Class A Biosolids

Terminal Island Treatment Plant

DRAFT

Interim Report I

July 2000

Terminal Island Treatment Plant and
Applied Research Group, WESD
Bureau of Sanitation, Public Works
City of Los Angeles

CITY OF LOS ANGELES
INTER-DEPARTMENTAL CORRESPONDENCE

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SUBJECT: Class "A" Biosolids at Terminal Island Treatment Plant: Interim Report I

This is the first interim report on the progress of thermophilic operations to produce a Class "A" Biosolids at Terminal Island Treatment Plant (TITP). This report covers the operations from middle-February to early May 2000. As noted in the report the thermophilic operations so far has been very successful. Other interim reports will follow to update the operation of Class "A" Biosolids at TITP.

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The following have been instrumental in the success of the project, in particular, the Environmental Monitoring Division Staff, and the volunteer engineers. Perry Schaffer from Brown and Caldwell has also been helpful.

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EXECUTIVE SUMMARY

This is the first interim report on the thermophilic sludge digestion project at Terminal Island Treatment Plant (TITP), covering the period up to early May, 2000. A second report is planned that would cover the results from May through July and additional topics, such as gas production, detailed economic analyses, and measurement and instrumentation issues, that have not yet been addressed, due to a combination of time pressure and the need to wait for the process to stabilize.

This project is being conducted by a task force composed of personnel from plant management and operators, the Applied Research Group, the Environmental Monitoring Division, Bureau of Sanitation management, consultants, and laboratory personnel from UCLA. The preparations began in early 1999 with a review of approximately two hundred research papers on previous studies of thermophilic digestion. This has been supplemented with consultation both with academic experts and with some of the engineers and operators who are responsible for currently operating thermophilic digestion systems in waste treatment plants in the United States and other countries. The protocols were revised three times before the final version was distributed in January, and the full-scale project began shortly after, in February, 2000.

As described below, the project has been highly successful so far, **meeting the USEPA Class A standard for coliform count, as defined in Federal regulation 40 CFR 503 and further discussed in several USEPA publications.** *Salmonella* tests have also been done, obtaining readings that are small fractions of the limit for this pathogen. Work to verify compliance with the rest of the pathogen standard alternative is in progress; we know that the 38% VS reduction standard for reducing vector attraction is being met; and we also anticipate carrying out the heavy metal testing included in the original protocols, which would allow assessing the prospect of gaining exceptional quality certification. The system is digesting the current feed rate so well that it seems certain that the whole plant production can be processed.

The City of Los Angeles Bureau of Sanitation previously conducted thermophilic digestion at Hyperion, as reported in the historically important papers of Garber and his colleagues. However, those periods were ended by changing economic and regulatory conditions, and present knowledge indicates that the slow heating rates at the startups produced an undesirable culture in the digesters.

The present study at TITP has been conducted with rapid heating and with attention to recent experience that provides guidance in feeding methods that maximize the rate of culture development. Four feeding plans have been used during the project to date, raising the feeding rate from near 30,000 gallons per day to the present level near 100,000 gallons per day. The development of the culture has followed a course similar to that seen at many other successful plants, with an initial rise of acid concentration as acidogenesis exceeded the activity of the methanogens, and a later decline and approximate stabilization of the acid concentration as the activities of the microbial communities came into balance. Balance was achieved in less than two weeks. A number of operational difficulties have been observed, but remedies are known for all of them, and plans have been made to carry out these remedies.

The chemical parameters have been stable since early in the startup period, indicating that a stable biological community has been established that has been able to increase in numbers to meet the increases in the feed rate. Likewise, disinfection has been effective for several weeks, and the combination of low VFAs and low hydrogen sulfide in recent weeks is good news for odor control. The following items summarize the conclusions from the data described in the report.

a. After the initial period of high concentrations, the VFA concentrations have stayed nearly stable despite several large increases in the feed rate.
b. The pH and alkalinity fluctuations are well correlated, but both are small.
c. The acid/alkalinity ratios have been in the range 0.1 to 0.2 since early March, and have recently been close to 0.1, indicating a healthy digester culture.
d. The gas composition has been nearly stable at around 65% methane and 35% carbon dioxide, which are typical for biogas systems.
e. Hydrogen sulfide concentrations in the gas have been low since early March, and declined further after early April.
f. The coliform count has exceeded the class A limit on only a statistically insignificant number of occasions, and since the middle of April it has held steady at around 100, one tenth the Class A biosolids limit requirement.

The stable low coliform counts make it very likely that the *Salmonella* concentrations in the product biosolids would have been low or undetectable if the tests for this organism had been made at the same time. We have also begun *Salmonella* testing, with favorable results so far, and soon will be testing for enteric viruses and helminth ova to verify compliance with the other pathogen specifications of Alternative 4 of the Class A standard (40 CFR 503.32 (a) (6)), since the timing of the drawing and filling does not guarantee that all the sludge meets the time-temperature relation in Alternative 1 (40 CFR 503.32 (a) (3)), as described in the Legal Background section. (Appendix I of the full report contains relevant excerpts from 40 CFR 503, and other EPA documents, such as USEPA (1994) Plain English Guide to the EPA Part 503 Biosolids Rule (EPA/832/R-93/003) have also been consulted in preparing the report.)

Measuring the pathogen content of the incoming sludge would provide additional insight into the disinfection effectiveness of the process. The separation of the sludge input and withdrawal pipes in the digester, combined with the relatively slow rate of mixing by the recirculation system, guarantees that the transit time from input to withdrawal is never less than several hours, even if drawing and filling are simultaneous. Direct contact between the sludge and the steam that is injected for heating during recirculation may also contribute to the good disinfection results that have been observed. In view of these complexities, determining the actual reduction factors achieved by this reactor as a function of temperature and feed rate will be critical for future efforts to improve efficiency while maintaining product quality.

We recommend:

a. Continuation of the study with efforts to remedy the observed operational difficulties and reduced frequency of monitoring of the current set of parameters, now that stable operation appears to have been achieved.

b. Carrying out planned measurements of enteric viruses and helminth ova to verify full compliance with Alternative 4.

c. Preparation for a meeting with Brown and Caldwell and the EPA experts for more information on obtaining Class A certification.

d. A period of modified operation in which Digester #2 is used for storage, to provide additional retention time, VS reduction, and gas production.

e. Now that the thermophilic process is stable, comparison of the existing thermophilic and mesophilic operations by simultaneous testing of important parameters.

f. Completion of other planned aspects of the study, such as investigation of gas production, detailed economic analyses, and measurement and instrumentation issues.

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KEYWORDS AND ACRONYMS

KEYWORDS

Alkalinity
Class "A" Biosolids
Enteric Virus
Fecal Coliform
Feed rate
Digester gas
Helminth ova
Mesophilic
Pathogen
Salmonella
Thermophilic
Two-phase anaerobic digestion
Volatile acid
Viruses
40 CFR, Part 503

ACRONYMS

BOE	Bureau of Engineering, City of Los Angeles
BOS	Bureau of Sanitation, City of Los Angeles
CFR	Code of Federal Regulation
CH_4	Methane
CO_2	Carbon Dioxide
EEL	Environmental Engineering Laboratory at UCLA
EMD	Environmental Monitoring Division, Bureau of Sanitation, City of Los Angeles
EQ	Exceptional Quality
EXE	Executive Division, Bureau of Sanitation or Engineering, City of Los Angeles
GPD (gpd)	Gallon per day
GPM (gpm)	Gallon per minute
HRT	Hydraulic Retention Time
H_2S	Hydrogen Sulfide
HTP	Hyperion Treatment Plant, City of Los Angeles
MPN	Most Probable Number
MG/L (mg/l)	Milligrams per Liter
ORP	Oxidation/Reduction Potential
PFU	Plaque-forming Unit

TITP	Terminal Island Treatment Plant, City of Los Angeles
TSS	Total Suspended Solids
UCLA	University of California, Los Angeles
USEPA	United State Environmental Protection Agency
VFA	Volatile Fatty Acids
VS	Volatile Solids
VSS	Volatile Suspended Solids

Section 1

INTRODUCTION

This is the first interim report on the thermophilic sludge digestion project at Terminal Island Treatment Plant (TITP), covering the period up to early May, 2000. A second report is planned that would cover the results from May through July and additional topics, such as gas production, detailed economic analyses, and measurement and instrumentation issues, that have not yet been addressed, due to a combination of time pressure and the need to wait for the process to stabilize.

This project is being conducted by a task force composed of personnel from TITP Plant management and operations, Applied Research of Wastewater Engineering Services Division, the Environmental Monitoring Division, Bureau of Sanitation management, consultants and laboratory personnel from UCLA and Bureau management. The preparations began about fifteen months ago with a review of approximately two hundred research papers on previous studies of thermophilic digestion. This has been supplemented with consultation both with academic experts and with some of the engineers and operators who are responsible for currently operating thermophilic digestion systems in waste treatment plants in the United States and other countries. The protocol was revised three times before the final version was distributed in January (Iranpour et al., 2000), and the full-scale project began shortly after, in February 2000. As described below, the project has been highly successful (chemically and biologically very stable) so far, meeting the Class A standards for coliform count, *Salmonella* and digesting the current feed rate so well that it seems certain that the whole plant production can be processed.

The Los Angeles Bureau of Sanitation has a long history of involvement with thermophilic digestion. Garber (1954) and Garber, et al. (1975) are historically important as reports on large-scale operational uses of thermophilic digestion that were highly unusual if not unique in the United States for their times. Nevertheless, changing economic, demographic and regulatory conditions led both times to a return to purely mesophilic processing at Hyperion after only a few years. Now that the Bureau is conducting a new project in response to new pressures to produce biosolids that meet the Class A standards, it is able to do so with a much more thorough understanding of the biology and chemistry of thermophilic digestion than what was used in the past (*e.g.*, Schmidt and Ahring, 1991ab-1994ab).

In retrospect it is clear that the first period of thermophilic digestion, in the middle 1950's, coincided with some of the research on anaerobic degradation chemistry that was summarized by Andrews and Pearson (1963) and McCarty (1964), and now is incorporated into standard textbooks, such as Stronach, et al. (1986), and shorter works, such as Boone (1989). This research provides useful perspective not only on the work reported in the Garber papers but on the observations reported in, for example, Pohland and Bloodgood (1963), showing that the tendency of thermophilic digesters to go sour can be represented by kinetic equations in which the conversion of food chemicals to VFAs occurs with a larger kinetic constant than the conversion of VFAs to methane and the other mineral end products.

Combining these results with others dating as far back as the classic paper of Fair and Moore (1934) makes it possible to appreciate that the temperature dependencies reported in both Garber papers were anomalous for thermophilic digestion. These results almost certainly indicate that the slow heating used by Garber and his colleagues led to development of a culture dominated by thermotolerant mesophilic organisms rather than true thermophiles, as may be inferred from Aitken and Mullenix (1992).

Such a culture is unacceptable for producing Class A biosolids under contemporary conditions, because it cannot operate at the temperatures of 55^{o}C or higher that are likely to be needed to achieve the required pathogen kill factors in digesters with continuous drawing and filling. Hence, the present study at TITP has been conducted with rapid heating and with attention to recent experience (such as in Ahring (1994)) that provides guidance in feeding methods that maximize the rate of culture development.

