric viruses) by digester inflow/outflow analysis (Alt. 3) or absence of these pathogens in biosolids at the last point of plant control (Alt. 4). The federal regulations are the basis of the Kern County ordinance, however, this ordinance contains a few additional requirements. The most important one is that both Class A limits for fecal coliforms and *Salmonella* sp. need to be met, rather than only one limit.

In December 2002, the City of Los Angeles received the permit for application of HTP's EQ Class A biosolids at the City's farm in Kern County. This was achieved after a research program of five phases of full-scale testing at HTP:

a) Phase I (Nov/Dec, 2001): Two-stage batch process (Alt. 1, 3), six digesters, holding for 13 hrs.
b) Phase II (Feb/Mar, 2002): Two-stage batch process (Alt. 1, 3), six digesters, holding for 24 hrs.
c) Phase III (Aug/Sep, 2002): Two-stage continuous process (Alt. 3), full-scale.
d) Phase IV (Oct, 2002): Two-stage batch process (Alt. 1), full-scale.
e) Phase V (Nov, 2002): Phase IV process but at lower temperature (Alt. 3), full-scale.

In several publications, we have discussed the results of Phases I and II as well as literature reviews on thermophilic anaerobic digestions and economic and regulatory evaluations (Ahring *et al.*, 2001[a,b], 2002; Alatriste-Mondragon *et al.*, 2001, 2003[a,b]; Cox *et al.*, 2003[a,b]; Gavala *et al.*, 2003; Iranpour *et al.*, 2000[a-c], 2001[a-e], 2002[a-d], 2003[a-c], Oh *et al.*, 2003; Shao *et al.*, 2002). One important outcome of Phases I and II was that the Class A limits were met in thermophilic anaerobic digestion, but increasing densities of fecal coliforms in post-digestion biosolids caused non-compliance with the Kern County ordinance.

In this contribution, the Phase III, IV and V full-scale operations at HTP are discussed regarding the following issues:

a) Disinfection of indicator (fecal coliforms) and pathogenic (*Salmonella* sp.) bacteria in biosolids.
b) Disinfection of non-bacterial pathogens (helminth ova and enteric viruses) in biosolids.
c) Temperature profiling and the effect of insulation of HTP's post-digestion train.
d) Fecal coliform regrowth studies.
e) Compliance with local and federal regulations at the farm.

BACKGROUND

Hyperion Treatment Plant

HTP is the main wastewater treatment facility for the City of Los Angeles, servicing a 600 square mile area with an approximate population of 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 digestion and post-digestion handling (screening, centrifuge dewatering, storage in silos at the Truck Loading Facility, transport to the farm). The average daily flowrate is 360 mgd with a peak wet weather flowrate of 850 mgd. The plant produces approximately 800 wet tons of biosolids per day, all of which are used for land application in Kern County.

Summary of previous tests at HTP (Phases I and II)

Phase I and Phase II tests were done in October/November, 2001, and February/March, 2002, respectively, with a designated battery of six thermophilic digesters and a post-digestion train dedicated to these digesters. The thermophilic battery and post-digestion train were isolated from other, mesophilic operations at HTP. A two-stage batch process (Figure 1) was employed to comply with the time-temperature requirement of Alternative 1 of Section 503.32. The first stage was continuous at a mean hydraulic retention time (HRT) of 13 days and an average temperature of around 136 ^{0}F. The second stage batch operation (guaranteed holding of 13 hours in Phase I and 24 hours in Phase II) was at average temperatures of 130.2 ^{0}F in Phase I and 128.2 ^{0}F in Phase II. Due to problems

with the steam supply to the digesters, these temperatures were a few degrees below the ones required by Alternative 1.

The Phase I and Phase II results were similar. The two-stage batch digestion process effectively reduced fecal coliforms and *Salmonella* sp. to below the EPA limits for Class A biosolids (Figures 2 and 3). *Salmonella* sp. in biosolids remained below the Class A limit of 3 MPN/4 g dry wt at all sampling locations in the post-digestion train and at the farm for land application. Fecal coliforms in biosolids remained below the Class A limit of 1000 MPN/g dry wt at all sampling locations in the post-digestion train, except in biosolids at the Truck Loading Facility where densities of over 10^6 MPN/g dry wt were found (Figure 4). Likewise, elevated densities of fecal coliforms were found in biosolids at the farm.

It is important to note that the biosolids were still Class A according to the federal regulations because the *Salmonella* density was below the Class A limit. However, the Kern County ordinance also required fecal coliform densities to be below the Class A limit. The recurrence of fecal coliforms in silo and farm biosolids, therefore, caused non-compliance with local regulations and additional investigations were conducted to determine the cause and possible solutions.

Temperature profiling along the post-digestion train demonstrated a large drop of the temperature. Average biosolids temperatures in the truck at the Truck Loading Facility were 108.3 ^{0}F in Phase I (Figure 1) and 105.8 ^{0}F in Phase II. The temperature drop occurred mainly between the centrifuge and the silo, and it was identified as a factor that probably contributed to the re-occurrence of fecal coliforms in biosolids at the Truck Loading Facility and the farm. Another possible cause was attributed to contamination of thermophilic biosolids with mesophilic biosolids, although QA/QC procedures were followed to have a dedicated thermophilic process train during Phases I and II.

MATERIALS AND METHODS

Phase III process description

During August and September, 2002, HTP temporarily employed seventeen out of twenty egg-shaped digesters for thermophilic anaerobic digestion and six conventional low digesters for mesophilic anaerobic digestion in a two-stage continuous process (Figure 5). Each digester has a capacity of approximately 2.5 million gallons and an internal draft-tube mixing system. The Phase III process treated the plant's total feed sludge of approximately 3.0 mgd primary sludge and 0.8 mgd of thickened waste activated sludge:

a) In the first stage, approximately 90% of the sludge was digested in 15 thermophilic digesters at an average temperature of 130^{0}F and a mean HRT of 10.9 days. First stage digesters were heated by steam.
b) In the first stage, approximately 10% of the sludge was digested in 6 mesophilic digesters at an average temperature of 95.3^{0}F and a mean HRT of 39 days.

c) In the second stage, the digested sludges from the first stage were mixed in two blending digesters at a mean HRT of 1.3 days and an average temperature of 124.5^{0}F.
d) Post-digestion processing included. The post-digestion train was insulated from the outlet of the digesters up to the silos at the Truck Loading Facility. The silos were emptied each day at 11:30pm to 12:30pm the next day for transport of the biosolids to the farm.

Phase IV process description

After completing the conversions and solving the problems with steam supply, the digester were operated in a two-stage continuous/batch process as illustrated in Figure 6. The Phase IV process contained:

a) A thermophilic first stage of 16 digesters that were operated in a continuous mode at an average temperature of 135.5 ^{0}F and a hydraulic retention time of about 10.5 days.
b) A thermophilic second stage of 4 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 treatment temperature of 133.3 ^{0}F. Continuous measurements indicated that the minimum temperature in any of the batch digesters during the entire test period was 133.8^{0}F.

Phase V process description

The Phase V process was the same as the Phase IV process (Figure 6), but operated at a lower temperature:

a) A thermophilic first stage with fifteen digesters (one was out of service), operated in a continuous mode. The average temperature was 126.8^{0}F at a mean hydraulic retention time (HRT) of 9.9 days.
b) A thermophilic second stage with four digesters, operated in a batch mode. The holding time was 16 hours at an average temperature of 126.6^{0}F.

