PROTOCOLS AND PLANS FOR CLASS A CERTIFICATION OF THERMOPHILIC ANAEROBIC DIGESTION BY DEMONSTRATING EQUIVALENCY TO PROCESSES TO FURTHER REDUCE PATHOGENS

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ABSTRACT

The City of Los Angeles Hyperion Treatment Plant (HTP) completed the conversion of its anaerobic digesters to thermophilic operation in August 2002. Extensive monitoring of the digesters in 2003 indicated stable thermophilic digestion performance: pH of 7.5; 300 mg/L volatile fatty acids (VFA) as acetic acid; VFA to alkalinity ratio of 0.074; 61% volatile solids destruction. Since December 2002, the two-stage continuous-batch process has been certified as Class A under Alternative 3 of the U.S. EPA Part 503 Biosolids Rule. *Salmonella* sp., viable helminth and enteric viruses were not detected during monthly monitoring of the biosolids at the Truck Loading Facility and the farm for land application. Fecal coliforms were always at least ten times below the Class A limit, and often not detected. Hence, near complete disinfection of the biosolids was achieved, even though the holding time and temperature in the second stage (16 hours at 129.2^{0}F) was well below the time-temperature requirement of Alternative 1. The City of Los Angeles Bureau of Sanitation aims to demonstrate that the process at HTP is equivalent to Processes to Further Pathogens (PFRP equivalency: Alternative 6). Detailed protocols have been developed to demonstrate a 2-log reduction of viable helminth ova and a 3-log reduction of enteric viruses, as required by U.S. EPA for Alternative 6. The experiments entail a laboratory setup with six 20-Liter digesters that will simulate the operation of HTP's second-stage batch digesters. The U.S. EPA Pathogen equivalency Committee gave final approval of the protocols in June 2004, and experiments are expected to start in 2005.

INTRODUCTION

The City of Los Angeles is committed to maintaining 100% beneficial reuse of the biosolids produced at its wastewater treatment plants. Since 1994, the biosolids from the Hyperion Treatment Plant (HTP) have been land applied at the Green Acres Farm in Kern County. Since January 2003, Chapter 8.05 of the Kern County Ordinance has banned the land application of Class B biosolids. In response to this ordinance, HTP has converted its sludge digestion process to thermophilic operation with the objective of meeting the Class A pathogen reduction standards as required for Exceptional Quality (EQ) biosolids. This has allowed the Hyperion Treatment Plant to continue the beneficial use of its biosolids in land application at the Green Acres Farm in 2003 and 2004.

After several years of full-scale testing, HTP produces EQ biosolids in a thermophilic two-stage continuous-batch process (Iranpour et al., 2003; 2004a, 2005a). The production and land application of EQ biosolids must comply with federal, state and local laws and regulations. The Class A pathogen standards are specified by the U.S. EPA in the Part 503 Biosolids Rule (U.S. EPA, 1993, 1994; Iranpour et al., 2004b):

- A general requirement of compliance with the density limits for pathogens in biosolids (<1000 MPN/g dry weight for fecal coliforms or <3 MPN/4 g dry wt for *Salmonella* sp.).
- A specific requirement for using one of six Alternatives with operational standards.

Alternatives 1, 3 and 6 are applicable for wastewater treatment plants such as HTP that produce Class A biosolids by thermophilic anaerobic digestion:

- Alternative 1 requires that the biosolids shall receive treatment in a batch reactor. This Alternative also specifies combinations of minimum temperatures and minimum durations of holding in the batch reactor in order to achieve sufficient disinfection of the biosolids.
- Alternative 3 does not specify requirements for the treatment of biosolids. Instead, this Alternative requires additional monitoring of pathogens in biosolids (helminth ova and enteric viruses) as well as monitoring of treatment conditions.
- Alternative 6 provides the opportunity to demonstrate that a process is equivalent to Processes to Further Reduce Pathogens (PFRP). This requires extensive testing and monitoring to demonstrate that the process is capable of achieving disinfection according to U.S. EPA requirements.

Since January 2003, HTP has complied with Alternative 3. The biosolids are produced by thermophilic anaerobic digestion at a temperature of about 128-129°F. Alternative 3 is currently under discussion and may in the future be deleted from the Part 503 Biosolids Rule. In anticipation of this possibility, HTP would need to seek compliance with other Alternatives.

Production of Class A biosolids under Alternative 1 would require upgrading and expansion of the digestion process, which is an option for the long-term. Currently, operation under Alternative 1 would be relatively expensive because of the limited batch digester capacity, thereby requiring a relatively high digester temperature. Therefore, the City of Los Angeles Bureau of Sanitation decided to seek compliance with Alternative 6.

The first part of this paper describes the operation, digestion performance and Class A disinfection data of HTP's thermophilic digestion process in 2003. The second part describes the protocols that were developed to demonstrate a 2-log reduction of viable helminth ova and a 3-log reduction of enteric viruses, as required by U.S. EPA for Alternative 6. The U.S. EPA Pathogen Equivalency Committee approved the protocols in June 2004, and we expect to start the tests in 2005. The stability of the process, the excellent disinfection results obtained in 2003 and the future test results will form the basis for demonstrating PFRP equivalency of HTP's digestion process.

OPERATION AND PERFORMANCE IN 2003

Process schematic

The average daily flowrate at HTP has recently been 350 mgd. The plant produces approximately 700 wet tons of biosolids per day in 20 egg-shaped digesters, each with a volume of 2.5 million gallons. Conversion of the anaerobic digesters from mesophilic to thermophilic operation started in 2001 and was completed in September 2002. Figure 1 presents a schematic of the process that has been in use at HTP since October 2002. The first stage contains 16 digesters that are operated with continuous feed and withdrawal. The biosolids from the first stage are combined and transferred to the second stage containing four batch digesters. These are operated in cycles of 8 hours feeding, 16 holding and 8 hours withdrawing, as shown in Figure 2.

Post-digestion biosolids handling consists of screening, centrifuge dewatering, transport of digested sludge and concentrated biosolids through pipes with Abel pumps, and biosolids storage in silos for a maximum of one day. In order to prevent regrowth of fecal coliforms in post-digestion biosolids (Iranpour et al., 2002, 2005b), the post-digestion train was insulated and provided with electrical heat-tracing from the digesters to the silos in the Truck Loading Facility.

Process operation

Operational parameters are presented in Figures 3 to 7 and summarized in Table 1.

Figure 3 demonstrates that the flowrate of primary sludge usually was between 2 and 3 mgd with an average value of 2.6 mgd. The average flowrate of thickened waste activated sludge was 0.8 mgd. The combined flow resulted in an average hydraulic retention time in the first-stage digesters of 11.3 days (Figure 4). The sludge is heated by injection of steam into the sludge feed lines to the first-stage digesters and into the sludge recirculation lines for mixing of the digesters. The first-stage temperature was in the range of 127.7 – 128.7^{0}F with an average value for 2003 of 128.3^{0}F (Figure 5).