A brief summary of the Class A standard has been presented in the project protocols in February, 2000. They discussed the relevant portions of Federal regulation 40 CFR 503 (USEPA, 1993), which also includes additional requirements for metals content and reduction of vector attraction. Although the objectives of this project do not include meeting the other specifications of 40 CFR 503, it seems worth noting that we are meeting or exceeding the 38% volatile solids reduction option in the vector attraction specification. Hence, if the metals limits are also met then TITP will be producing biosolids that are exempt from the general regulation and mamgement practices mandated in 40 CFR 503. Such bioslids are said to be of exceptional quality (EQ). Obtaining this rating could be valuable, so we hope to obtain some metals measurements in the near future.

We believe that it will eventually be useful to compare these results with those from two-phase anaerobic digestion systems (e.g., Ghosh (1998), Hagley (1998), Huyard, et al. (1998), Meredith, et al (1998), Wilson and Dichtl (1998)). We also hope that in the long run some of the future research projects will provide more insight into the biological composition of the culture that has developed, especially the methanogens and other archaea (Madigan, et al., 1999). However, our only currently planned modification of operation is to test using Digester #2 for storage, to see whether it can provide additional operational flexibility by increasing retention time, VS reduction, and gas production (Appendix 2).

The following sections summarize the legal background, the experimental setup and procedures, the destruction results, with an analysis of the expected economic impact of increased volatile solids destruction, the sludge heating scheme, operational issues that have arisen, the feeding history, a discussion of a number of plots of measurements made during the test program, our conclusions, and our recommendations. All in all, our effort so far (5/3/2000) at TITP has been highly successful.

Section 2

LEGAL BACKGROUND

This section summarizes the legal requirements that are quoted in more detail in Appendix I. The statement of the six alternatives for the Class A pathogen standard constitutes §32 of 40 CFR 503 (USEPA, 1993, pp. 48-52). We list the conditions that are potentially relevant for TITP to produce biosolids in Class A, and hence suitable for unrestricted use.

1. Either the concentration of fecal coliforms is never to exceed 1,000 MPN (Most Probable Number) per gram of total dry solids or the concentration of *Salmonella* is never to exceed 3 MPN per 4 grams of total dry solids. This is item (i) for each of the six alternatives (*e. g.*, §503.32 (a) (3) (i) (USEPA, 1993, p. 49).

2. One of the following conditions must be met:

   Since the sludge at TITP is less than 7% solids, the relevant subsection giving the time-temperature relationship is the fourth case in Alternative 1, §503.32 (a) (3) (ii) (D) (USEPA, 1993, p. 49).

   a. (Alternative 1) For a temperature T in degrees Centigrade that is at least 50°C, digestion time D in days is at least

   $$D = 50{,}070{,}000/10^{0.14T}, \qquad (1)$$

   except that if T >67°C then D is always at least 30 minutes (§503.32 (a) (3) (ii) (D) (USEPA, 1993, p. 49)).

   b. (Alternative 4) Microbiological testing verifies that enteric virus concentration is less than 1 plaque-forming unit (pfu) per 4 grams of total dry solids, and helminth ova concentration is less than 1 ovum per 4 grams of total dry solids (§503.32 (a) (6) (ii) and (iii) (USEPA, 1993, p. 51)).

Information about other alternatives is quoted in **Appendix I**.

Section 3

EXPERIMENTAL SETUP / PROCEDURES

Figure 1 shows the existing digesters at TITP. Only one digester (digester 1) was used for thermophilic operation. To avoid permit violations, the mesophilic operation was continued at TITP, using digesters 3 and 4. Digester 2 was removed from service to be cleaned for use if additional thermophilic digestion would be needed or for storage in a two phase digestion. The figure shows heat exchangers, flow recirculation, valve positions, etc.

From the list of parameters suggested for monitoring as outlined in the "Startup Process and Protocols" Report (Feb 2000), the ones that were deemed more important are being currently monitored. Three different laboratories are used for the analysis of the monitored parameters. The Environmental Monitoring Division (EMD) Laboratory at the Hyperion Treatment Plant (HTP) is in charge of measuring the levels of fecal coliforms and *Salmonella* as well as CH_4 and CO_2 present in the samples. The EMD laboratory at the Terminal Island Treatment Plant (TITP) does the analysis of alkalinity, VFA, total solids, volatile solids and pH. The Environmental Engineering Laboratory (EEL) at UCLA is in charge of VFA contents of the samples. The information on the methods and instrumentation testing for various components used by the various laboratories to analyze the samples together with the sampling rates are summarized in Table 1.

Unfortunately due to the limited resources available, only an essential set of parameters are currently being monitored. Among the untested parameters we have the Oxidation/Reduction Potential (ORP), the total protein concentration, total Kjeldahl nitrogen, heavy or toxic metals, oil and grease, etc. A partial list of parameters and their descriptions can be found in **Appendix IV** of this Report.

Figure 1. TITP process flow diagram for digester operations.

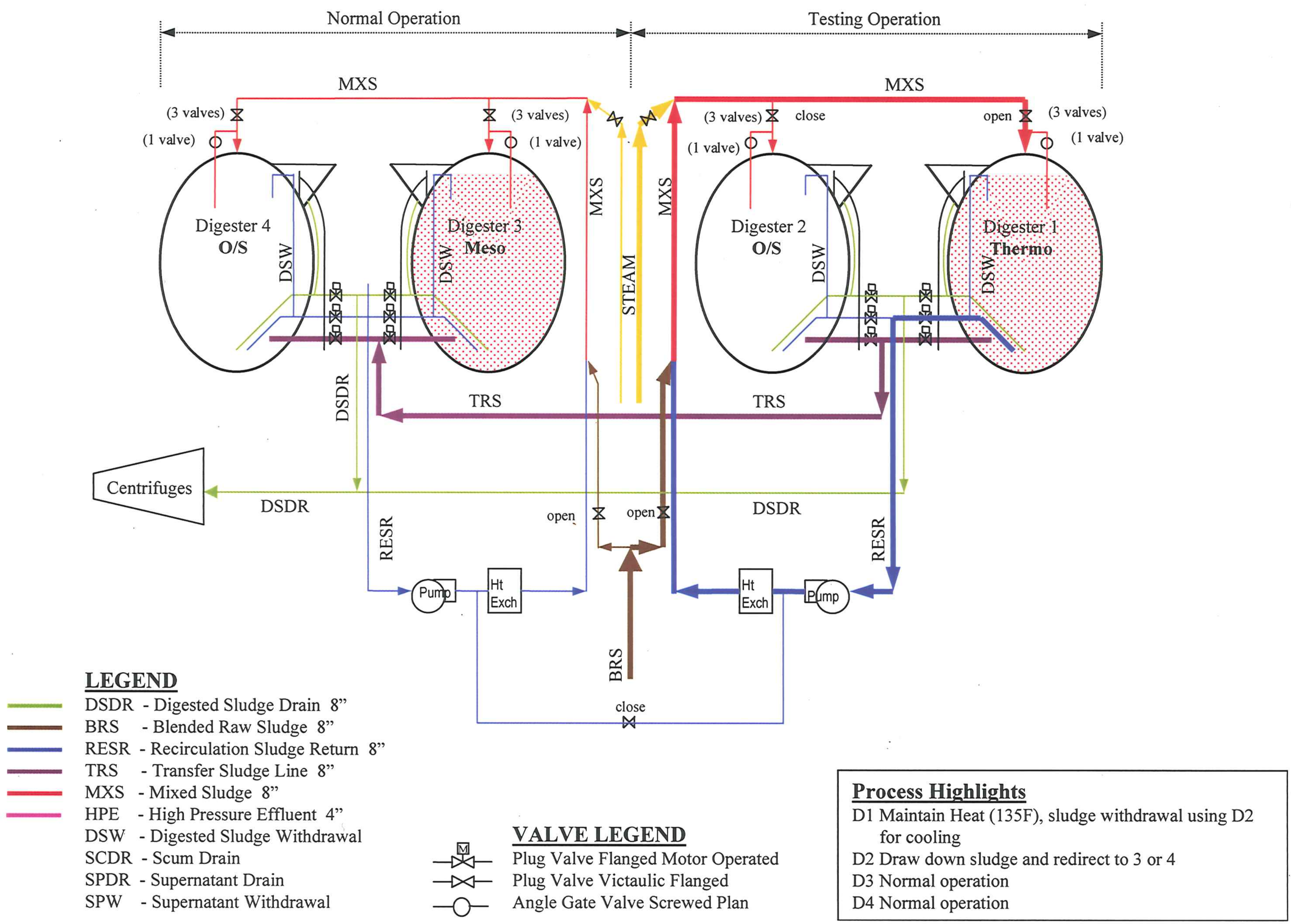


Table 1. Information on lab analysis for selected parameters.

Parameter	Method	Instrumentation	Sampling Frequency
EMD-HTP			
Fecal coliforms	9221 E 2 (Standard Methods, 19th Ed.)		Five days per week
Salmonella	Standard Methods and County Sanitation Distric of LA microbiology procedure.		Once a week
CH4			Daily
CO2			Daily
EMD-TITP			
1. Alkalinity	Titration, SM 2320 B	pH meter	Daily
2. VFA (total)	Distillation and Titration, SM 5560 C	Centrifuge, Distillation Assembly	Daily
3. Total suspended solids	Gravimetric, 1003-105 C, SM 2540 B	Balance, Oven	Daily
4. Volatile suspended solids	Gravimetric, 550 C, AM 2540 E	Balance, Furnace	Daily
5. pH	Electrometric, SM 4500-H B	pH meter	Daily
6. H2S			Daily
EEL-UCLA			
VFA (individual)			Three times per week

Section 4

SOLIDS DESTRUCTION RESULTS AND ECONOMIC IMPACT

Actual data on solids destruction for mesophilic and thermophilic processes have been collected during the simultaneous operations at TITP. The sludge going into each digester came from a common source, assuring that it had the same initial composition. Table 2 shows the data on total solids and volatile solids going into and coming out of the digesters. The table also shows the percent of total solids destruction and volatile solids destruction through the digesters. When comparing the mesophilic and the thermophilic operations, the increase in total solids destruction is 8.6%, the increase in volatile solids destruction is 18.4% and the corresponding increase in gas production is 13.6%.

At first glance one might expect that running a thermophilic operation is more costly than running a mesophilic one due to the fact that the thermophilic process requires substantially more heat. However, if the thermophilic gas production is higher than the mesophilic gas production by a large enough factor, it turns out that the thermophilic operation is less expensive than the mesophilic. This is the case for the thermophilic and mesophilic operations at TITP. One should note that an increase in the gas production induces a reduction in volatile solids, which implies that less polymers are needed in the dewatering process and less wet-cake needs to be stored and or transported. It is then the combination of these factors together with the increase in the value of the gas that make it possible for a thermophilic operation to be less expensive than a mesophilic one. Additional operational costs can be reduced in thermophilic operations if the heat from the digested sludge is recovered via a heat exchanger. This can be implemented by introducing a sludge/sludge heat exchanger where heat from the digested sludge is passed on to the sludge entering the digester. Due to the relatively small temperature differential between the undigested and the digested sludge in the mesophilic operation, a heat exchanger is usually not used for this type of operation.

Figure 2 shows the net savings as a function of increase in gas production if thermophilic digestion (without heat recovery from the sludge) were used at TITP instead of mesophilic digestion. For an increase in gas production of 17%, the yearly savings at TITP would be about $39,500, which extrapolates to $1,063,000 per year under the same conditions at Hyperion Treatment Plant (HTP), Oh et al., (2000). Including sludge heat recovery system would increase the savings more. Combining these calculations with the above field results confirms our expectations about the superiority of the thermophilic operation over the mesophilic one from a financial point of view.