Sampling and analytical procedures

All analyses were performed by the Environmental Monitoring Division at HTP and BioVir Laboratories (Benicia, CA) according to the requirements of the Part 503 Biosolids Rule:

a) Fecal coliform: Parts 9221-B and 9221-E in "*Standard Methods for the Examination of Water and Wastewater*", 18th edition (APHA, 1992).
b) *Salmonella* sp.: Parts 9260-D in "*Standard Methods for the Examination of Water and Wastewater*", 18th edition (APHA, 1992).
c) Viable helminth ova: U.S. EPA (1987).
d) Enteric viruses: D 4994-89 (ASTM, 1992).
e) Total solids: Part 2540-G in "*Standard Methods for the Examination of Water and Wastewater*", 18th edition (APHA, 1992).

At each sampling event, the sample temperature was measured in the total solids sample immediately after collection.

RESULTS

Phase III

Process performance was evaluated by analysis of biosolids at the Truck Loading Facility and the farm as the locations most important for compliance with the Class A indicator and pathogen requirements. The results are summarized in Table 1. At the Truck Loading Facility, which contains 8 silos, 30 out of 32 samples from more than 2 weeks of testing complied with the Class A limit for fecal coliforms of 1000 MPN/g dry wt. Fecal coliform densities were at least 10 times below the limit in 75% of the samples, and at least 100 times under the limit (non-detect) in 58% of the samples. The two exceedances were only slightly above the limit, and could be correlated to low biosolids temperatures.

7 out of 8 biosolids samples at the farm complied with the Class A requirement for fecal coliforms. The density in complying samples was below 25 MPN/g dry wt, including 6 samples with no detectable fecal coliforms (<6.8 MPN/g dry wt). A comparison of fecal coliform densities at the farm and corresponding densities at the Truck Loading Facility indicates that the number of fecal coliforms were in general comparable. Hence, reactivation and/or growth of fecal coliforms during transport to the farm, which normally took about four hours, is not a reason for concern.

Salmonella sp. were not detected in biosolids at the farm at a detection limit of approximately 1.6 MPN/4 g dry wt (Table 1), and, consequently, all samples were below the Class A limit of 3 MPN/4 g dry wt. Disinfection of *Salmonella* sp. was complete and no reactivation and/or growth of *Salmonella* sp. occurred in biosolids during post-digestion processing at the plant and during transport to the farm. These results confirm the findings of Phase I and II tests that the Class A standards for *Salmonella* sp. are easily met and maintained.

Viable helminth ova were present in primary at a concentration of 1 ovum/4 g dry wt, but they were non-detect (<1 ovum/4 g dry wt) in farm biosolids. Likewise, the number of enteric viruses decreased from 69 PFU/4 g dry wt in primary sludge to non-detect (<1 PFU4 g dry wt) in farm biosolids.

The average biosolids temperature in the digester outflow and the silos were the same (around 125 ^{0}F), indicating that little or no cooling of biosolids occurred during Phase III post-digestion processing. This was confirmed by measurements of the temperature profile along the post-digestion train, as shown in Figure 5. It can be seen that insulation was very effective in maintaining a constant biosolids temperature (124 – 125 ^{0}F) up to the silos.

Regrowth tests were performed with biosolids collected during Phase III from the Truck Loading Facility and the farm on September 18, 2002. Fecal coliform densities in these

samples at the time of collection were less than 10 MPN/g dry wt (Figure 7). Subsequent storage of these samples in the laboratory at approximately 75 ^{0}F did not result in an increase of the fecal coliform density over a period of at least 140 hours.

Phase IV

The Phase IV process was the configuration originally planned for demonstrating compliance with local and federal requirements for EQ biosolids. At this time (October, 2002), the steam supply to the digesters was sufficient to comply with the time-temperature requirement for batch holding in Alternative 1. Biosolids at the farm as the location of final use were almost daily sampled over a period of 2 ½ weeks. Fecal coliforms and *Salmonella* sp. in farm biosolids were non-detect in all samples and, therefore, the farm biosolids were Class A (Figures 8a and b).

Though not required for Alternative 1 in the Part 503 Biosolids Rule, the Phase IV process was also tested for destruction of non-bacterial pathogens. Primary sludge contained enteric viruses at a density of approximately 40 PFU/4 g dry weight, but they were non-detect (<1 PFU/4 g dry wt) in farm biosolids. Helminth ova could not be detected in farm biosolids or in primary sludge.

During Phase IV testing, a sharp increase of odorous emissions from thermophilic operations was noted. Analysis of the digester gas showed a sharp increase of the production of methyl mercaptan when the digester temperature was raised to meet the time-temperature requirement of Alternative 1. Prevention of odor emissions is an important priority of the City of Los Angeles. Hence, it was decided to reduce the digester temperature with the rationale that Phase III testing at lower temperature still achieved Class A pathogen reductions but without unacceptable odor emissions from thermophilic operations.

Phase V

This Phase of testing became necessary because the time-temperature requirement of Alternative 1 would not be met after lowering the digester temperature. Hence, compliance with Alternative 3 was required. Testing during November, 2002, demonstrated that fecal coliforms and *Salmonella* sp. were still non-detect in farm biosolids (Figure 9), despite the lower digester temperature. Helminth ova and enteric viruses were also non-detect in farm biosolids. The Phase V process, therefore, met both the federal and local regulations.

DISCUSSION AND CONCLUSIONS

Except for a few exceedances, the Phase III process complied with the Class A requirements for fecal coliforms and Salmonella in silo and farm biosolids. Likewise, complete destruction of helminth ova and enteric viruses or absence in the final product, required when using Alternative 3, was demonstrated. An important outcome of Phase III

was, therefore, that fecal coliform densities in biosolids remained below the Class A limit during post-digestion processing. Recurrence of fecal coliforms, previously observed during Phases I and II, did not occur during Phase III. This can possibly be attributed to a combination of the two following factors:

a) During Phase III, the entire plant was in thermophilic operation after the first stage digesters. This would greatly have reduced the risk of contamination of thermophilic biosolids with mesophilic biosolids, which usually contain high densities of fecal coliforms. Although several plant walk-throughs during Phases I and II did not reveal locations where contamination of the designated thermophilic train could have occurred, complete isolation of this train from other, mesophilic operations would be difficult to ensure. High pressure effluent (slip injection) and polymer (centrifuge dewatering), added during all full-scale tests to HTP's post-digestion biosolids, did not contain fecal coliforms; these additions were therefore ruled out as contamination sources during Phases I and II.
b) Insulation of the post-digestion train during Phase III and later phases prevented the large temperature drop in post-digestion biosolids, that was observed during Phases I and II without insulation. The importance of the temperature during post-digestion processing is related to the maximum temperature for growth of fecal coliforms and *Salmonella* sp. (either those surviving digestion or those introduced by contamination). If it can be assumed that the maximum temperature for growth generally is in the range of 113 – 122 ^{0}F, which seems to be a reasonable estimate (APHA, 1992; Neidhardt, 1987), then it follows that maintaining a biosolids temperature of greater than about 122^{0}F would prevent the reactivation and/or growth of fecal coliforms and *Salmonella* sp. during post-digestion processing.

Further evidence that the Phase III process effectively prevented the recurrence of fecal coliforms was obtained from regrowth tests. In contrast to centrifuge and farm biosolids from Phases I and II (e.g., Cox et al., 2003[a]; Iranpour et al., 2002[c], 2003[b]), no regrowth of fecal coliforms occurred during storage at ambient temperature of silo and farm biosolids from Phase III.

Another important outcome of the Phase III process was that the disinfection results were better than at first expected considering that:

a) the digestion temperature was a few degrees below the target temperature of 131 ^{0}F;
b) the second stage received large amounts of fecal coliforms from the first stage mesophilic digesters;
c) the HRT was relatively short for the whole process, and in particular in the second stage digesters;
d) a small part of biosolids received treatment for a period significantly shorter than mean HRT (short-circuiting, Farrell et al., 1988).