The batch holding time in the second-stage digesters was on average 16 hours (Figure 6), and the average digester temperature during holding in the second stage was 129.2^{0}F (Figure 7). This temperature is well below the minimum temperature of 133.0^{0}F as required for 16 hours holding by the time-temperature relationship in Alternative 1. Although Figures 6 and 7 show the operation of batch Digester 1E, it should be noted that operation of the other batch digesters was comparable. Overall, these results demonstrate operational conditions of the first- and second-stage digesters were relatively stable.

Digestion performance

Parameters reflecting digestion performance are presented in Figures 8 to 12, and summarized in Table 2.

Volatile fatty acids (VFAs), alkalinity and the pH were determined once or twice per week and analyzed according to procedures in *Standard Methods* (APHA et al., 1992). As shown in Figure 8, the total concentration of VFAs was relatively constant with an average value of 300 mg/L. The alkalinity fluctuated between 4,000 and 4,500 mg/L as $CaCO_3$ in the first part of 2003, but a slight decrease to 3,500 – 4,000 mg/L occurred in the second part of the year (Figure 8). This had no significant effect on the VFA to alkalinity ratio, shown in Figure 9, which remained well below 0.1 throughout the year except for measurements on three days. Likewise, Figure 10 shows that the pH remained relatively constant in 2003. The results in Figures 8, 9 and 10 are indicative of a healthy thermophilic culture in the digesters. Moreover, the small standard deviations reported in Table 2 demonstrate that digester performance was relatively constant throughout the year without major changes in VFA production, alkalinity or pH.

Volatile solids destruction was determined on a daily basis, as reported in Figure 11. The average volatile solids reduction in 2003 was 61%, with some small variations occurring on a daily basis. The Part 503 Biosolids Rule requires for Class A biosolids that volatile solids reduction shall be greater than 38% (Option 1 in 40 CFR Part 503, section 33). Figure 11 demonstrates that this condition was always met.

Digester gas production was relatively constant in 2003 with an average production of 7.4 mscf/day (Figure 12). The gas production appeared to have increased slightly after conversion of

the digesters to thermophilic operation, although more detailed analyses would be necessary to quantify the effect of temperature on gas production.

Disinfection performance

Table 3 summarizes the U.S. EPA requirements for pathogen monitoring under Alternative 3. HTP analyzes the biosolids on a monthly basis according to the required procedures. The biosolids are usually sampled from the silos in the Truck Loading Facility, but once every four months the samples are taken from biosolids after delivery at the farm. Both sampling locations can be considered as the last points of plant control, where compliance with the Class A pathogens should be demonstrated. This contrasts with many research projects described in the literature, in which sampling is usually done at the digester outlet. This, however, neglects the possibility of reactivation and/or growth of pathogens during post-digestion solids handling, which may cause non-compliance at the last point of plant control even though the digesters were shown to produce Class A biosolids.

Figures 13 to 16 present the results of pathogen monitoring of the biosolids produced in the period of January 2003 to July 2004. Fecal coliforms (indicators of pathogens) are usually present in raw sludge in a density of about 10^7 MPN/g dry wt, but they were often below the detection limit (~ 8 – 9 MPN/g dry wt) in biosolids from the silos at the Truck Loading Facility and at the farm for land application (Figure 13). In the few cases that fecal coliforms were detected, their density was still at least ten times less than the Class A limit. As shown in Figures 14, 15 and 16, *Salmonella* sp., viable helminth ova and enteric viruses were never detected in the biosolids. For these three classes of pathogens, the Class A limit and the detection limit are the same, which reflects the requirement that Class A biosolids shall not contain pathogens.

Overall, these results demonstrate that HTP biosolids at the Truck Loading Facility and the farm for land application consistently complied with the Class A limits for fecal coliforms, Salmonella sp., viable helminth ova and enteric viruses, and hence with Alternative 3 of the Part 503 Biosolids Rule. It is interesting to note that fecal coliform reductions were much better than required, that is, fecal coliform densities were almost always 100 times less than the Class A limit. This is a remarkable result because a temperature of 129.2^{0}F in the second-stage batch digesters was much lower than the temperature of 133^{0}F required by Alternative 1 for 16-hours holding. This may indicate that the Alternative 1 time-temperature relationship is conservative, as the present results indicate that the Class A pathogen reduction requirements can be achieved under less stringent conditions.

PROTOCOLS FOR DEMONSTRATING PFRP EQUIVALENCY

Objectives

The objectives of the protocols are to:

1. Demonstrate compliance of the process with the U.S. EPA requirements for Alternative 6:
   - ≥2-log reduction of viable helminth ova;
   - ≥3-log reduction of enteric viruses.
2. Determine the reductions of helminth ova and enteric viruses at other combinations of holding time and temperature.

Hence, the first objective is to demonstrate PFRP equivalency of the process at HTP at the current operational conditional conditions of 16-hours holding at a temperature of 128-129^{0}F. The second objective is to determine the minimum conditions at which the same disinfection performance can

be achieved. This may provide HTP with potential cost savings and a greater flexibility in operation of the digesters if the PFRP Class A pathogen reduction requirements can be achieved at a shorter holding time and/or lower temperature. For instance, a reduction of the digester temperature by one degree Fahrenheit would correspond to yearly savings in the steam costs of about $75,000.

Experimental set-up

Bench-scale setup: An important consideration was that the densities of helminth ova and enteric viruses in HTP's raw sludge are too low to demonstrate the required log-reductions (e.g., see Figures 15 and 16). Since spiking of the full-scale digesters with the pathogens would not be feasible, a bench-scale setup was developed for determining the time-temperature dependent disinfection of helminth ova and enteric viruses.

The bench-scale set-up uses six glass reactors with a volume of about 22 L each. The initial sludge volume in the reactors is 20 L. Each reactor is equipped with heating tapes, temperature probe and controller, stirrer/mixer, gas collection bag and feed and ports for feeding and sampling (Figure 17). The reactors are designed for operation in a batch mode at constant temperature and with continuous mixing. The headspaces of the reactors are connected to a 10-L gas collection bag.

Disinfection tests: The disinfection tests will be performed in two series of experiments. In the first series, the batch reactors will be operated at temperatures in the range of 120 to 136^{0}F with sampling at intervals ranging from 0 to a maximum of 36 hours (Table 4). Most combinations of temperature and holding time are well below the requirements following the time-temperature requirement for batch treatment in Alternative 1, as illustrated in Figure 18. The second series of experiments will duplicate the time-temperature combinations from the first series with temperatures that are the most relevant for HTP (Table 5).