Table 2. Comparion of solids destruction (mesophilic and thermophilic).

Parameters	Blended sludge	Digested sludge	
		Meso	Thermo
TS	3.6%	2.36%	2.26%
VS	75.9%	62.0%	59.0%
TS Destruction rate		33.9%	36.6%
VS destruction rate		48.1%	54.2%
Increase in TS destruction		na	8.6%
Increase in VS destruction		na	18.4%
Expected increase in gas production			13.6%

Figure 2. Economic analysis of mesophilic vs thermophilic operations at TITP.

Section 5

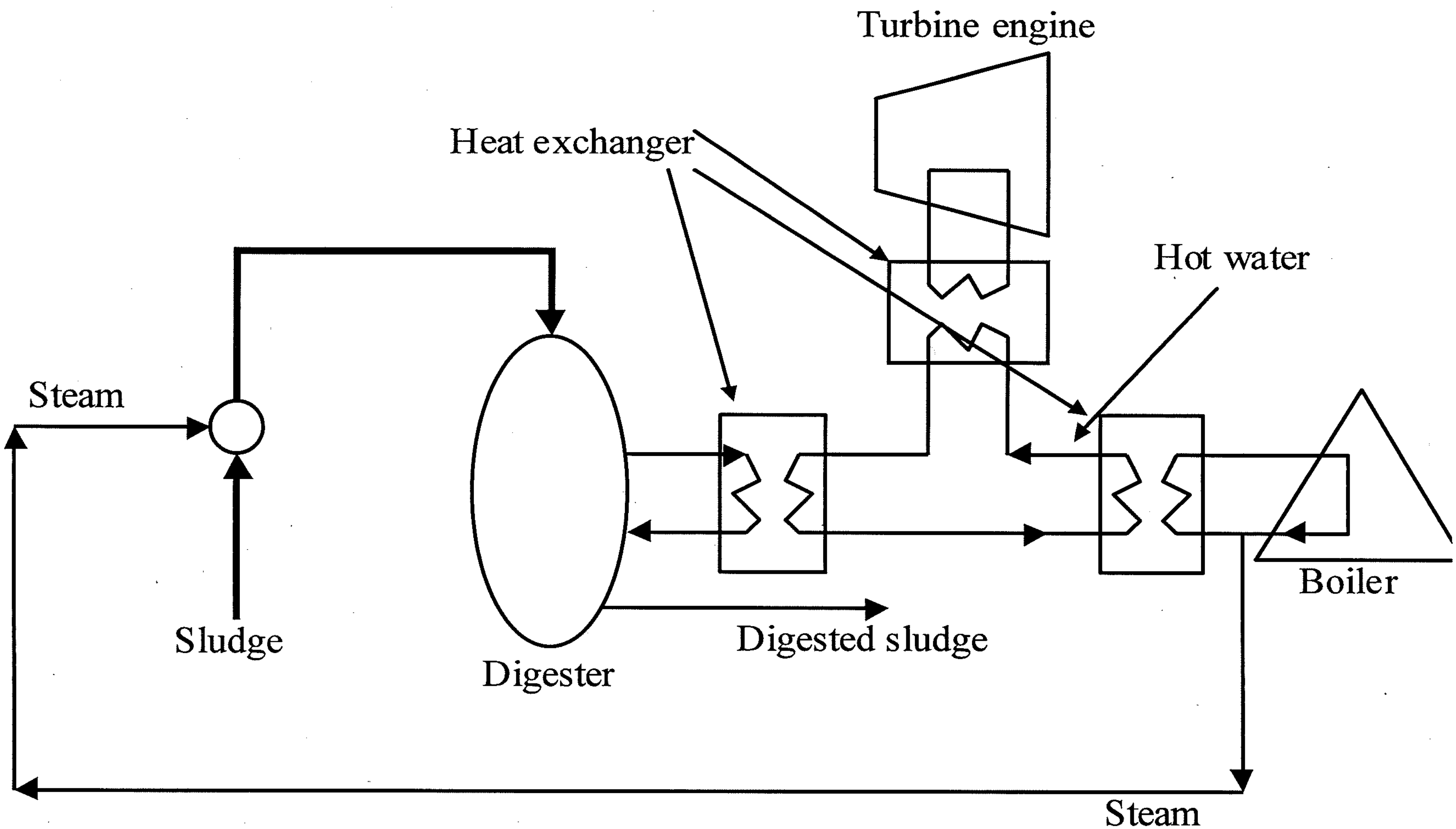
DIGESTER SLUDGE HEATING SCHEME

In order to maintain an optimum thermophilic operation, the sludge inside the digester is to be maintained at an optimum near constant temperature. To maintain this optimum temperature, initially the sludge needs to be heated, and due to the heat losses to the surroundings, additional heat needs to be provided.

The temperature of the sludge inside the digester at TITP is maintained at the optimum operating conditions by adding heat through two different sources. One source of heat comes from steam, which is added directly to the sludge before it goes into the digester. The other source of heat comes from a heat exchanger, where heat from hot water is transferred to the digester sludge. The hot water supply to the sludge/hot water heat exchanger can be heated through any combination of boiler steam or heat generated by turbine engines. The turbine engines can use digester or natural gas as fuel and are used for power generation. The temperature inside the digester can be regulated by controlling the amount of heat added through direct injection of steam into the sludge, or by varying the amount of digester sludge that circulates through the heat exchanger or by changing the heat amount going into the hot water. These heating options provide flexibility in compensating for the heat losses to the environment and also for any variations in the initial sludge temperature. Figure 3a shows the sludge heating scheme used for the thermophilic operation at TITP. Digital pictures of the components of the system appear in Figures 3b through 3f.

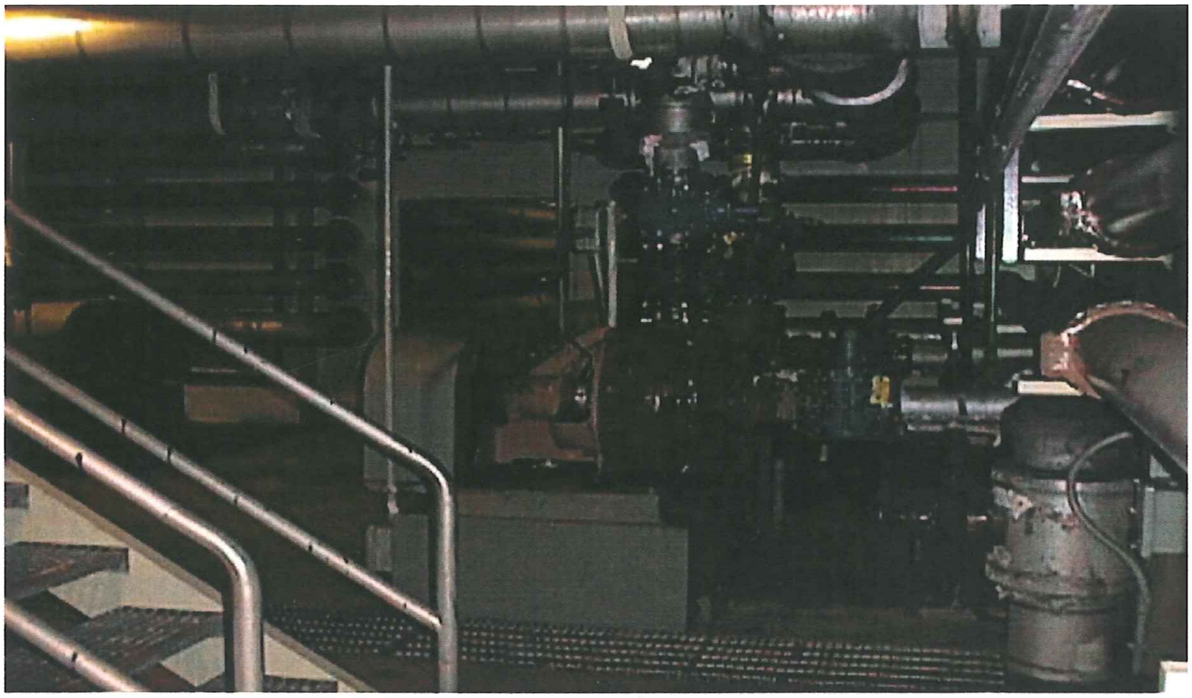
The current sludge heating scheme could be improved by adding a sludge/sludge heat exchanger where heat from the digested sludge is recovered by transferring it to the unheated incoming sludge. The presence of the sludge/sludge heat exchanger would not only be beneficial from an energy-saving-recovery point of view, but it would also help improve the quality of the digested sludge. If the temperature of the digested sludge is lowered (by means of the sludge/sludge heat exchanger), the emission gases will also be lowered improving the odor properties of the digested sludge (Kelly et al., 1999).

Figure 3. Heating scheme for thermophilic operation at TITP.



(a) Total heat system

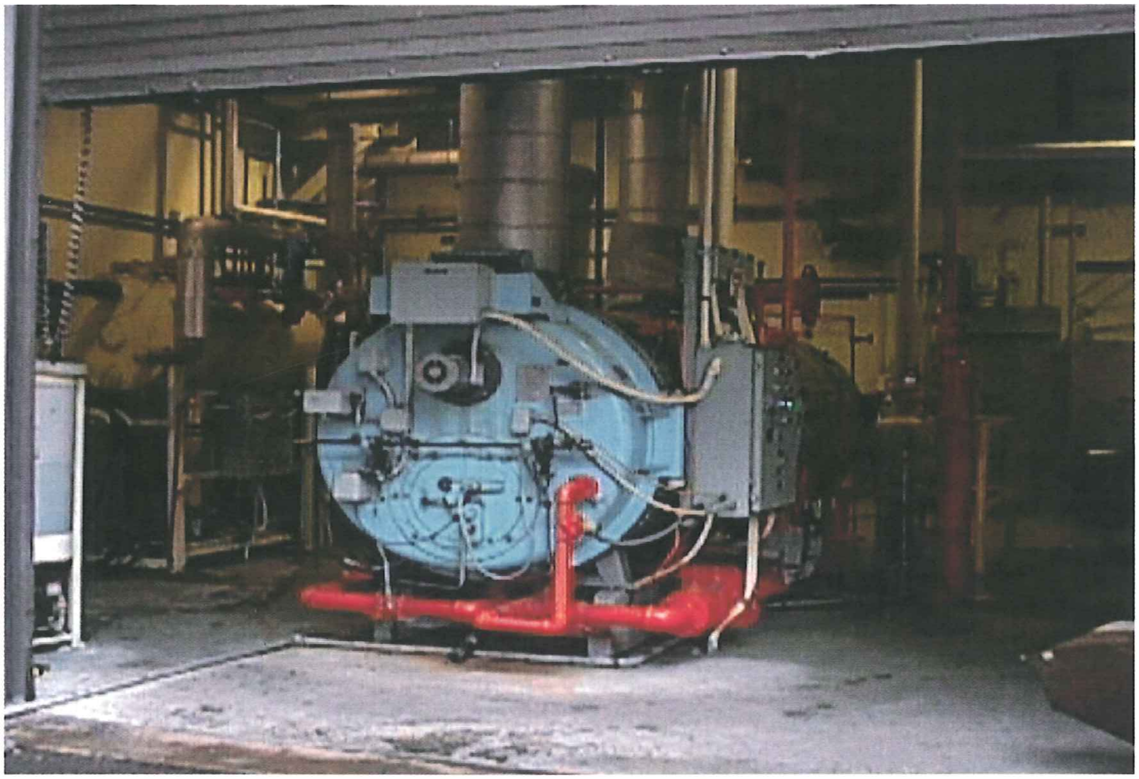
Figure 3. (Continued)



(b) Re-circulation pumps.