The disinfection efficiency is related to the temperature and duration of treatment, for instance as quantified by the time-temperature relation of Alternative 1 of 40 CFR 503.32 for batch treatment. As could be expected from complying with this relation, the Phase

IV process reduced fecal coliforms and *Salmonella* sp. according to and even better than the Class A pathogen reduction requirements. The same disinfection was achieved, however, when during the Phase V the temperature was reduced while maintaining the same holding time. This is an indication that the time-temperature relation of Alternative 1 is conservative and that the Class A pathogen reduction requirements can be met under less stringent conditions. Reducing the temperature for disinfection may provide the advantages of savings in the energy costs for heating as well as a reduction of odor emissions from thermophilic operations. Alternatively, the holding time may be reduced, which would provide a more efficient use of the digester capacity. Presently, further experiments are being conducted to determine the effect of temperature on disinfection and the production of odor.

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Figure 1. Phase I and II – Digester Operation and Post-digestion Temperatures (No insulation)

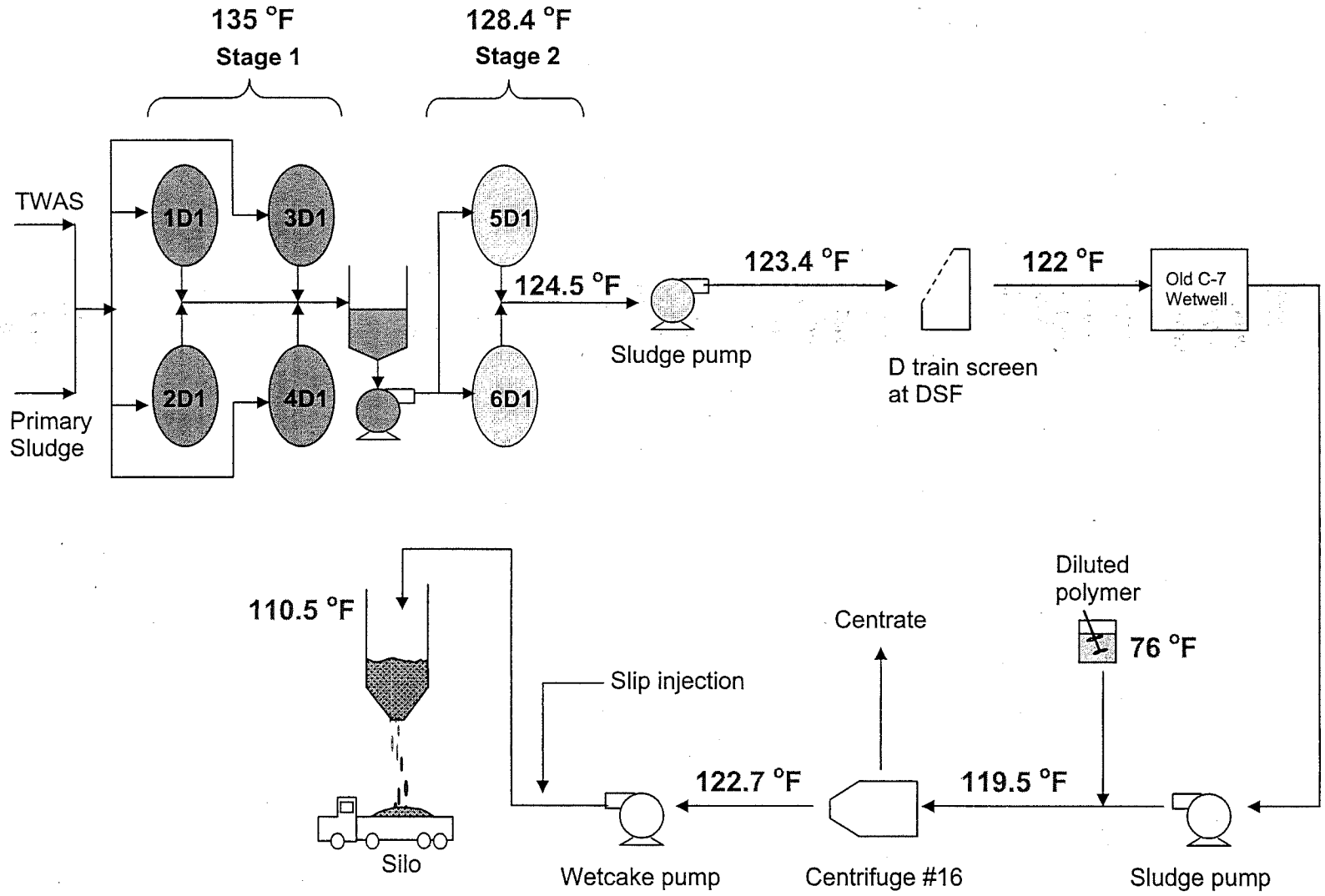

Figure 2. Phase II - Fecal Coliforms Before and After Batch Digestion

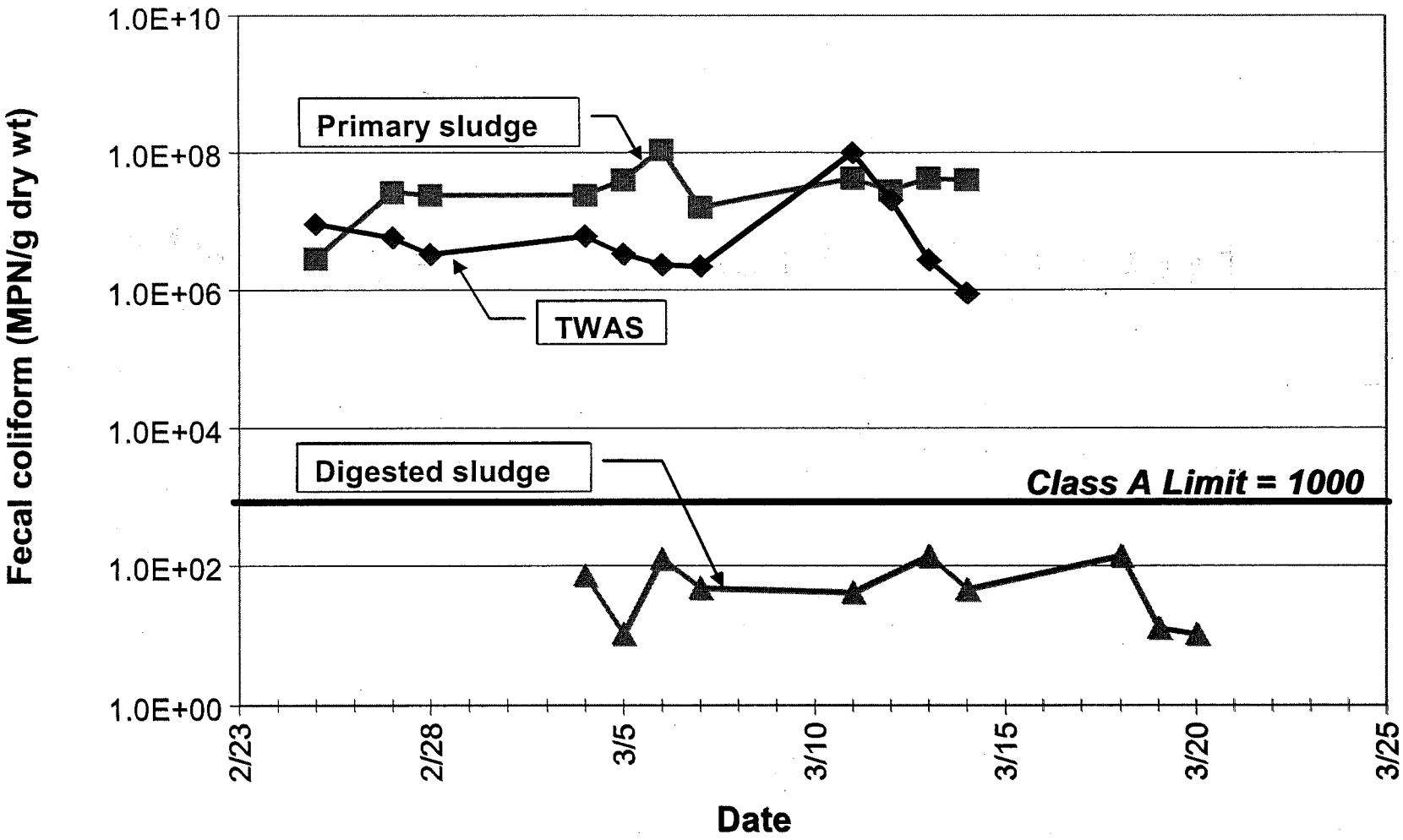

Figure 3. Phase II - *Salmonella* Before And After Batch Digestion

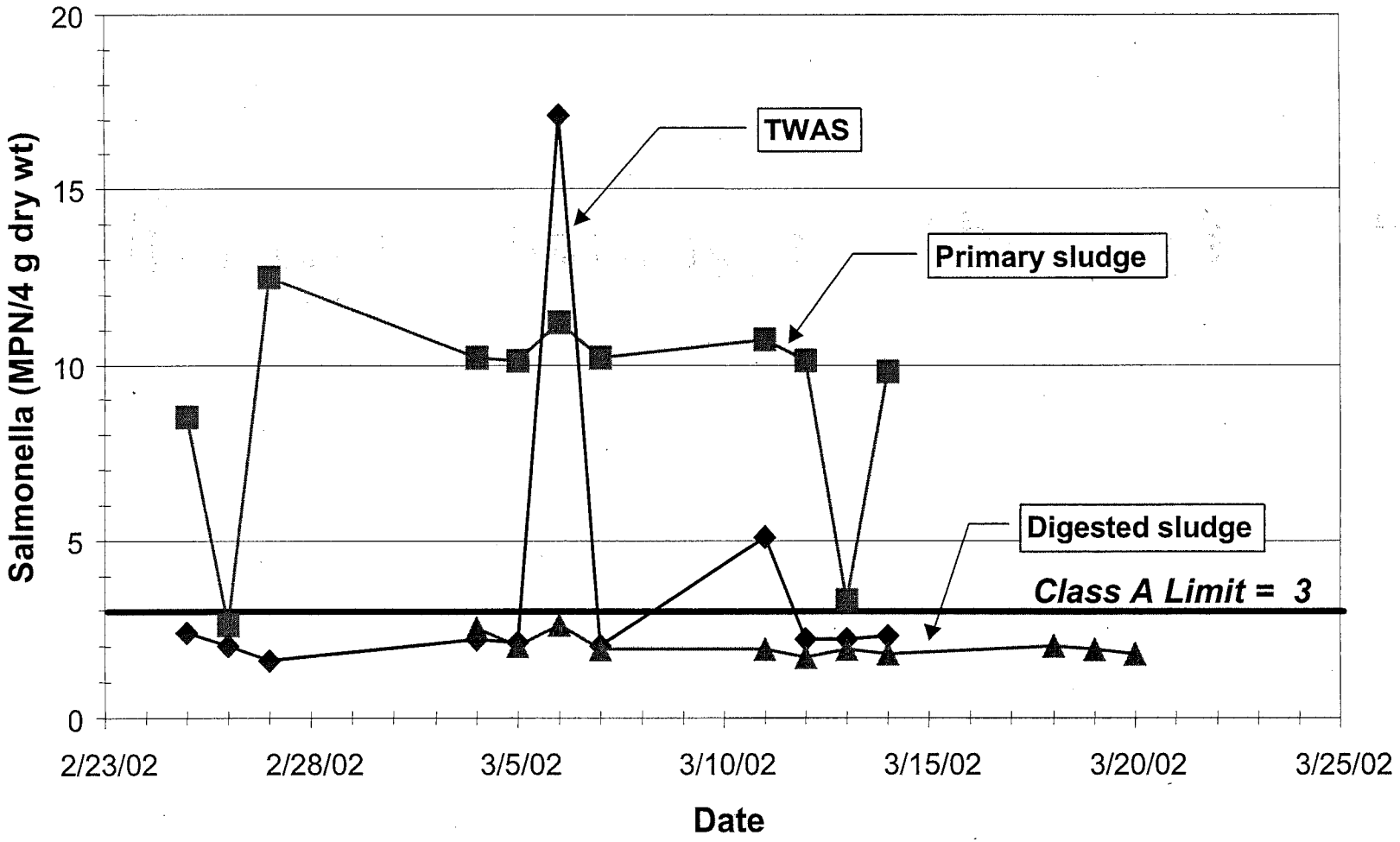

Figure 4. Phase II - Fecal Coliforms in Post-digestion Biosolids

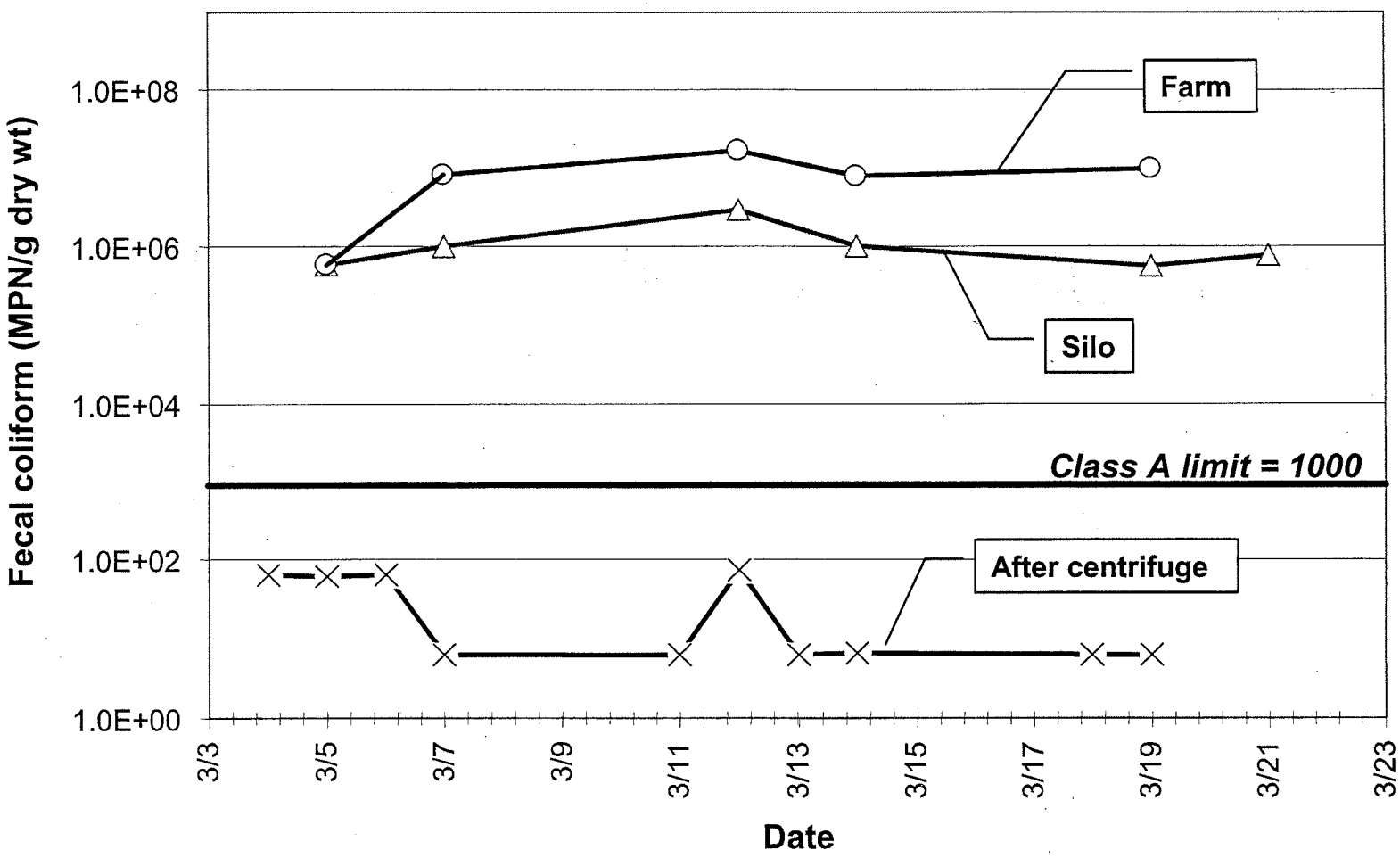

Figure 5. Phase III - Digester Operation and Post-Digestion Temperatures (Insulation)