Simulation of actual conditions: Several measures were developed to ensure that conditions during the bench-scale tests would simulate actual conditions in the second-stage digesters at HTP as much as possible:

- The reactors will be filled with digested sludge sampled from the outlet of the first-stage digesters at HTP.
- First-stage digested sludge will be insulated during transport to the laboratory in order to maintain the same temperature as the one at the time of sampling, and immediately be heated to the temperatures in Tables 4 and 5 after transfer into the reactors. Spiking with helminth ova and enteric viruses will be done immediately after the target temperatures have been reached.
- After filling the reactors with first-stage digested sludge, the head-space of the reactors will be flushed with digester gas that will be collected at the same time of sampling of first-stage digested sludge.

QA/QC: A large part of the protocols deals with QA/QC measures:

- The procedures for sampling and sample storage, transport and analysis are according to U.S. EPA requirements.
- The experiments will be conducted in a Biosafety Level 2 laboratory, which is required when working with enteric viruses and helminth ova.
- All equipment will be sterilized before and after use.

- Several control experiments were developed to determine the recovery of pathogens after addition to first-stage digested sludge (i.e., matrix interference) and potential reductions of pathogens during sampling and transport the laboratory.
- Detailed sampling programs were developed to coordinate the disinfection tests with the time-constraints for sample transport and sample analysis.

Current status

The protocols were developed in 2003 with several in-house revisions. After a first review by U.S. Pathogen Equivalency Committee, the protocols were finalized in December 2003. Final approval by U.S. EPA was received in June 2004 and we expect to conduct the tests in early 2005.

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Table 1. Operational parameters in 2003.

Parameter	Unit	Mean	Standard deviation
Primary sludge			
- Flowrate	mgd	2.6	0.3
- Total solids (TS)	%	3.6	0.5
- Volatile solids (VS)	% of TS	79.0	1.6
Thickened waste activated sludge (TWAS)			
- Flowrate	mgd	0.8	0.1
- Total solids	%	6.0	0.8
- Volatile solids	% of TS	82.9	1.5
First-stage digesters			
- Hydraulic retention time	day	11.3	1.2
- Temperature	^{0}F	128.3	0.2
Second-stage digesters[a]			
- Batch holding time	hour	16.0	0.2
- Batch holding temperature	^{0}F	129.2	0.6

[a] Average operation of Digester E1; operation of batch Digesters E5, E6 and E7 was comparable.

Table 2. Digestion performance in 2003.

Parameter	Unit	Mean	Standard deviation
pH	-	7.5	0.1
Total volatile fatty acids	mg/L as acetic acid	303	72
Total alkalinity	mg/L as $CaCO_3$	4079	331
VFA/alkalinity ratio	-	0.074	0.017
Volatile solids destruction	(%)	61.0	4.8
Gas production	mscf/day	7.4	0.4

Table 3. U.S. EPA pathogen monitoring requirements and limits under Alternative 3.

Pathogen	Limit	Analytical procedure/reference
General for Class A biosolids		
Fecal coliforms	<1000 MPN/g dry wt	Part 9221E or Part 9222D in APHA et al. (1992)
Salmonella sp.	<3 MPN/4 g dry wt	Kenner and Clark (1974) or Part 9260D in APHA (1992)
Specific requirement for Alternative 3		
Viable helminth ova	<1 ova/4 g dry wt	U.S. EPA (1987)
Enteric viruses	< 1 PFU/4 g dry wt	ASTM (1992)

Table 4. Time-temperature combinations for first series of disinfection tests for PFRP Equivalency.

Reactor	Temp. (^{0}F)	Holding time (hours)						
A	120	0	2	8	12	16	24	36
B	124	0	2	8	12	16	24	36
C	128	0	2	8	12	16	24	36
D	132	0	2	6	9	12	16	20
E	136	0	2	4	6	8	12	16
F[d]	70	0	No holding, time 0 sampling only					

Table 5. Time-temperature combinations for second series of disinfection tests for PFRP Equivalency.

Reactor	Temp. (^{0}F)	Holding time (hours)						
A and B	124	0	2	8	12	16	24	36
C and D	128	0	2	8	12	16[c]	24	36
E and F[a]	132	0	2	4	6	8	12	16

Figure 1. Schematic of thermophilic anaerobic digestion process.

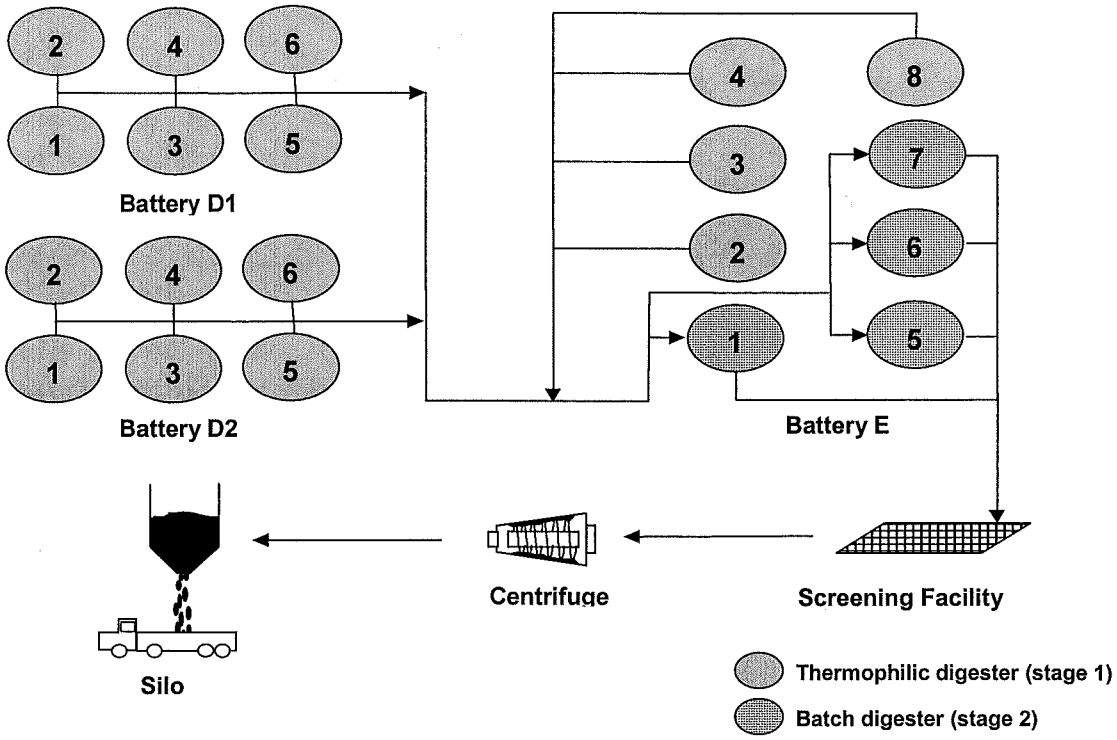

Figure 2. Second-stage batch digester operation.