(c) Heat exchangers.

Figure 3. (Continued)



(d) Boiler.

(e) Centrifuges

Figure 3. (Continued)

(f) Wet cake from centrifuges to conveyor belts.

Section 6

OPERATIONAL ISSUES

In the course of the startup and stabilization phase of the thermophilic operation several problems have been identified. These problems may be categorized into the areas of heating, sampling, mixing, wasted gas and flow measuring equipment. The following describes these issues and some possible solutions.

A) Heating

1) The boiler used to generate the steam is old, outdated and inefficient. Perhaps a newer, more efficient boiler should be considered to replace the current one.
2) The boiler system is close to its maximum capacity in terms of generating heat. If the heat demand of the system increases, the current boiler may not be able to generate enough heat to sustain the thermophilic operation. A moderate increase in the sludge feed rate or a decrease in the ambient temperature may be enough to create a heat demand that is above the capacity of the current boiler. The addition of a sludge/sludge heat exchanger is an alternative that may be considered for lowering the heat demand of the process.
3) There is no reliable heat generating backup system for the boiler. In case the boiler becomes inoperative for a longer period of time, there is currently no dependable alternative to generate the needed heat. The turbine engines could be used as a source of heat, but they (alone) do not generate enough heat at the required levels and they are not always available (as mentioned in item 4).
4) Due to lack of personnel, the boiler has been turned off periodically for a few days (usually during weekends). This causes a decrease in the digester temperature about 4 to 5^{O}F, creating conditions that are not ideal for the thermophilic sludge digestion. The lack of personnel is also reflected on the unreliability of heat production, since the engines are not permanently staffed with operators.
5) If the boiler for any reason fails to maintain a high enough level of pressure in the steam, sludge flows into the steam lines. This problem usually occurs when the boiler abruptly stops operating. There is a check valve in place, but it seems not to be operating properly. To avoid this problem, a new replacement (or additional) check valve should be installed.

B) **Sampling**

When collecting sludge samples form the digester the sampling line should be flushed for some time before the actual sample is taken. On occasions, the sample was taken without flushing the sampling line. This generated a "contaminated" sample, since the line contained sludge that was in it for some period of time (since the last sampling).

C) **Mixing**

On some occasions the gas compressor system malfunctioned. No mixing through gas was performed during the compressor system downtime. In order to run an appropriate digestion process it is very important that the sludge is properly mixed. The lack of mixing will not only reduce the efficiency of the digestion (and thus gas generation) but it may also create the chance that nearly undigested sludge (with high levels of pathogens) would be drawn from the digester. A thorough check of the gas compression system is suggested in order to evaluate and remedy any possible problem with it

D) **Wasted Gas**

On several occasions it occurred that at the same time the high-pressure gas holder tank was full, and the boiler and the gas engines were inoperative. At these times nothing could be done but to release and burn the additional gas that was being produced by the digester. This waste of resources could be avoided if the gas engines were in operating conditions and staffed with operators most of the time. An alternate solution would be to consider ways to store or transport the gas to other facilities.

E) **Measuring Equipment**

Currently an outdated (magnetic) faulty sludge flow meter is being used to measure the sludge flow. At this time the meter is being tested and evaluated to see if can be calibrated and used again or if it needs replacement. Problems with measuring the gas flow also occurred initially, and they have been solved. Originally there was a single gas flow meter which measured the gas flow coming from all the digesters (it was located at the main gas pipe which channeled the gas coming from all the digesters). The location of the meter made it impossible to differentiate the gas production from the mesophilic and from the thermophilic digester. Additionally, this gas flow meter was delivering questionable readings. These problems were solved by installing two new flow meters; one measuring the flow from the mesophilic digester and the other measuring the gas flow from the thermophilic digester.

Section 7

FEEDING HISTORY

Four feeding plans had been used by May 3. The first, in effect from late February to March 20, is represented by Table 3a, which shows that there were to be two feeding sessions a day, one from 0700 to 0900, and the other from 1500 to 1700, each with a feed rate of 150 gpm. Withdrawal was done from 2300 of one day to 0700 of the next. As shown by the actual feeding history in Figure 4, there were many days between February 23 and March 14 on which the actual amount fed was less than the 36,000 gallons for which this plan calls, and on some days no feeding was done, to allow the culture time to adapt. After March 14 the full dose of 36,000 gpd was used every day.

The second feeding plan was in effect from March 21 to March 28, and is shown in Table 3b. The feed rate was reduced to 130 gpm, but a third feeding period was added from 2300 of one day to 0100 of the next, so that the total fed was 46,800 gpd, and the withdrawal period was reduced to cover the period from 0100 to 0700. The third feeding plan, in effect from March 29 to April 26, reduces the feed rate to 120 gpm and extends each feeding period to three hours, for a total of 64,800 gpd, Table 3c. The withdrawal period overlaps the third feeding period, running from 2300 to 0700. The fourth feeding plan, in effect since April 27, increases the feed rate to 150 gpm and maintains each feeding period to three hours, for a total of 81,000 gpd, Table 3d. The withdrawal period overlaps the third feeding period, running from 2300 to 0700.

Table 3. Feeding and withdrawing schedule for thermophilic digestion at TITP until May 2000.

Time	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	0000	0100	0200	0300	0400	0500	0600
Mode	Feed		No feed & no withdraw						Feed		No feed & no withdraw						**Withdraw** **Mon to Thurs:** Lower digester level to 57' **Fri:** Lower digester level to 52' for weekend feed **Sat & Sun:** No withdraw							
Flow rate	150 gpm								150 gpm								Depends on centrifuge status							

(a) 36,000 gallons per day

Table 3. (Continued)

Time	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	0000	0100	0200	0300	0400	0500	0600
Mode	Feed		No feed & no withdraw						Feed		No feed & no withdraw						Feed		**Withdraw** **Mon to Thurs:** Lower digester level to 57' **Fri:** Lower digester level to 52' for weekend feed **Sat & Sun:** No withdraw					
Flow rate	130 gpm								130 gpm								130 gpm		Depends on centrifuge status					

(b) 46,800 gallons per day

Table 3. (Continued)

Time	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	0000	0100	0200	0300	0400	0500	0600
Mode	Feed								Feed								Feed							
	No withdraw																**Withdraw** **Mon to Thurs:** Lower digester level to 56' **Fri:** Lower digester level to 52' for weekend feed **Sat & Sun:** no withdraw							
Flow rate	120 gpm								120 gpm								120 gpm							

(c) 64,800 gallons per day

Table 3. (Continued)

Time	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	0000	0100	0200	0300	0400	0500	0600
Mode	Feed								Feed								Feed							
	Withdraw			No withdraw													**Withdraw** **Mon to Thurs:** Lower digester level to 56' **Fri:** Lower digester level to 52' for weekend feed **Sat & Sun:** no withdraw							
Flow rate	150 gpm								150 gpm								150 gpm							

(d) 81,000 gallons per day

Section 8

RESULTS

Figure 4 is a plot of the total acid concentration as a function of time, along with the feeding history. This figure shows that the development of the culture has followed a course similar to that seen at many other plants, with an initial rise of acid concentration as the acidogen activity initially exceeded the activity of the methanogens, and a later decline and approximate stabilization of the acid concentration as the activities of the microbial communities came into balance.

The most important feature of this plot is the speed at which balance was achieved. The period of high acid concentration lasted less than two weeks. This is clearly due at least in part to the careful feeding schedule, which started with a relatively low feeding rate and interrupted feeding during the period of imbalance. It is also likely that the initial digester load of mesophilically digested biosolids contained significant numbers of dormant thermophilic microbes, and hence was favorable for development of the needed culture.

As the feeding rate was further increased, the acid concentration rose irregularly in late March and early April, but declined again in the most recent weeks. This is an encouraging result, suggesting that the system will be able to accommodate the rest of the planned increases in the feed rate.

Another view of the chemistry of the digester is provided by Figure 5a, which compares the pH to the alkalinity and the feeding schedule. It is evident that the fluctuations in the pH and alkalinity are well correlated, despite the small magnitude of the pH variations, and that most of the decreases of both parameters are associated with resumptions of feeding after interruptions, or increases after periods of steady feeding. It is also evident from this plot that the pH remained nearly stable at very slightly alkaline values during the whole period of the study, despite the wide variations of acid concentration shown in Figure 4.

Such changes in pH and alkalinity would be expected from the rapid increase of acid production when the acidogens receive an increased supply of food, and the corresponding consumption of alkalinity that neutralizes much but not all of the additional acid. Later, the alkalinity is restored and the pH rises slightly as the methanogens consume the additional acid. Since these fluctuations are small, they show that the digester culture has been adapting successfully to the changes in food supply.

Comparing Figures 4 and 5a suggests what is shown explicitly in Figure 5b, that even at the peak of the acid concentration it was no more than half of the alkalinity, and since the large decrease of the acid concentration in early March the acid/alkalinity ratio has been in the range 0.10 to 0.20, as is typical for healthy digester cultures in both the thermophilic and mesophilic temperature ranges. This figure also confirms that, since the alkalinity has undergone only relatively small fluctuations during the period of the project, the changes in the ratio are primarily due to the changes in the acid concentration, and that the most recent downward trend in the acid concentration has brought the ratio down to the neighborhood of 0.10 or a little less.

Figure 6 shows that the relative proportions of the principal gases produced by the fermentation have fluctuated only modestly since the acid concentration decreased in the early days of March, and have stayed in concentration ranges around 65% CH_4 and 35% CO_2 that are typical for biogas fermentation systems. On the other hand, the first few points provide the most direct observation in these data that methanogen activity was low when the acid concentration was high, since this was the only time when the CH_4 concentration was below 60%, and the CO_2 concentration was correspondingly higher than at any later time.

Laboratory studies have shown that one of the principal mechanisms of methane formation is to cleave an acetate ion, CH_3COO^-, into a CO_2 molecule and, with the addition of a hydrogen ion, a CH_4 molecule; and that some of the CO_2 is then reduced to CH_4 by microbes that live at very low oxidation-reduction potentials. Hence, the concentrations of CO_2 and CH_4 observed here and at other plants are consistent with this fundamental biochemistry of fermentation, and obtaining these gases in these proportions is understood as additional evidence of a healthy digestion culture. The modest trend toward lower CH_4 concentrations and higher CO_2 concentrations in late March and early April and the later return to slightly higher CH_4/CO_2 ratios is consistent with the simultaneous trends in acid concentrations seen in Figures 4 and 5b, implying a temporary reduction in degradation effectiveness with increasing feed rates, and a later adjustment by the culture.

Figure 7 shows that the time history of the H_2S concentration of the gas collected from the digester is related to the variations in acid concentration in Figures 4 and 5b, with a high concentration of H_2S during the period of high acid concentration and much less H_2S once the methanogen activity reached a high level. This is attributed to the competition between the methanogens and the sulfate-reducing microbes that generate the H_2S, since the pH values in the figure show that the H_2S concentration is not well correlated with the pH. The overall decrease in the H_2S concentration in April and May after the transient spike at the beginning of April is consistent with the increased methanogen effectiveness suggested by the decrease in acid concentrations and increase in CH_4/CO_2 ratios already discussed for the previous figures.