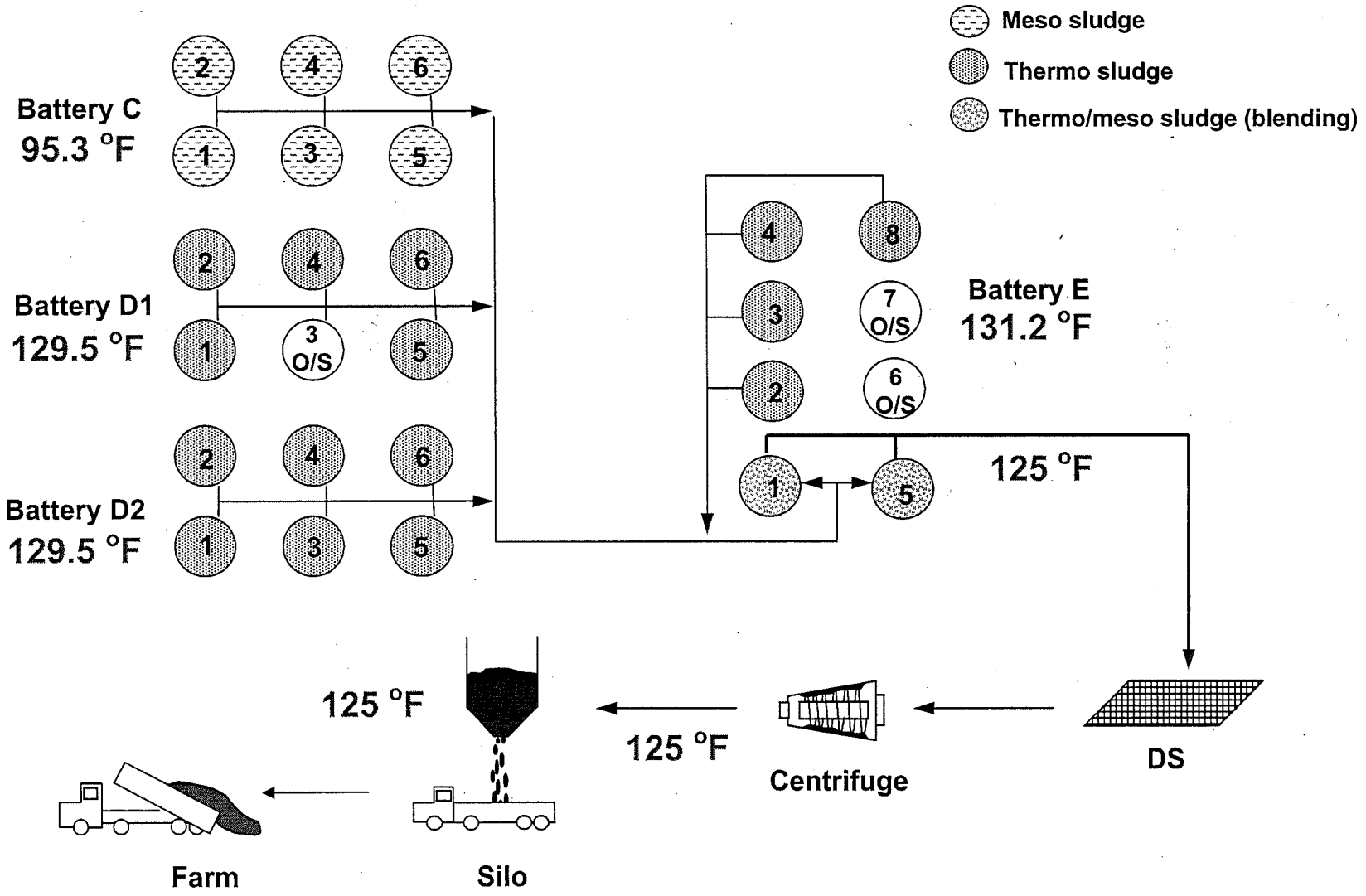

Figure 6. Phase IV and V - Digester Operation

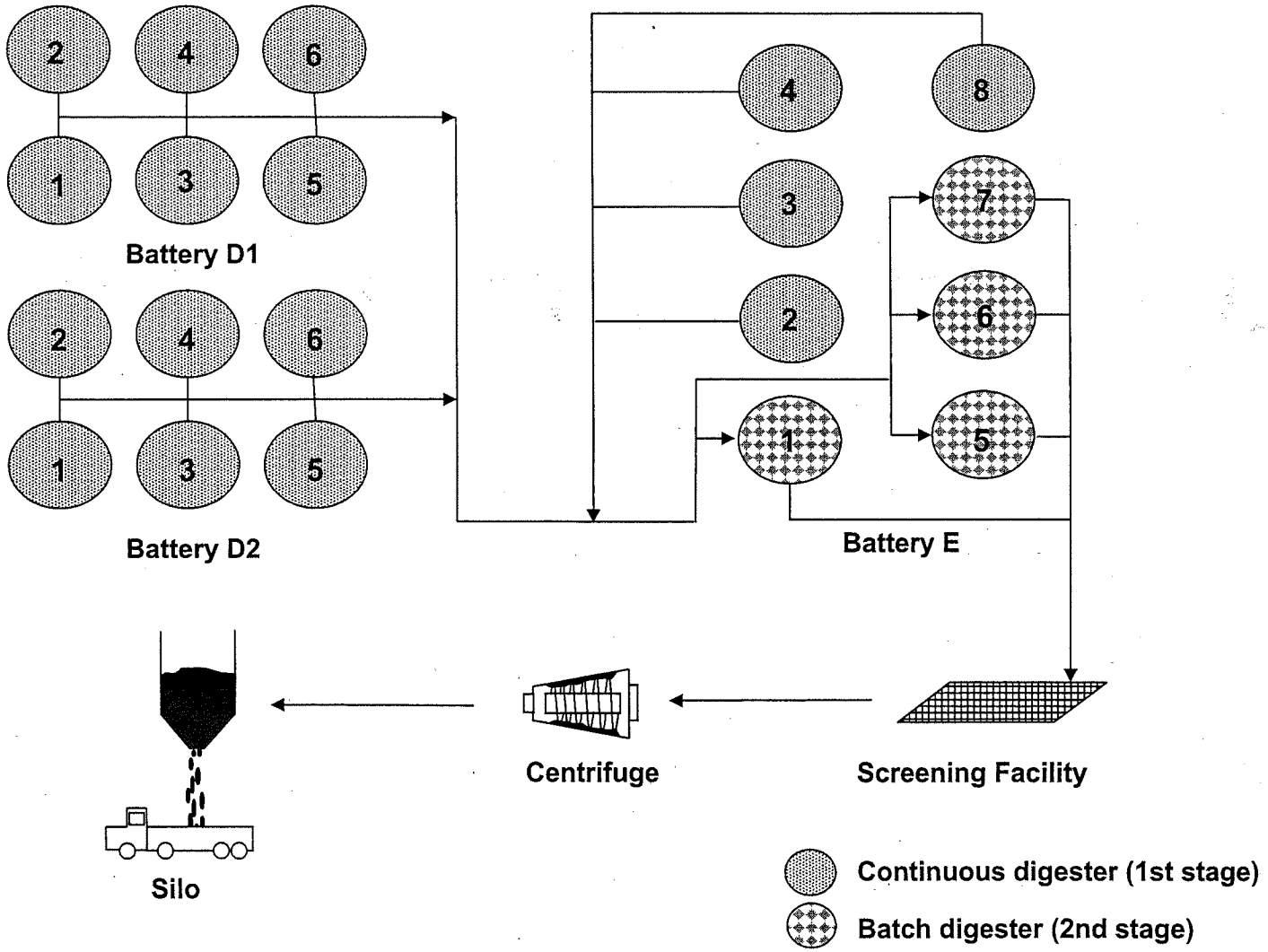

Figure 7. Phase III - Regrowth of Fecal Coliforms in Post-Digestion Biosolids (70 °F)