	8 hr	8 hr	8 hr	8 hr	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	Wihdraw	Feed	Hold	Hold
7E	Hold	Hold	Withdraw	Feed	Hold

Figure 3. Flowrates of primary sludge and thickened waste activated sludge.

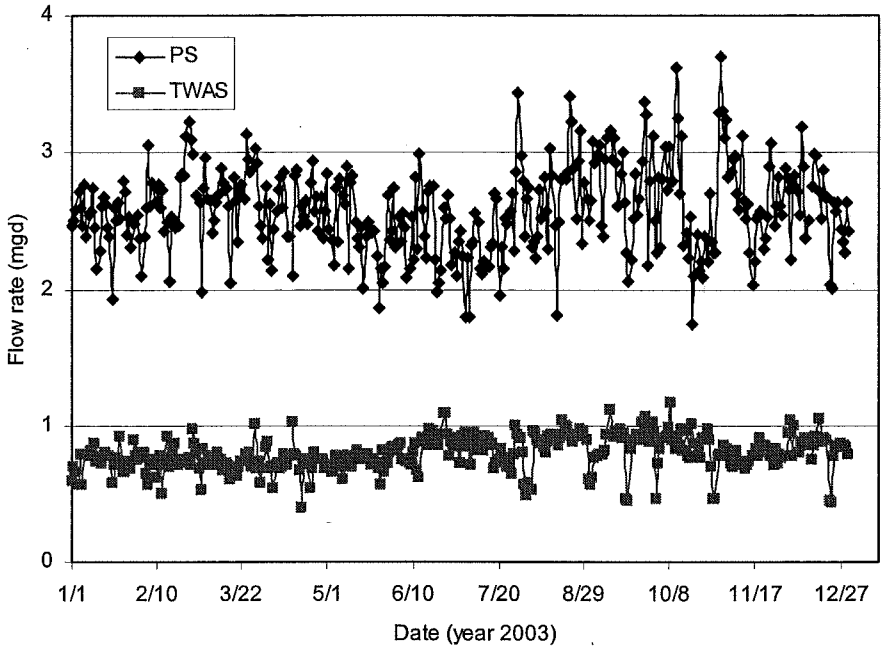

Figure 4. Hydraulic retention time in first-stage digesters.

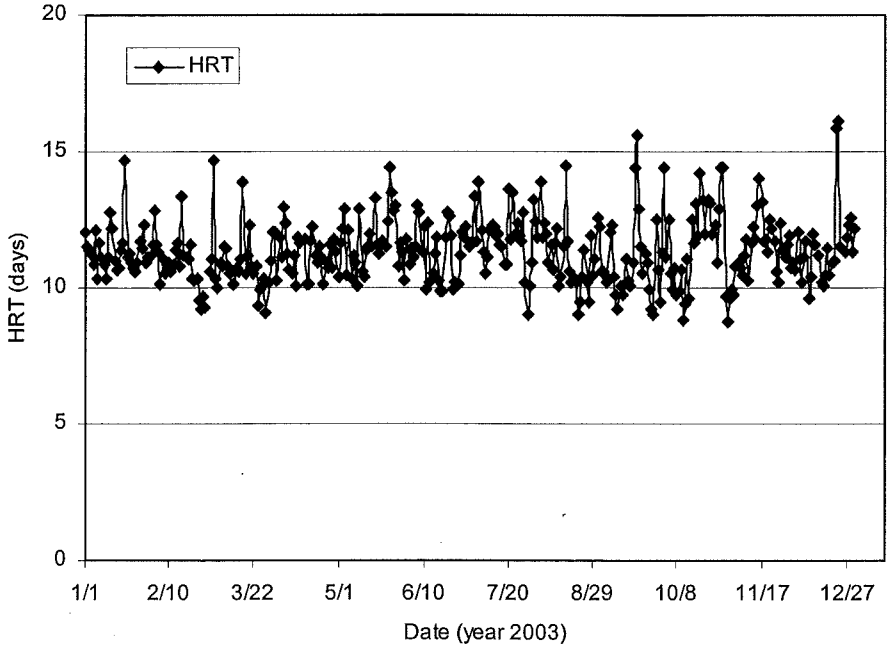

Figure 5. Average daily temperature in first-stage digesters.