Figure 8 shows the coliform concentration as a function of time, with the concentration plotted on a logarithmic scale to accommodate the fluctuations of this concentration over several orders of magnitude, and with the temperature also shown for comparison. Although these parameters are much less well correlated than the correspondence of pH with alkalinity and feedings, the excursions to high coliform levels in early March and early April begin at the time of lowest temperature, and are consistent with the usually assumed exponential dependence of kill rate on temperature. However, the rise in temperature near the end of March is not accompanied by a rapid further decrease in coliform concentration, but is followed, with a lag, by a rise in MPN to more than the Class A standard of 1000 MPN/g TS; another peak occurs just before the middle of April, just before a major decrease in temperature, and the count then stays strikingly constant for the rest of the month and early May, during further wide temperature swings. The coliform counts are also not evidently correlated with the feeding schedule shown in Figure 4. Hence, the available data do not appear to explain fully the observed fluctuations in coliform count.

Figure 9 replots these data with a more compressed vertical scale for the temperature, and with a third trace showing a seven-day running geometric mean of the coliform counts. Horizontal lines showing typical thermophilic and mesophilic temperatures and the Class A coliform limit of 1000 MPN/g TS have also been included. Evidently, except for the period of high counts in early March, the geometric means have been below the Class A limit, showing the insignificance of the brief excursions, but the visual correspondence between the geometric means and the temperatures is not much better than the correspondence between the raw data and the temperatures.

It is possible that some of the earlier results were distorted by regrowth in the pipe from which the samples are taken, since sampling is done by opening a valve that is not directly attached to the digester.. The sampling procedure was revised in April to require running out an adequate quantity of sludge before the sample is collected, to guarantee that the sample consists of material immediately removed from the digester. Since the disinfection value of thermophilic operation is the primary reason for this project, the recent stability of the coliform count near one tenth the Class A limit is also highly encouraging.

This is especially true considering the temperature swings, from which the experience of previous months would have led us to expect a greater effect. The swings are attributed to a lag in adjusting the heat supply to meet the increased thermal load on the digester imposed by the increased feeding rate, since no heat is being recovered from the outgoing to the incoming sludge. We anticipate better control of the temperature in the future.

Figure 4. Time history of total volatile acid concentrations and feed rates.

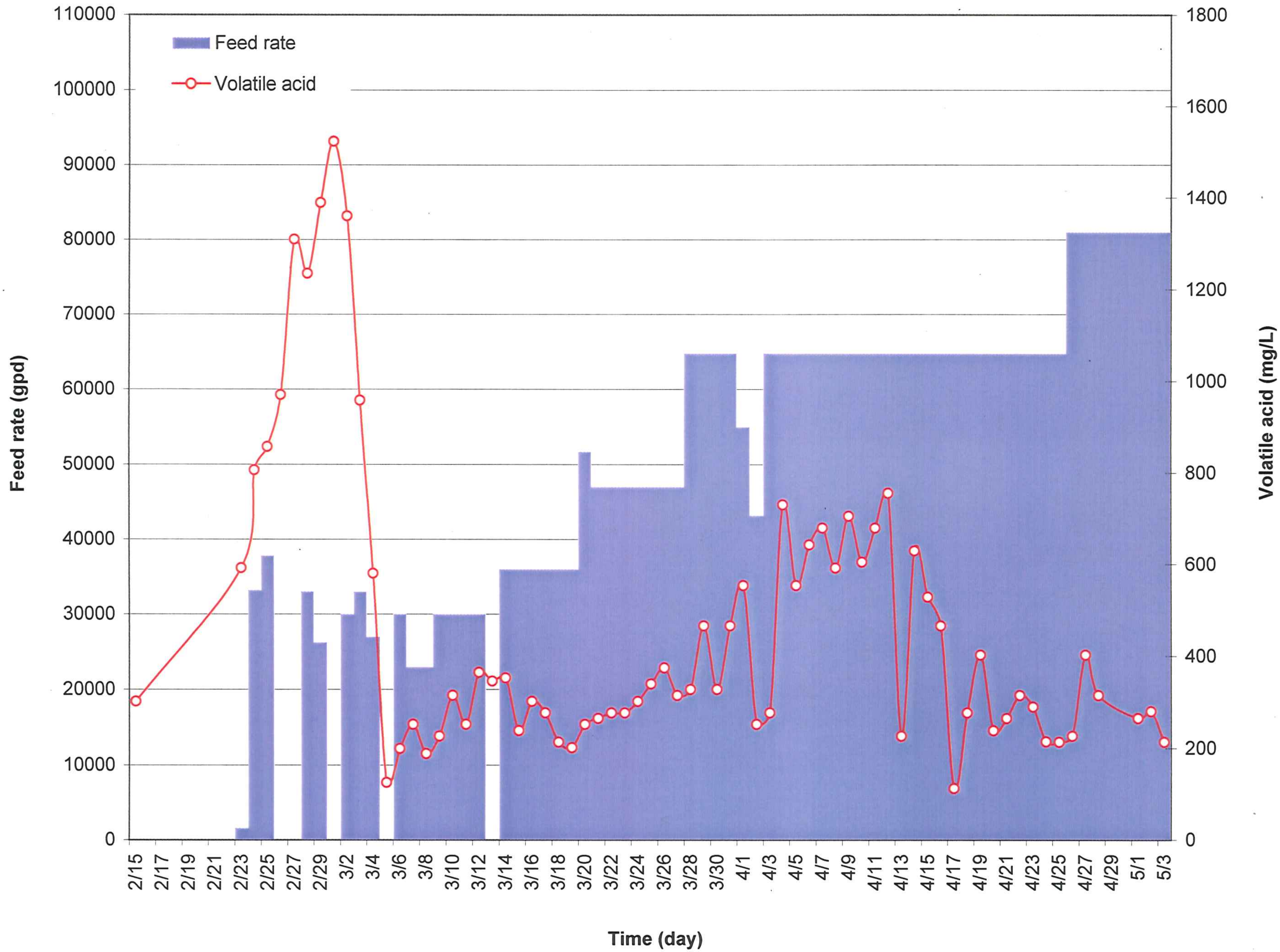


Figure 5a. Time history of alkalinity concentrations and pH's.

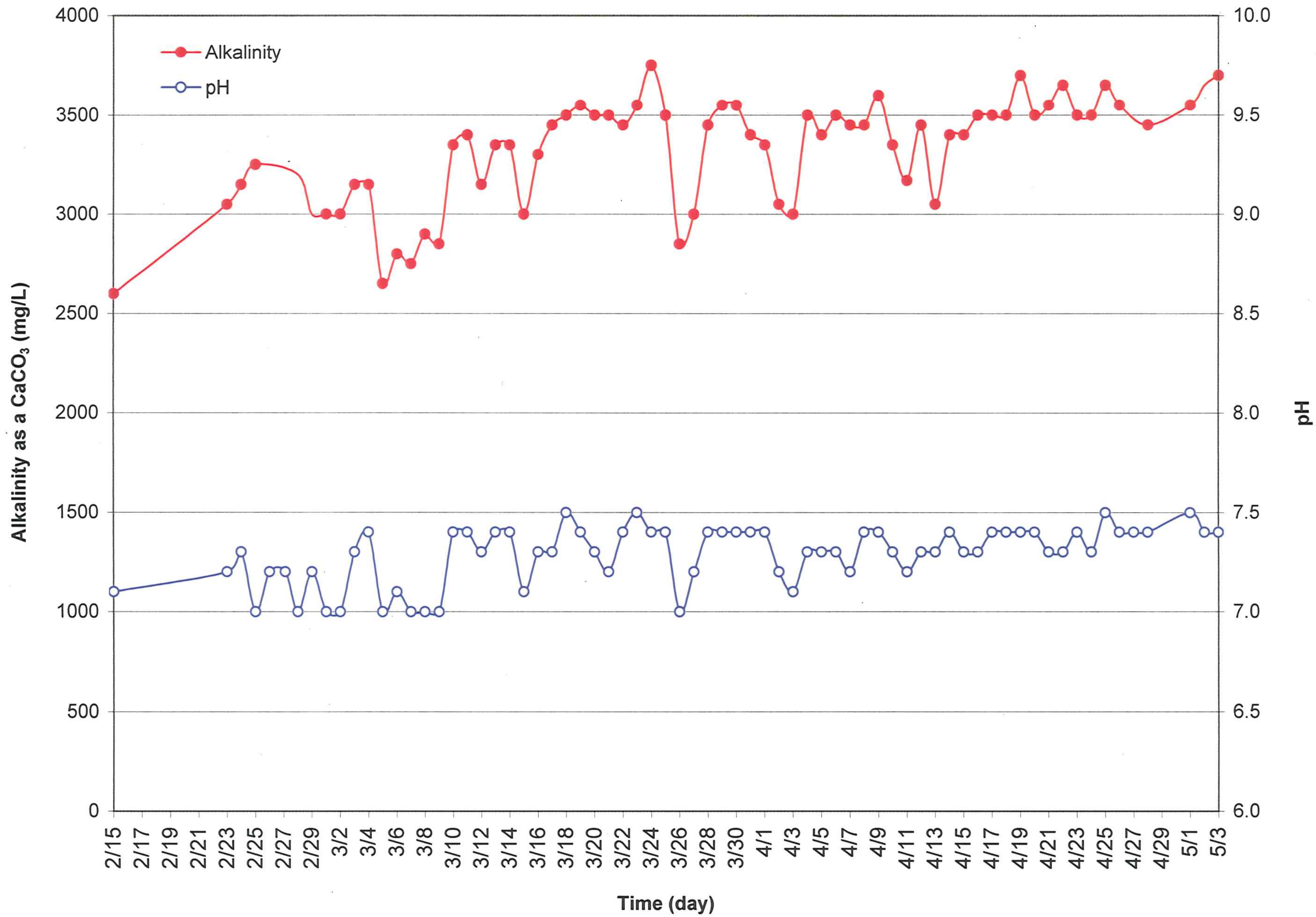


Figure 5b. Time history of volatile acid/alkalinity ratios.