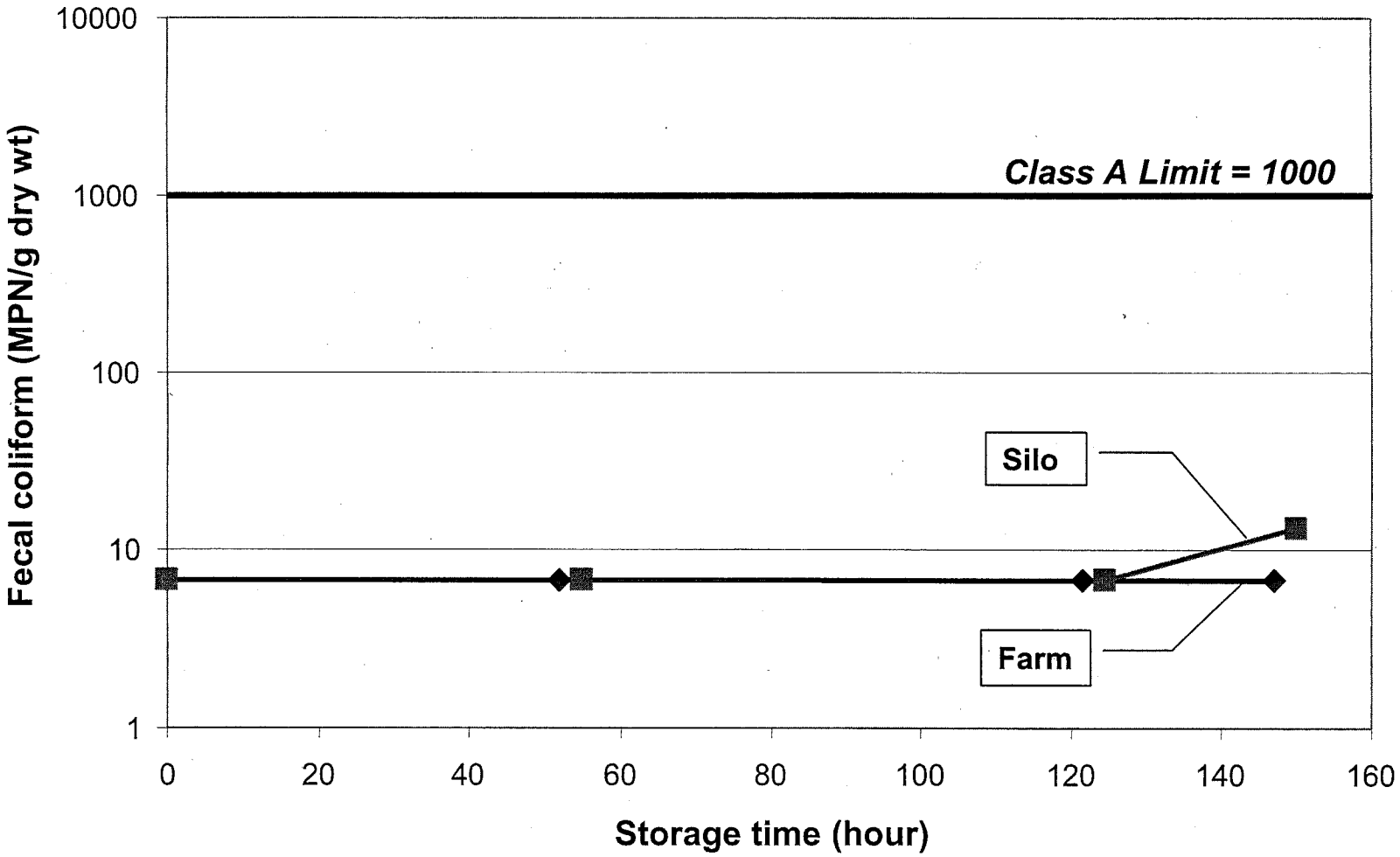

Figure 8a. Phase IV – Fecal Coliform in Farm Biosolids

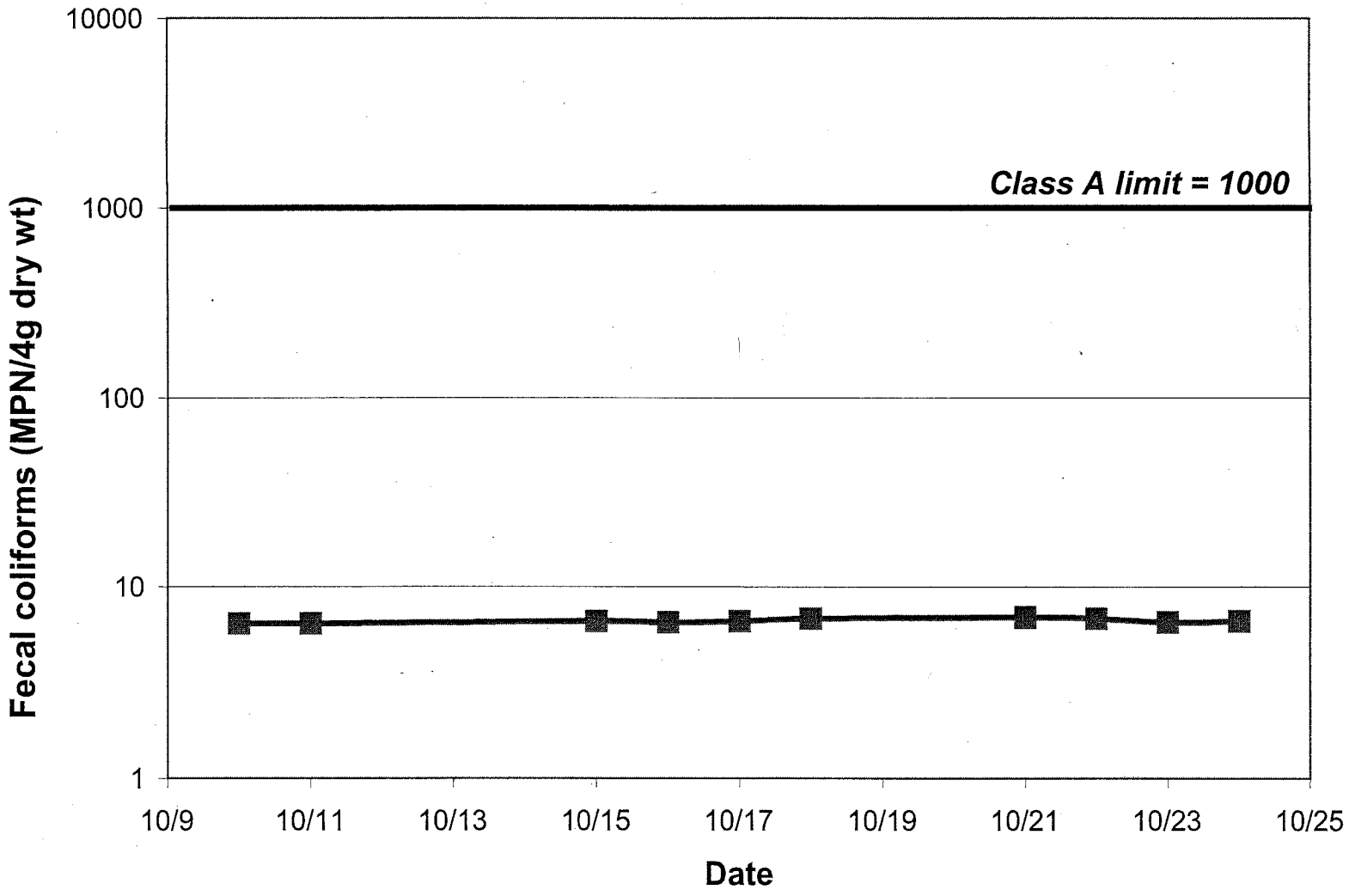

Figure 8b. Phase IV – Salmonella in Farm Biosolids

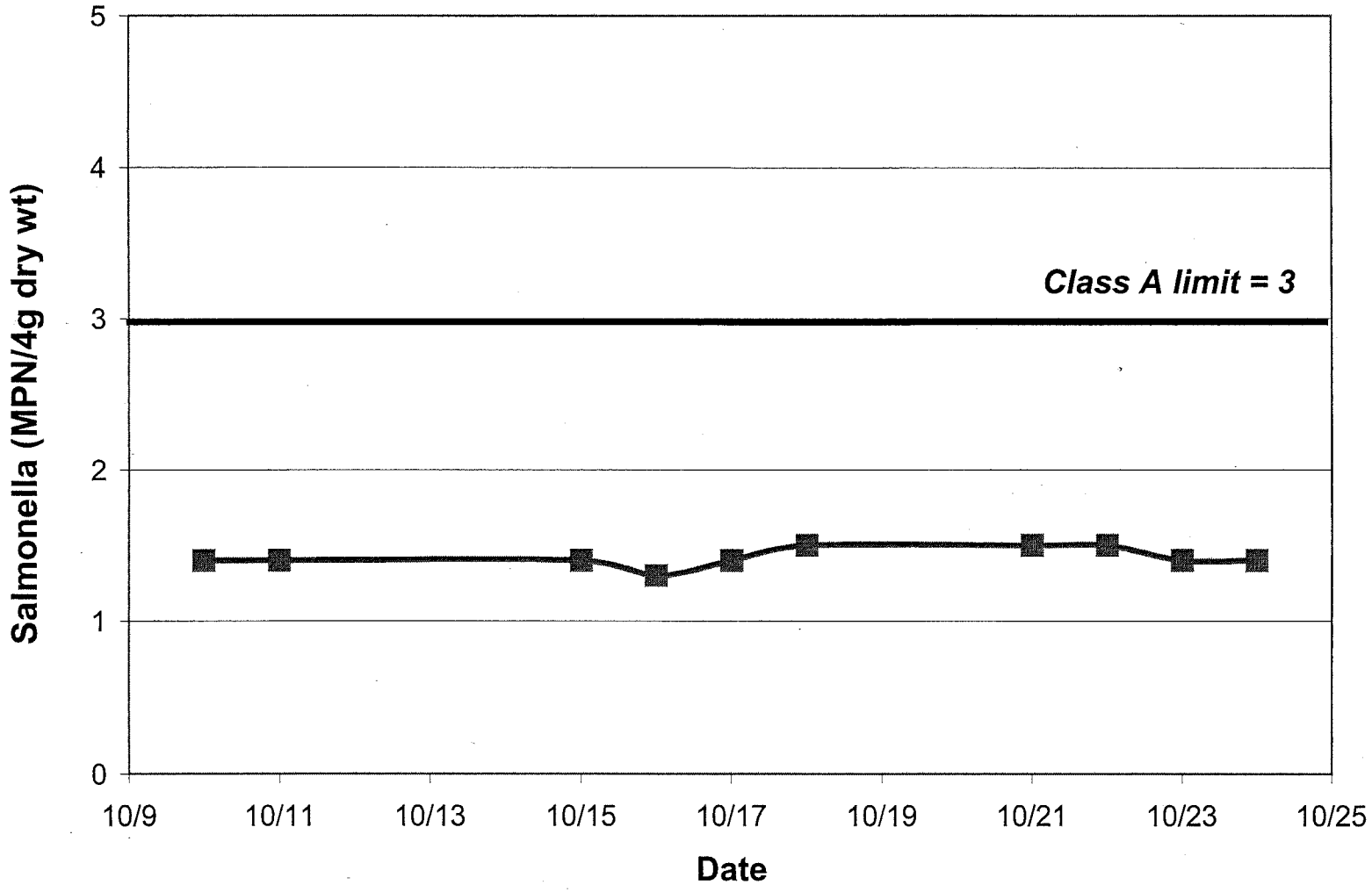

Figure 9a. Phase V – Fecal Coliform in Farm Biosolids

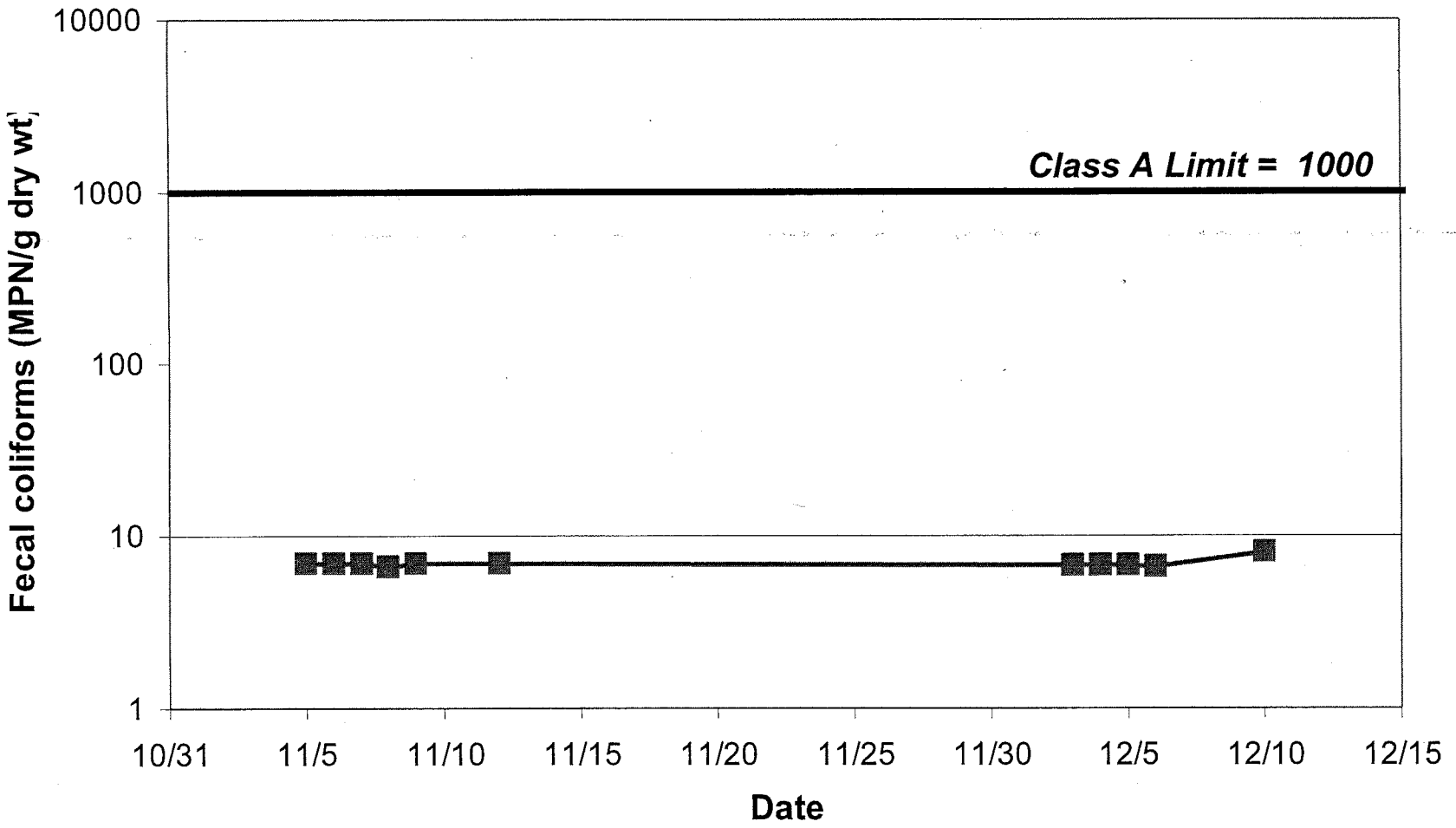

Figure 9b. Phase V – Salmonella in Farm Biosolids

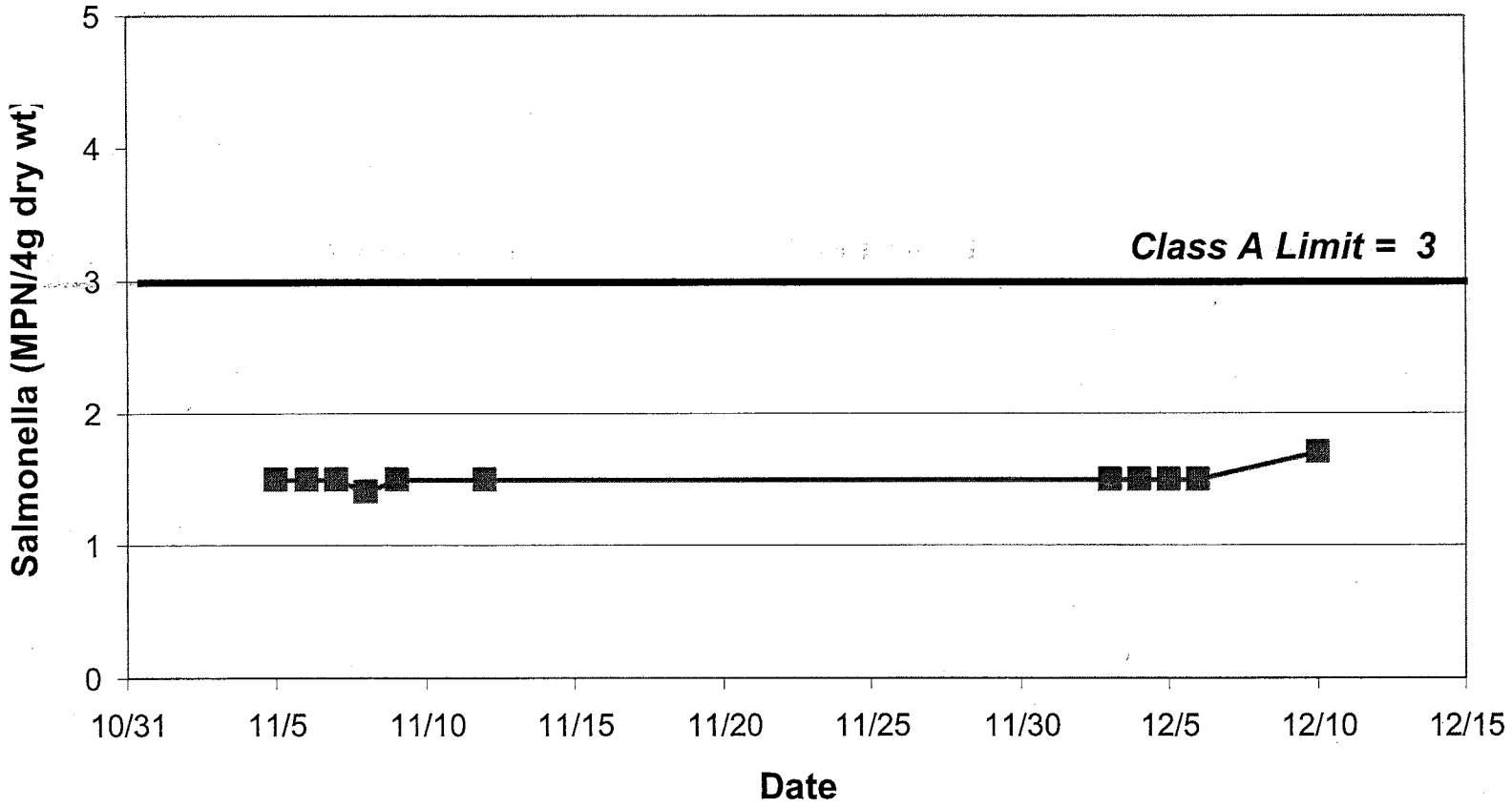

Table 1. Phase III – Bacterial/Nonbacterial Counts and Temperature

		Week 1		Week 2				Week 3			
Location	Analysis	9/4 Wed	9/5 Thu[c]	9/9 Mon	9/10 Tue	9/11 Wed	9/12 Thu[c]	9/16 Mon	9/17 Tue	9/18 Wed[e]	9/19 Thu
Primary Sludge	Salmonella(EMD)	35	16	2.3	16	16	2.1				
	Salmonella(BioVir)	46.55	11.73	39	> 38	36	19				