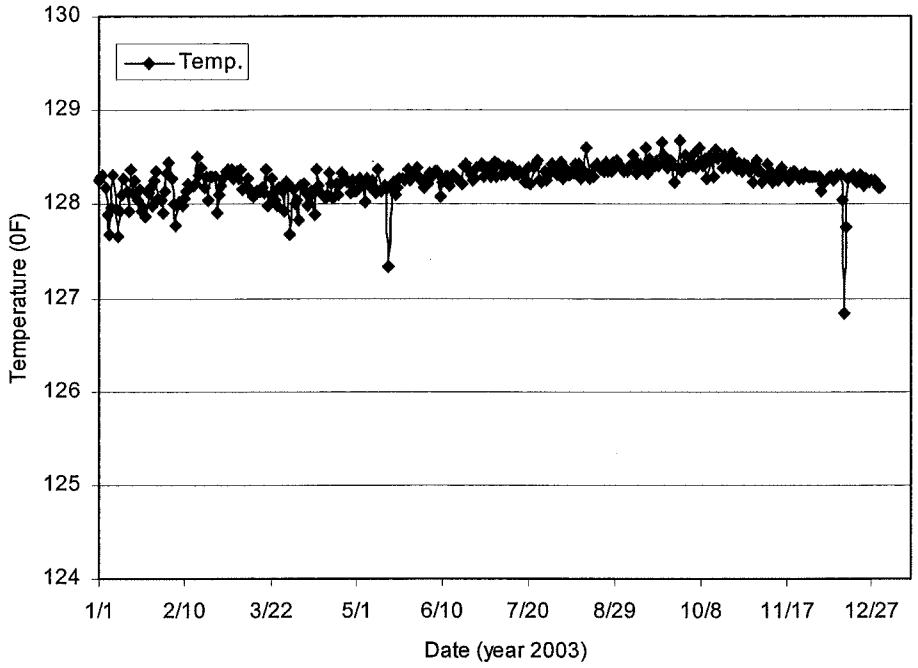

Figure 6. Batch holding time in second-stage Digester E1

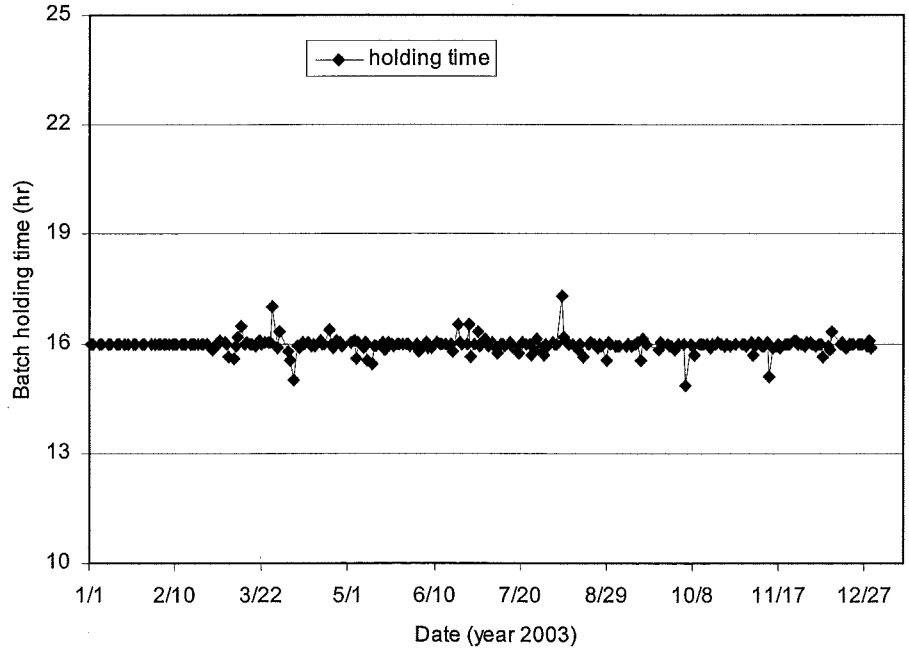

Figure 7. Batch holding temperature in second-stage Digester E1.

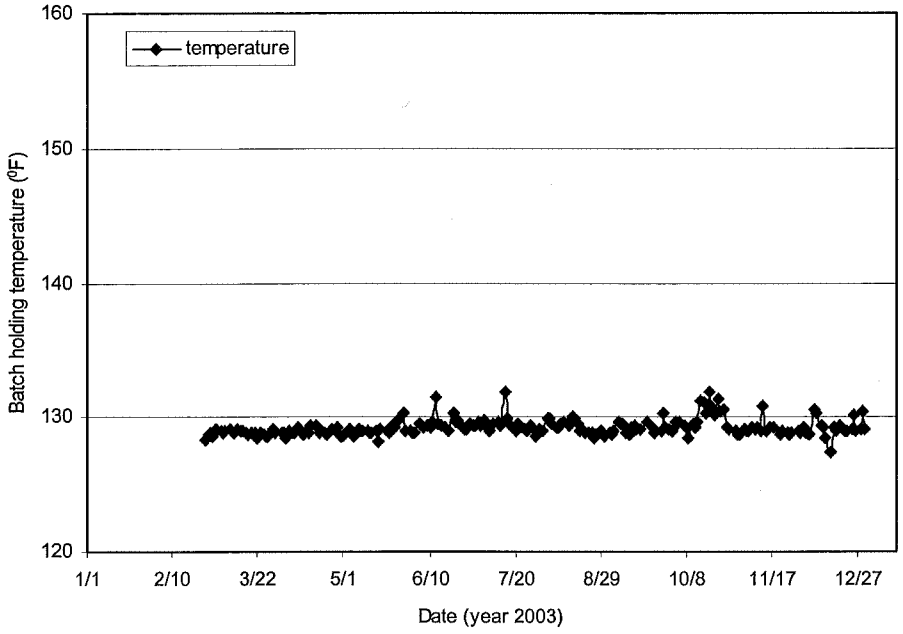

Figure 8. Total VFAs and alkalinity in first-stage digesters.

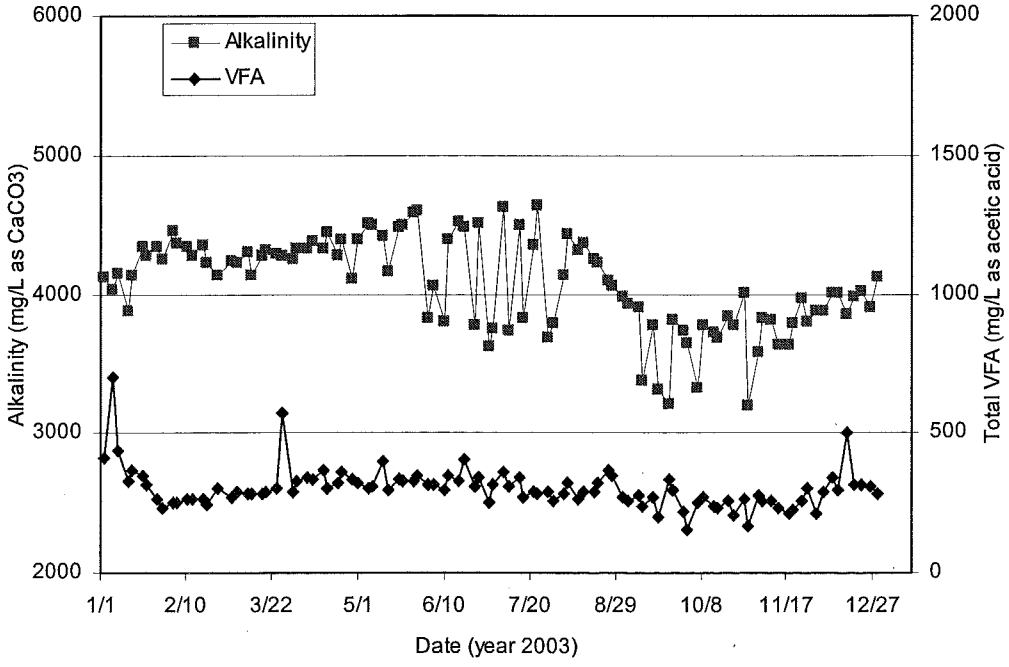

Figure 9. Ratio of total VFAs to alkalinity in first-stage digesters.