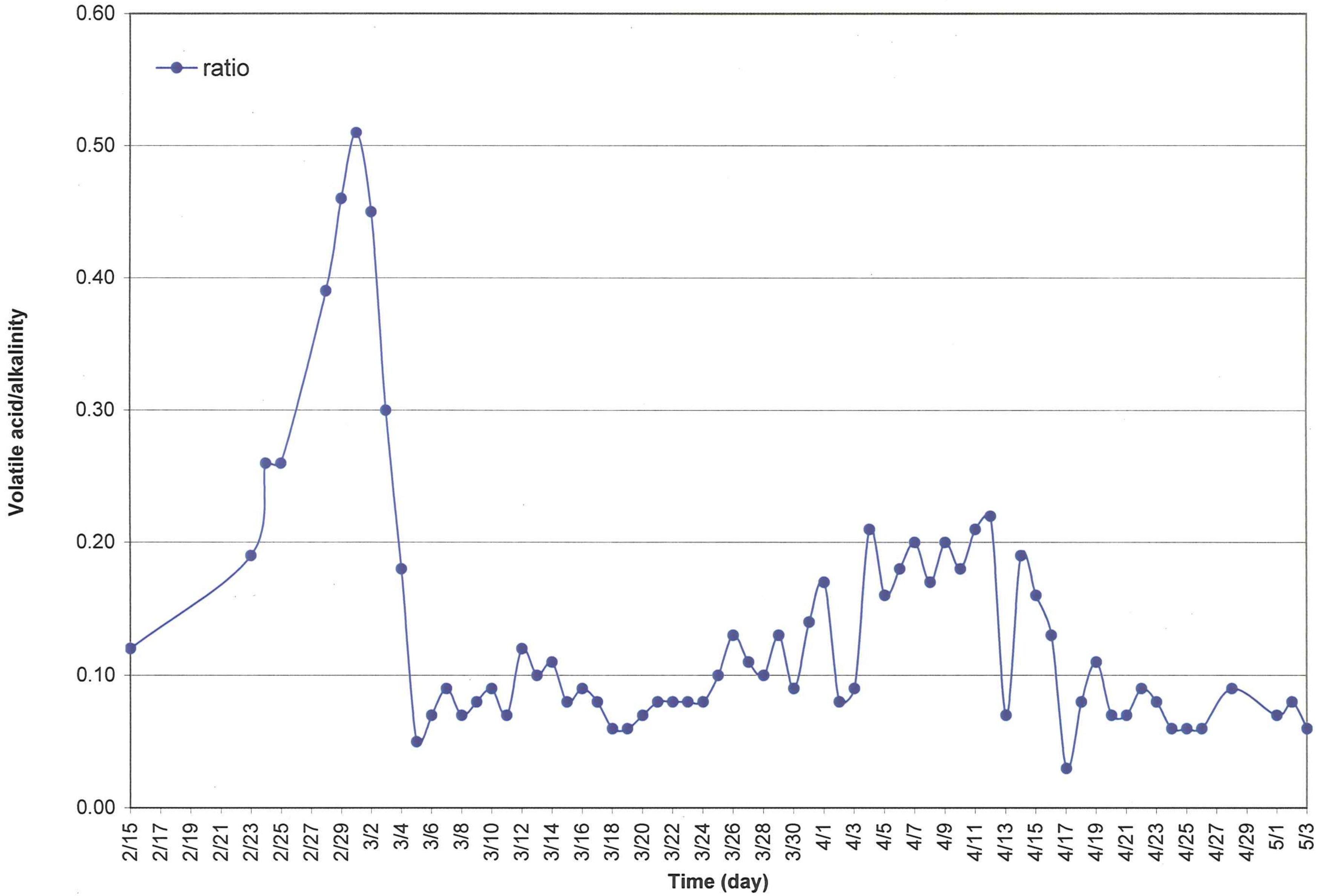


Figure 6. Time history of CH_4 and CO_2 concentrations.

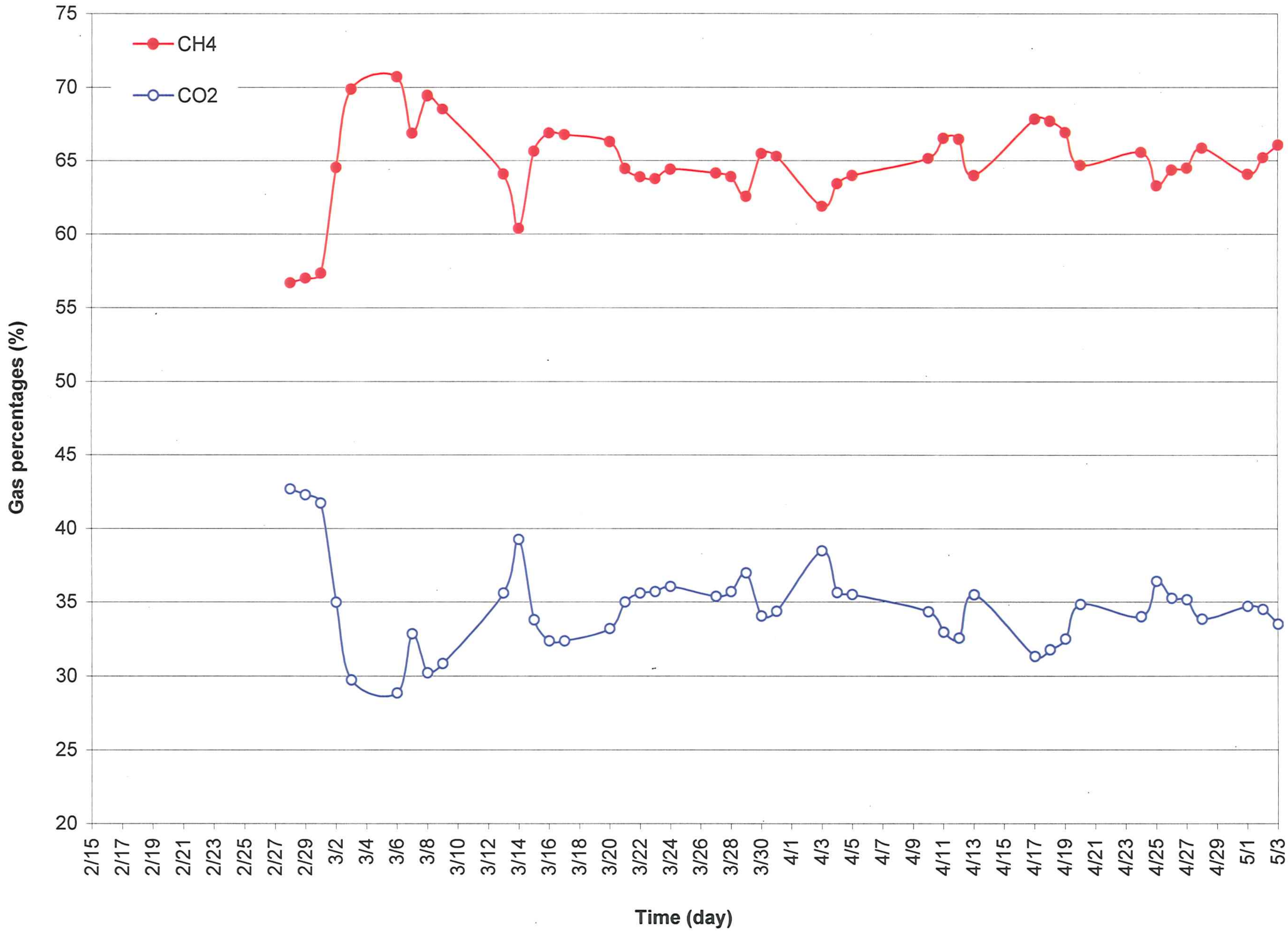


Figure 7. Time history of H_2S concentrations and pH's.

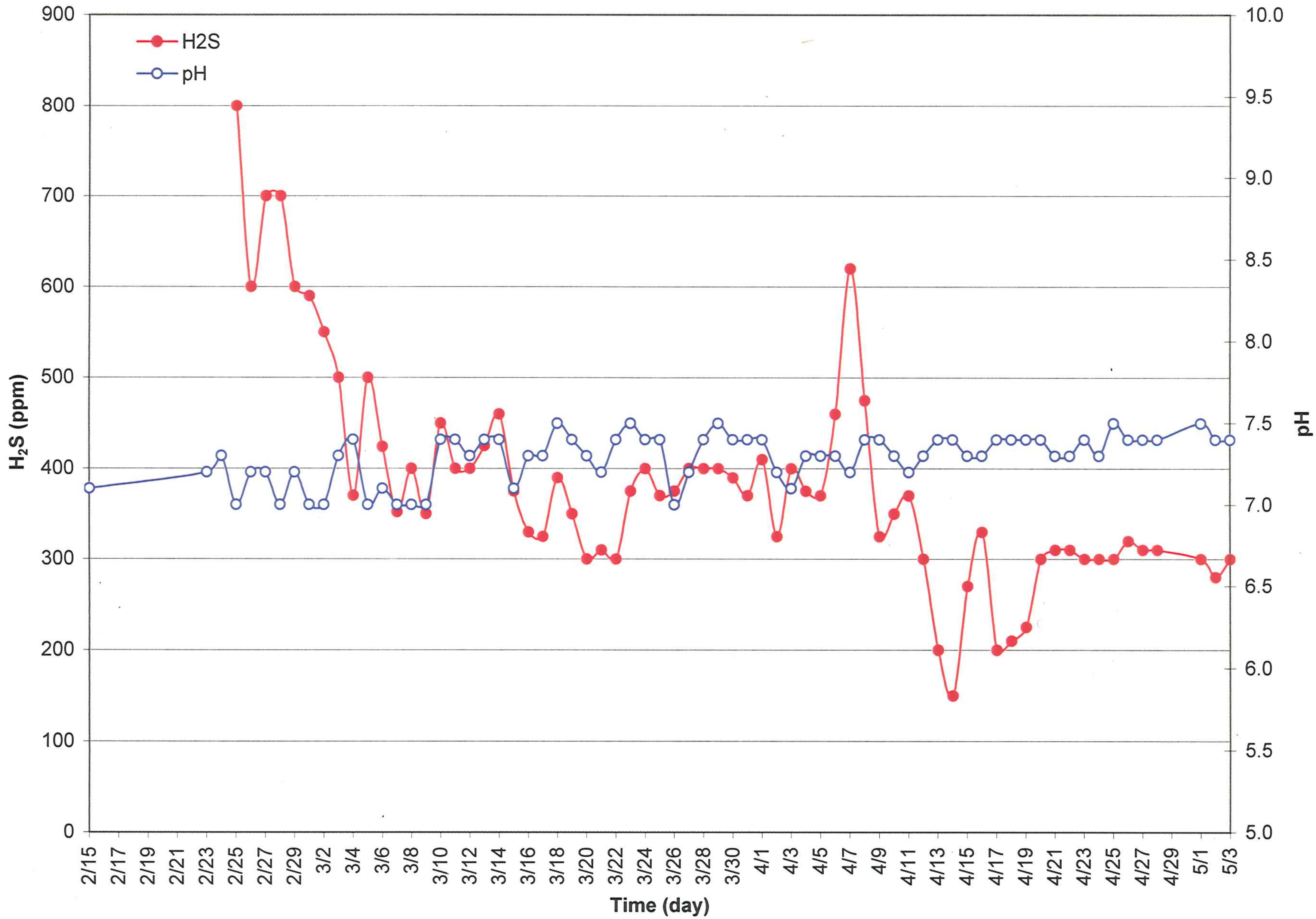


Figure 8. Time history of coliform concentrations and temperatures.