	Helminth Ova										
	Enteric virus										
Silo 1	Temperature	123		124.5		123.5a		125.3[a]		123.1	
	Fecal coliform	55		< 6.8		< 6.5		6.6		55	
Silo 2	Temperature				121.5				122.8[a]		124.1[a]
	Fecal coliform				1700				54000		6.5
Silo 3	Temperature	127.6[a]		125.5		125		124.9		124.7[a]	
	Fecal coliform	< 6.5		< 6.6		< 6.7		< 6.6		< 6.7	
Silo 4	Temperature				125.2				126.5		129.8
	Fecal coliform				6.6				420		100
Silo 5	Temperature	NR[b]		126.0		120.5		125.9		123.6	
	Fecal coliform			< 6.6		< 6.6		< 6.8		< 6.7	
Silo 6	Temperature				126.7				125.2		123.6
	Fecal colifrom				100				< 6.6		34
Silo 7	Temperature	120.7		119.0[a]		118.5		124.7		123.4	
	Fecal coliform	< 6.5		< 6.7		< 6.5		< 6.6		42	
Silo 8	Temperature				124.4[a]				125.5		123.8
	Fecal coliform				58				< 6.5		6.2
Farm	Temperature	127.1		126.7	126	124		125	120.9	125.9	121.8
	Ambient Temp	77.0		58	63	65		63	58	62.8	62
	Fecal coliform	< 6.5		< 6.7	< 6.8	< 6.5		23	< 6.8	< 6.7	3600
	Salmonella(EMD)			< 1.4	< 1.5	< 1.4		< 1.4	1.5	<1.5	<1.4
	Salmonella(BioVir)			< 1.47	< 1.52	1.56		< 1.7	< 1.6	< 1.7	< 1.8
	Helminth Ova										
	Enteric virus										

Notes

Temperatures in °F; fecal coliforms in MPN/gdry wt.; Salmonella sp. in MPN/4 g dry wt.

[a] Farm sample was collected from truck loaded at the indicated silo.

[b] Sample not according to protocols. Results not shown

[c] Electrical SOPER on 9-4 and 9-11-02 interfered with testings on 9-5 and 9-12-01. Results not shown.