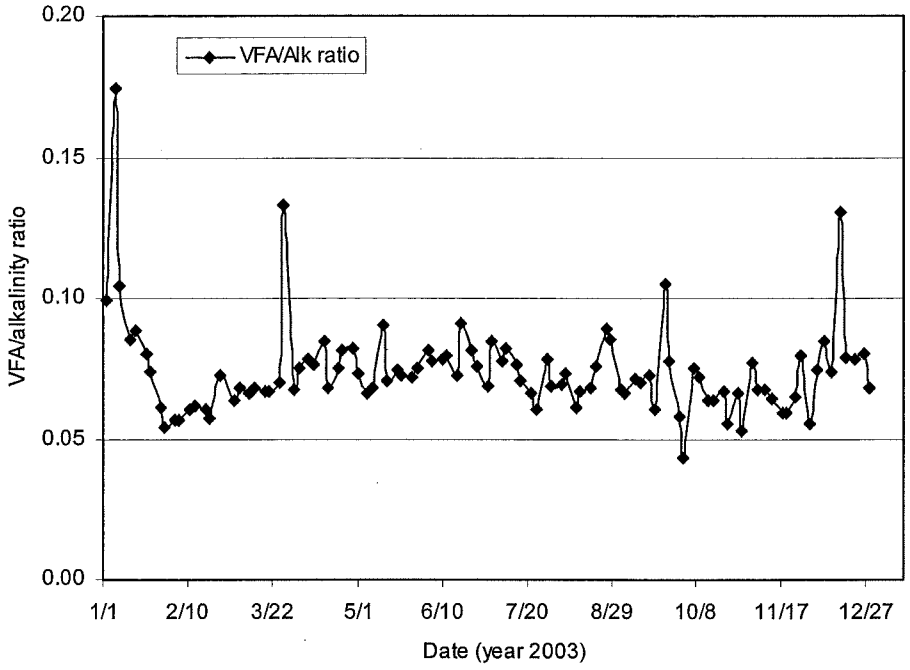

Figure 10. pH in first-stage digesters.

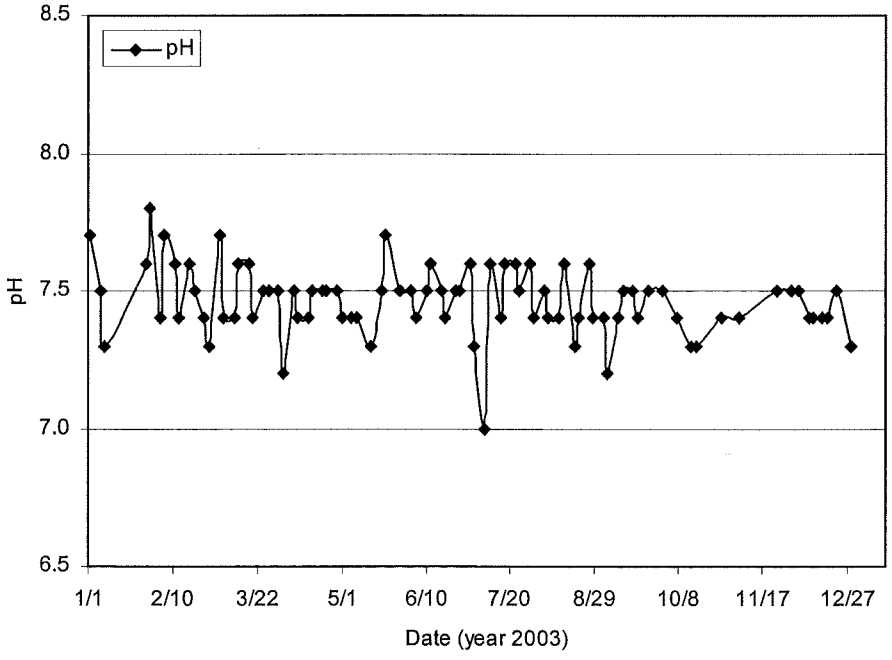

Figure 11. Volatile solids destruction by thermophilic anaerobic digestion.

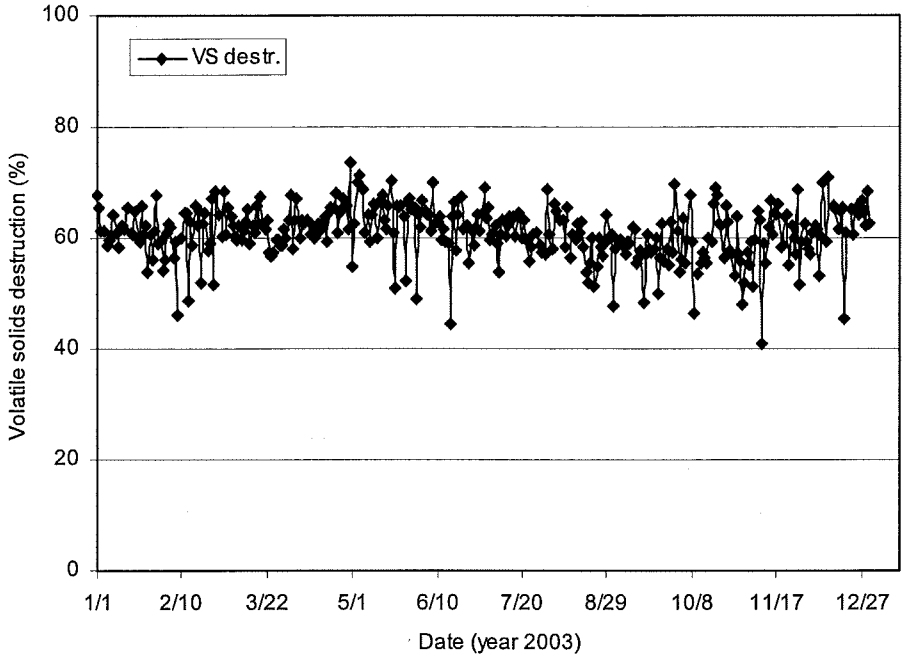

Figure 12. Digester gas production by thermophilic anaerobic digestion.

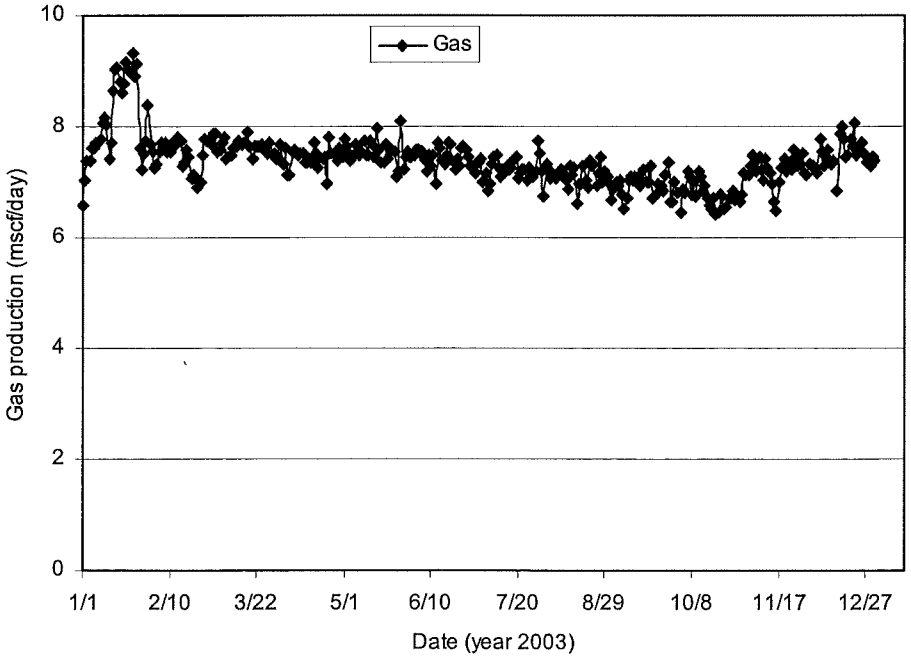

Figure 13. Monitoring of fecal coliforms in biosolids.