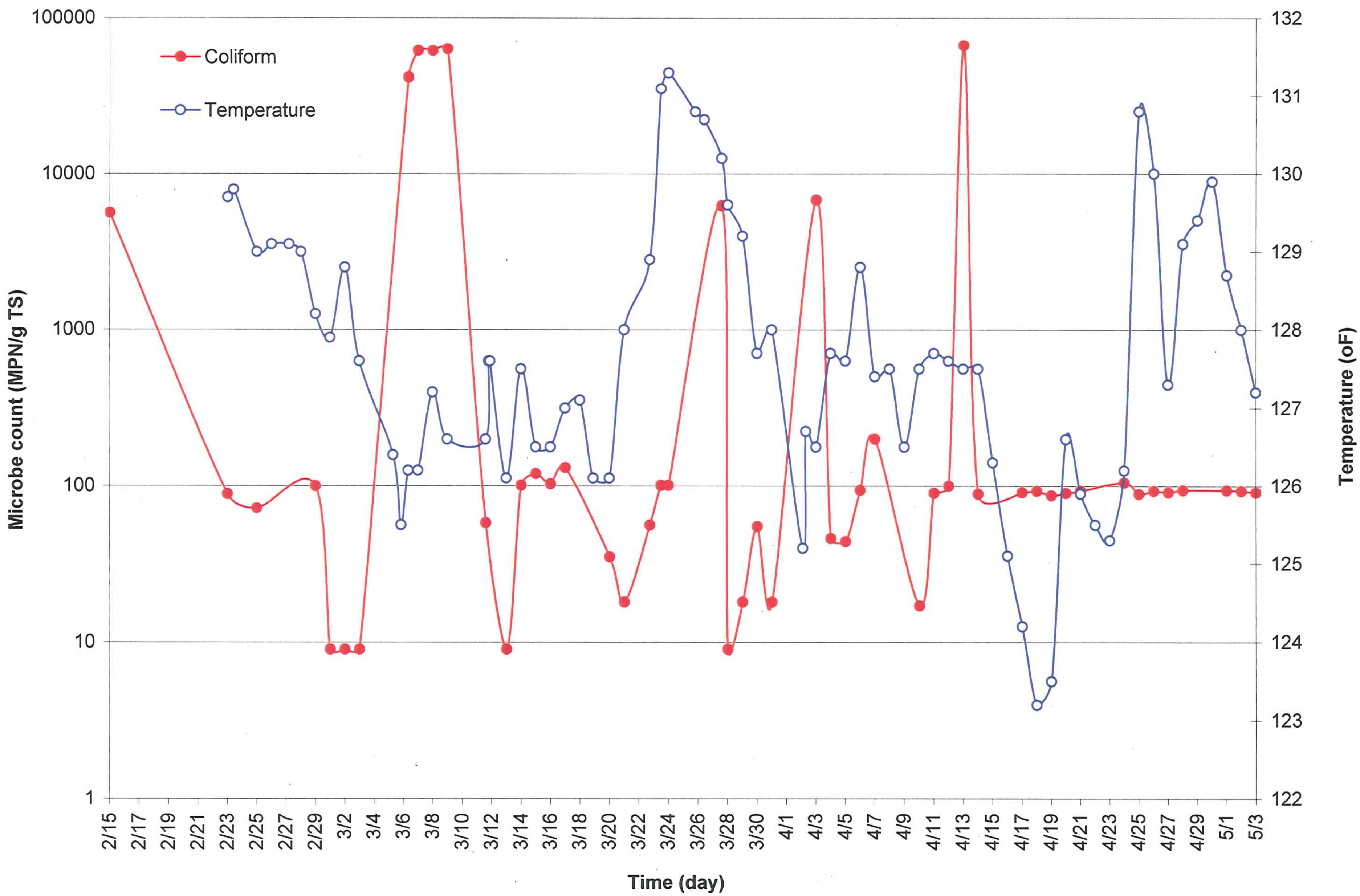
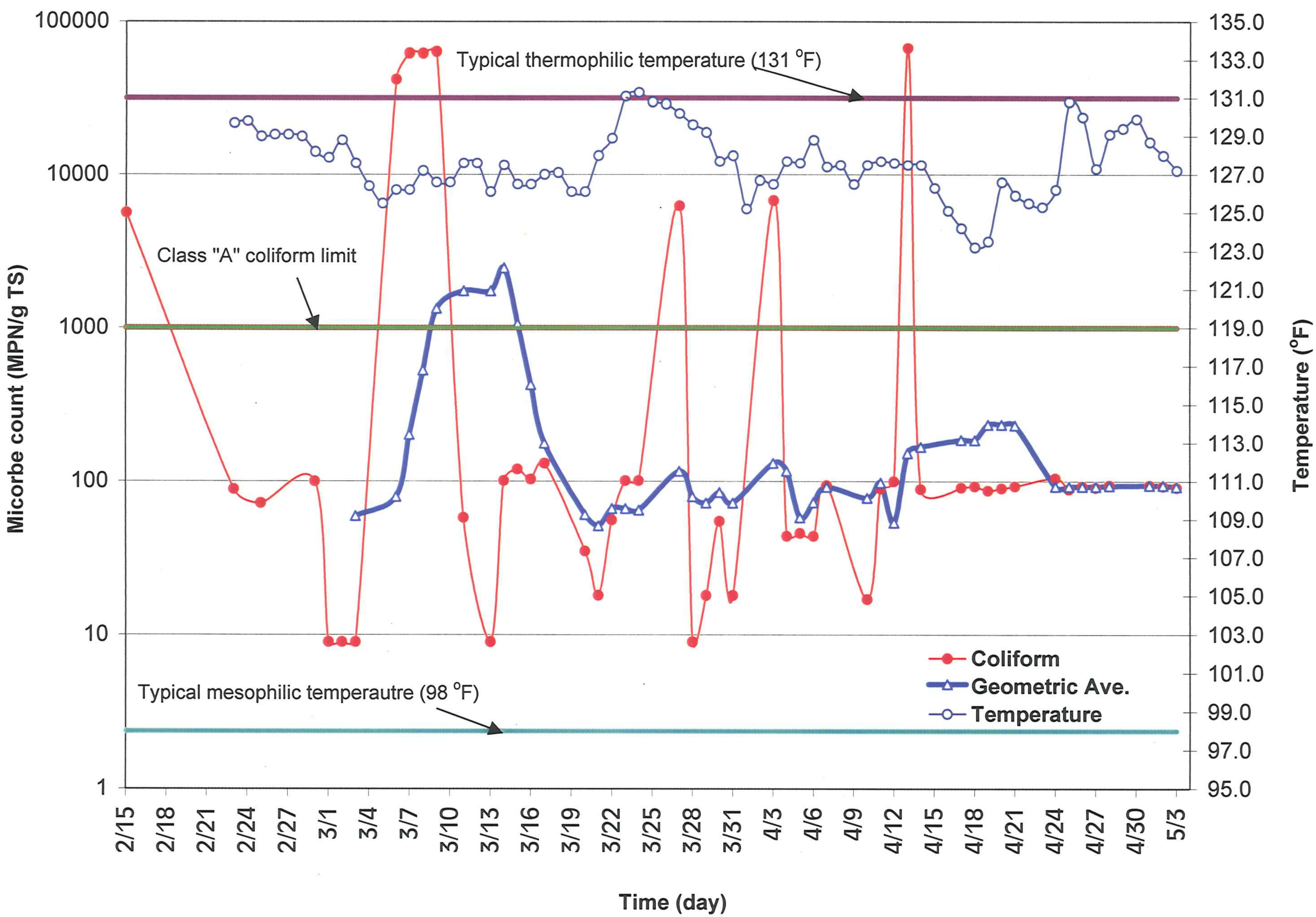


Figure 9. Running 7-day geometric mean for coliform concentration.



Section 9

CONCLUSIONS

The development of the culture has followed a course similar to that seen at some other successful thermophilic operations, with an initial rise of acid concentration as the acidogen activity initially exceeded the activity of the methanogens, and a later decline and approximate stabilization of the acid concentration as the activities of the microbial communities came into balance. Balance was achieved in less than two weeks.

The chemical parameters have been stable since early in the startup period, indicating that a stable biological community has been established that has been able to increase in numbers to meet the increases in the feed rate. Likewise, disinfection has been effective for several weeks, and the combination of low VFAs and low hydrogen sulfide in recent weeks is good news for odor control. The following items summarize the conclusions from the data described in the report.

a. After the initial period of high concentrations, the VFA concentrations have stayed nearly stable despite several large increases in the feed rate.
b. The pH and alkalinity fluctuations are well correlated, but both are small.
c. The acid/alkalinity ratio has been in the range 0.1 to 0.2 since early March, and has recently been close to 0.1, indicating a healthy digester culture.
d. The gas composition has been nearly stable at around 65% methane and 35% carbon dioxide, which are typical for biogas systems.
e. Hydrogen sulfide concentrations in the gas have been low since early March, and declined further after early April.
f. The coliform count has exceeded the class A limit on only a a statistically insignificant number of occasions, and since the middle of April it has held steady at around 100, one tenth the Class A biosolids limit requirement.

The stable low coliform counts make it very likely that the *Salmonella* concentrations in the product biosolids would have been low or undetectable if the tests for this organism had been made at the same time. The few *Salmonella* tests done to date comply with the Class A specification, as expected from (USEPA, 1994, pp. 35-36) which quotes previous research showing that *Salmonella* are rarely detectable when the coliform count meets the Class A standard. Soon we will be testing for enteric viruses and helminth ova to verify compliance with the other pathogen specifications of the USEPA Class A standard for biosolids, since (USEPA, 1994, p. 36) notes that the concentrations of these organisms are usually low or undetectable in untreated sludge, and it is also know that they are rapidly killed by thermophilic temperatures.

As the digester is now operating successfully while being fed most of the plant's daily sludge production, there appear to be no barriers to carrying out our plan to increase the feed to process the whole sludge production of the plant in the next few weeks. We are extremely satisfied with the progress of this project to date.

Section 10

RECOMMENDATIONS

We recommend:

a. Continuation of the study with efforts to remedy the observed operational difficulties and reduced frequency of monitoring of the current set of parameters, now that stable operation appears to have been achieved.

b. Carrying out planned measurements of enteric viruses and helminth ova to verify full compliance with Alternative 4.

c. Preparation for a meeting with Brown and Caldwell and the EPA experts for more information on obtaining Class A certification.

d. A period of modified operation in which Digester #2 is used for storage, to provide additional retention time, VS reduction, and gas production.

e. Now that the thermophilic process is stable, comparison of the existing thermophilic and mesophilic operations by simultaneous testing of important parameters.

f. Completion of other planned apsects of the study, such as investigation of gas production, detailed economic analyses, and measurement and instrumentation issues.

Section 11

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APPENDIX I.

BIOSOLIDS REGULATIONS
(Exceptional Quality)

EXCERPTS FROM 40 CFR 503

The following items are direct quotations from "Standards for the Use and Disposal of Sewage Sludge" (USEPA, 1993), describing several alternatives for biosolids to be certified Class A, and also describing an exemption from mandated general requirements and management practices if the biosolids not only meet the class A standard, but also standards for metal pollutant concentrations and vector attraction reduction.

§503.10 (b) (1) (USEPA, 1993, p. 16).

The general requirements in §503.12 and the management practices in §503.14 do not apply when bulk sewage sludge is applied to the land if the bulk sewage sludge meets the pollutant concentrations in §503.13 (b) (3), the Class A pathogen requirements in §503.32 (a), and one of the vector attraction reduction requirements in §503.33 (b) (1) through §503.33 (b) (8).

Comments: Sludge meeting all the conditions in §503.10 (b) (1) is usually said to be exceptional quality (EQ) sludge, although this term does not appear in 40 CFR 503.

§503.10 (b) (2) allows for an exception to the exemption in §503.10 (b) (1) if the EPA Regional Administrator or the State Director of an approved sludge management program determines that some or all of the general requirements or management practices are necessary to protect public health or the environment.

§503.10 also includes subsections (c) through (g) making related exemptions from the general requirements in §503.12 and the management practices in §503.14 as follows:

Section	Material and use
§503.10 (c)	Land application of bulk material that has exceptional quality and is derived from sludge
§503.10 (d)	Land application of bulk material that is derived from exceptional quality sludge

§503.10 (e)	Selling or giving away sludge of exceptional quality for land application
§503.10 (f)	Selling or giving away bulk material that has exceptional quality, is derived from sludge, and is for land application
§503.10 (g)	Selling or giving away bulk material that is derived from exceptional quality sludge, and is for land application

§503.10 (c) also includes a provision §503.10 (c) (2) allowing for an exception corresponding to §503.10 (b) (2), but subsections (d) through (g) do not.