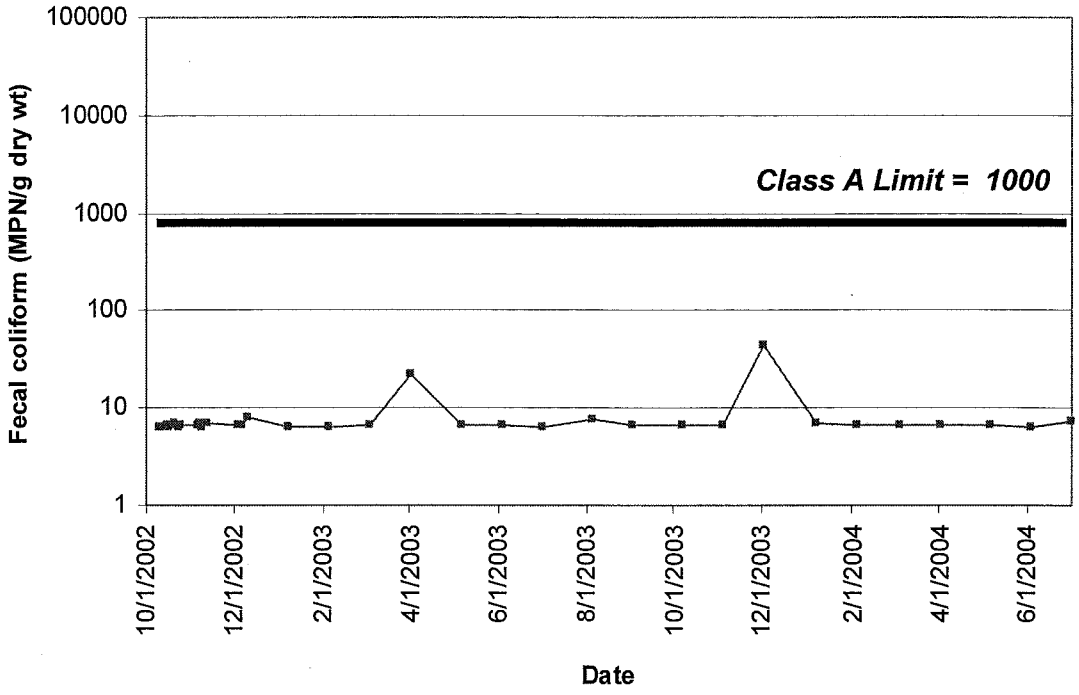

Figure 14. Monitoring of *Salmonella* sp. in biosolids and raw sludge.

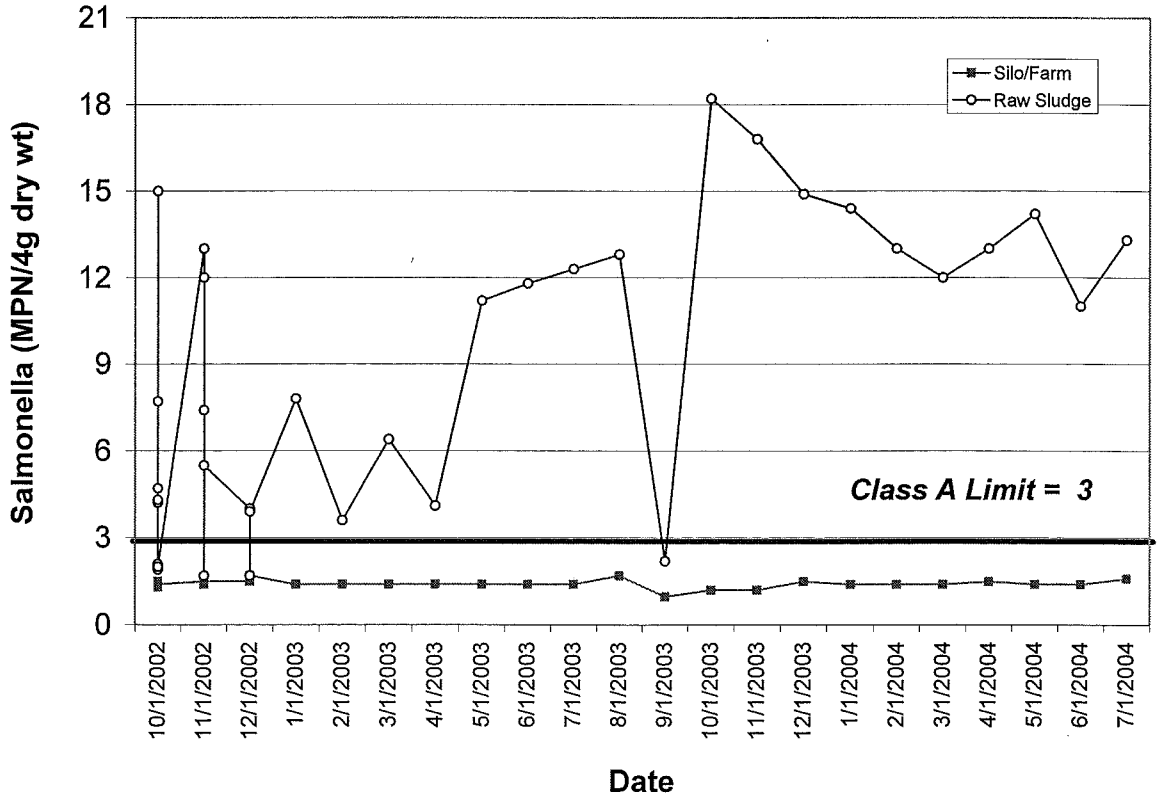

Figure 15. Monitoring of viable helminth ova in biosolids and raw sludge.

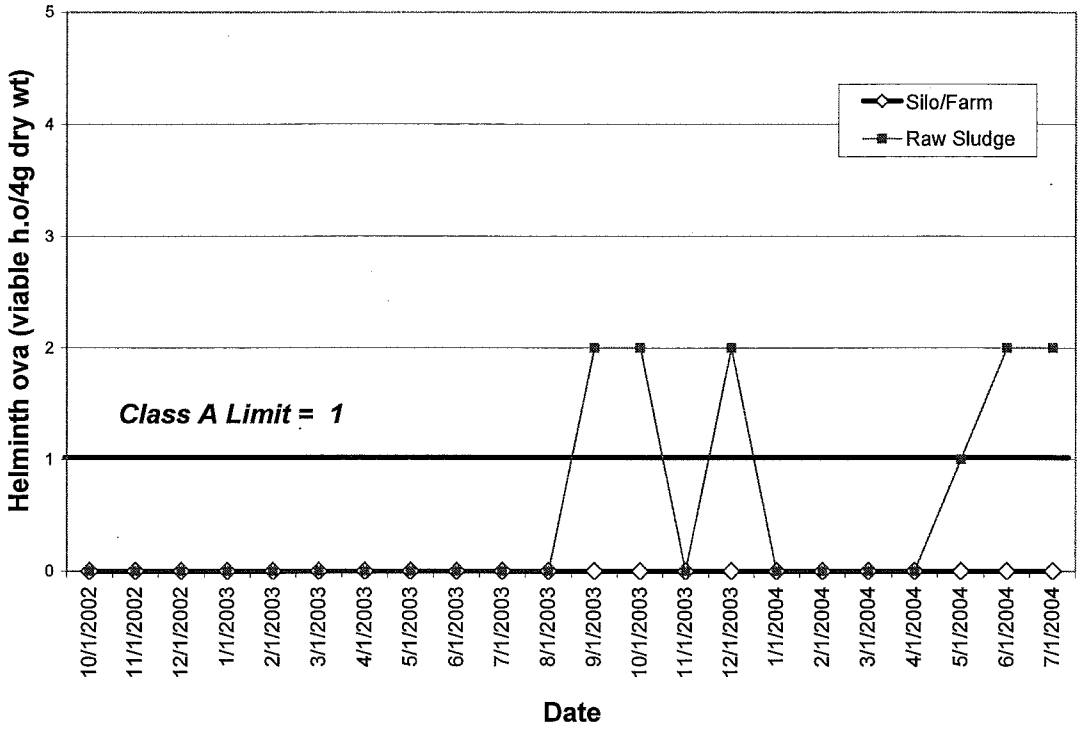

Figure 16. Monitoring of enteric viruses in biosolids and raw sludge.

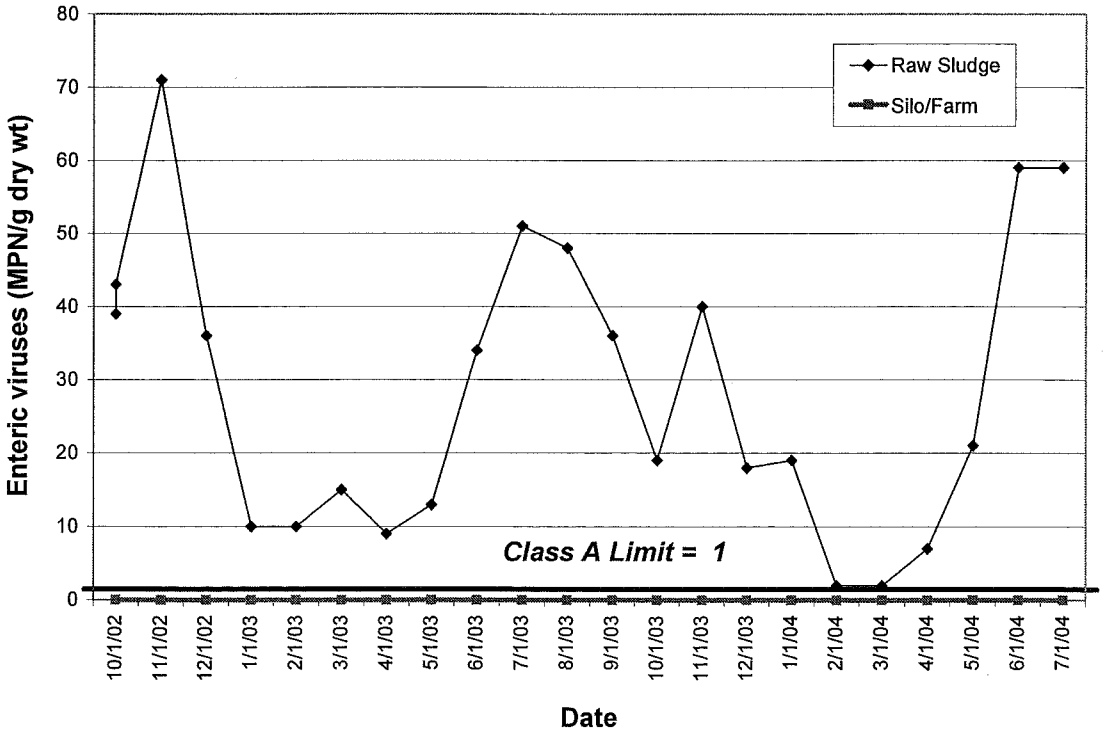

Figure 17. Bench-scale unit for disinfection tests for PFRP equivalency (one of six reactors).

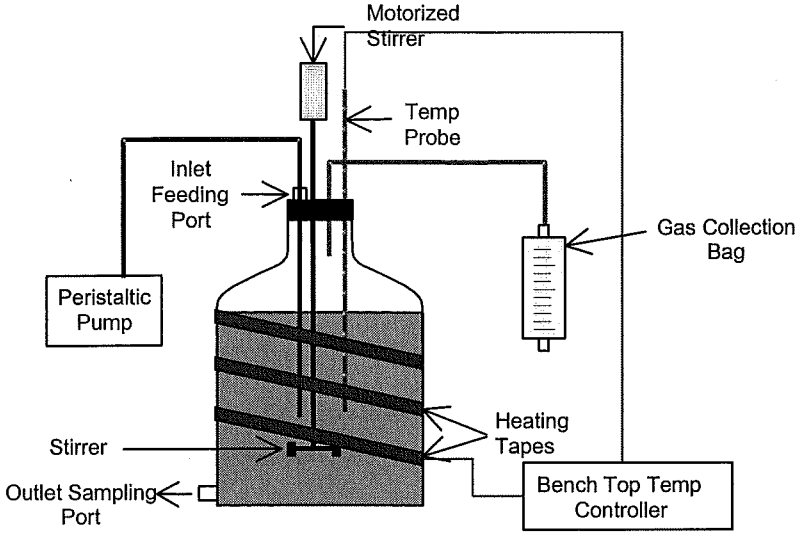

Figure 18. Time-temperature combinations of first series of disinfection tests for PFRP equivalency.