§503.32 (a) (1) (USEPA, 1993, p. 48).

The requirements in §503.32 (a) (2) and the requirements in either §503.32 (a) (3), §503.32 (a) (4), §503.32 (a) (5), §503.32 (a) (6), §503.32 (a) (7), or §503.32 (a) (8) shall be met for a sewage sludge to be classified Class A with respect to pathogens.

§503.32 (a) (2) (USEPA, 1993, p. 48).

The Class A pathogen requirements in §503.32 (a) (3) through §503.32 (a) (8) shall be met either prior to meeting or at the same time the vector attraction reduction requirements in §503.33, except the vector attraction reduction requirements in §503.33 (b) (6) through §503.32 (b) (8), are met.

§503.32 (a) (3) (i) (USEPA, 1993, p. 48).

Either the density of fecal coliform in the sewage sludge shall be less than 1000 Most Probable Number per gram of total solids (dry weight basis), or the density of *Salmonella* sp. bacteria in the sewage sludge shall be less than three Most Probable Number per four grams of total solids (dry weight basis) at the time the sewage sludge is used or disposed; at the time the sewage sludge is prepared for sale or give away in a bag or other container for application to the land; or at the time the sewage sludge or material derived from sewage sludge is prepared to meet the requirements in §503.10 (b), §503.10 (c), §503.10 (e), or §503.10 (f).

§503.32 (a) (3) (ii) (D) (USEPA, 1993, p. 49).

When the percent solids of the sewage sludge is less than seven percent; the temperature of the sewage sludge is 50 degrees Celsius or higher; and the time period is 30 minutes or longer, the temperature and time period shall be determined using equation (4).

$$D = 50{,}070{,}000/10^{0.14t}, \qquad (4)$$

Where,

D = time in days.

t = temperature in degrees Celsius.

Comment: §503.32 (a) (4) and §503.32 (a) (5) specify Alternatives 2 and 3 for producing Class A biosolids, describing processes that are not relevant for TITP.

§503.32 (a) (6) (ii) (USEPA, 1993, p. 51).

The density of enteric viruses in the sewage sludge shall be less than one Plaque-forming Unit per four grams of total solids (dry weight basis) at the time the sewage sludge is used or disposed; at the time the sewage sludge is prepared for sale or give away in a bag or other container for application to the land; or at the time the sewage sludge or material derived from sewage sludge is prepared to meet the requirements in §503.10 (b), §503.10 (c), §503.10 (e), or §503.10 (f), unless otherwise specified by the permitting authority.

§503.32 (a) (6) (iii) (USEPA, 1993, p. 51).

The density of viable helminth ova in the sewage sludge shall be less than one per four grams of total solids (dry weight basis) at the time the sewage sludge is used or disposed; at the time the sewage sludge is prepared for sale or give away in a bag or other container for application to the land; or at the time the sewage sludge or material derived from sewage sludge is prepared to meet the requirements in §503.10 (b), §503.10 (c), §503.10 (e), or §503.10 (f), unless otherwise specified by the permitting authority.

§503.32 (a) (7) (ii) (USEPA, 1993, p. 52). Sewage sludge that is used or disposed shall be treated in one of the Processes to Further Reduce Pathogens described in Appendix B.

§503.32 (a) (8) (ii) (USEPA, 1993, p. 52).

Sewage sludge that is used or disposed shall be treated in a process that is equivalent to a Process to Further Reduce Pathogens, as determined by the permitting authority.

§503.33 (a) (1) (USEPA, 1993, p. 54).

One of the vector attraction reduction requirements in §503.33 (b) (1) through §503.33 (b) (10) shall be met when bulk sewage sludge is applied to agricultural land, forest, a public contact site, or a reclamation site.

§503.33 (b) (1) (USEPA, 1993, p. 55).

The mass of volatile solids in the sewage sludge shall be reduced by a minimum of 38 percent.

Comment: Appendix B of 40 CFR 503 specifies five Processes to Significantly Reduce Pathogens (PSRP): aerobic digestion, air drying, anaerobic digestion, composting, and lime stabilization; and seven Processes to Further Reduce Pathogens (PFRP): a higher-temperature, longer-duration composting process, heat drying, heat treatment, thermophilic aereobic digestion, beta ray irradiation, gamma ray irradiation, and pasteurization. Most or all of these processes were "grandfathered" from the previous sludge disposal regulation, 40 CFR 257, which specified processes, but not pathogen concentration standards comparable to §503.32 (a) (3) (i). However, the process specifications in this appendix that involve heating must be judged to be conservative, perhaps excessively so, since they mandate combinations of time and temperature that greatly exceed the heating required to meet Equation (4) in §503.32 (a) (3) (ii) (D).

APPENDIX II.

MEMO ON NEW PHASE OF TESTING

MEMO CONCERNING A NEW PHASE OF TESTING

DATE:

TO: Distribution

FROM: Seung Oh, Applied Research / WESD

SUBJECT: **Installing digester #2 as secondary digester for thermophilic digestion**

The purpose of this new mode of operation is to find a better operational strategy for thermophilic digestion. Since this is a relatively new technology, different modes of operation will be selected and tested for the next several months to search for the best operational mode. The most important is to comply with the requirements for class A biosolids according to the 40 CFR 503 Rule as well as Kern County's requirement. However, the economic impact on plant operation is also important an issue. The operational cost of each mode will be calculated and they will be compared to each other.

In the last 4 months, only one digester has been utilized to produce class A bio-solids. It had good results, meeting all the requirements. For the next stage of the test program, the operators and engineers decided to put #2 digester into service as a secondary digester for thermophilic operation. No heat will be applied to the secondary digester, which will be used as a storage tank before discharging for de-watering. This will give us more detention time to produce more gas and reduce the possibility of contamination. We are anticipating that the characteristic of the sludge will be better for de-watering. During this testing period all the parameters will be monitored as usual and will be compared to the previous mode of operation.

Currently digester #2 is filled to 28 feet with 0.7 million gallons of mostly digested sludge. For the next one or two weeks, until digester #2 is filled with thermophilic sludge, operators will transfer digested sludge from #1 into #2 by utilizing the recirculation pump. During this period the same amount of sludge as is fed to digester #1 will be transferred to digester #2, maintaining a constant level in #1. After digester #2 is filled to 59 feet with the thermophilic sludge, the digested sludge from digester #1 will be transferred to digester #2 by gravity through the transfer line. The digested sludge will be withdrawn only from #2 digester for de-watering. The following is the procedure for the new mode of thermophilic operation.

Period 1. Filling digester #2

Since the blended sludge of 100,000 gallons per day is fed to digester #1, the same amount of sludge will be transferred to digester #2 during the day and/or swing shift. No sludge will be withdrawn for de-watering from the thermophilic digesters until the digester #2 has been filled. Please do not run the recirculation gas compressor for mixing while tank #2 is being filled.

1. Open digester #2 feed valve.
2. Close digester #1 feed valve and leave it for 3 hours. Please monitor the digester #1 level and maintain the digester level at between 59 and 56 feet.
3. Open digester #1 feeding valve and close digester #2 feed valve.
4. Resume normal operation.

Period 2. After digester #2 is filled to 59 feet or to the same level as digester #1, the transferring of digested sludge will be done by gravity. The level of digester of #1 and #2 will be kept at the same level. The minimum level of digester #1 and #2 will be maintained at 56 feet. The transfer valves between two digesters will be kept open. A re-circulation gas compressor will be used to mix the sludge in digester #2. The sludge in digester #1 will be mixed with recirculation gas compressor and sludge re-circulation pumps as before.

Please make sure that the recirculation gas compressors are available before conducting this procedure. If you have any questions on this memo or procedure, please let Hisang Kim or Seung Oh know.

APPENDIX III.

DATA MATRIX

Date	Day	Feeding gallons/day	Detention Time Days	Temp F	TS %	VTS %	pH	Volatile Acids mg/L	Alkalinity mg/L as CaCO3	VolatileAcids/Alkalinity	Bicarbonate Alkalinity mg/L as CaCO3	H2S ppm	CH4 %	CO2 %	Fecal Coliform MPN/100 ml	Fecal Coliform MPN/g of Solids
2/15/00	Tuesday	no feed	na	93.5	2.31	61	7.1	302	2600	0.12	2387	na	na	na	13000	5628
2/16/00	Wednesday	no feed	na	93.5												
2/17/00	Thursday	no feed	na	94.7												
/18/00	Friday	no feed	na	101.2												
/19/00	Saturday	no feed	na	103.2												
/20/00	Sunday	no feed	na	108.9												
/21/00	Monday	no feed	na	118.1												
/22/00	Tuesday	no feed	na	126.5												
/23/00	Wednesday	1600	812.5	129.7	2.24	58	7.2	592	3050	0.19	2632	na	na	na	<200	<89
/24/00	Thursday	33200	39.2	129.8	2.12	na	7.3	806	3150	0.26	2581	na	na	na	na	na
/25/00	Friday	37800	34.4	129.0	2.79	56	7.0	857	3250	0.26	2645	800	na	na	<200	<72
/26/00	Saturday	no feed	na	129.1	2.24	60	7.2	970	na	na	na	600	na	na	na	na
/27/00	Sunday	no feed	na	129.1	2.28	59	7.2	1310	na	na	na	700	na	na	na	na
/28/00	Monday	33030	39.4	129.0	2.24	61	7.0	1235	3200	0.39	2329	700	56.7	42.7	na	na
/29/00	Tuesday	26250	49.5	128.2	2.30	59	7.2	1390	3000	0.46	2019	600	57.02	42.29	230	<100
/1/00	Wednesday	no feed	na	127.9	2.25	59	7.0	1525	3000	0.51	1924	590	57.35	41.73	20	9
/2/00	Thursday	30000	43.3	128.8	2.30	59	7.0	1361	3000	0.45	2040	550	64.54	34.98	20	9
/3/00	Friday	33000	39.4	127.6	2.27	59	7.3	958	3150	0.30	2474	500	69.89	29.74	20	9
/4/00	Saturday	27000	48.1	126.4	2.15	58	7.4	580	3150	0.18	2741	370	na	na	na	na
/5/00	Sunday	no feed	na	125.5	2.51	61	7.0	126	2650	0.05	2561	500	na	na	na	na
/6/00	Monday	30000	43.3	126.2	2.36	61	7.1	200	2800	0.07	2659	na	70.71	28.86	99000	41949
/7/00	Tuesday	23000	56.5	126.2	2.58	61	7.0	252	2750	0.09	2572	352	66.88	32.84	160000	62016
/8/00	Wednesday	23000	56.5	127.2	2.59	61	7.0	189	2900	0.07	2767	400	69.45	30.21	>1.6E+05	>61776
/9/00	Thursday	30000	43.3	126.6	2.52	60	7.0	227	2850	0.08	2690	350	68.54	30.85	>1.6E+05	>63492
/10/00	Friday	30000	43.3	126.6	2.23	59	7.4	315	3350	0.09	3128	450	na	na	130	58
/11/00	Saturday	30000	43.3	127.6	2.18	58	7.4	252	3400	0.07	3222	400	na	na	na	na
/12/00	Sunday	30000	43.3	127.6	2.44	59	7.3	365	3150	0.12	2892	400	na	na	na	na
/13/00	Monday	no feed	na	126.1	2.25	58	7.4	346	3350	0.10	3106	425	64.1	35.6	20	9
/14/00	Tuesday	36000	36.1	127.5	2.28	58	7.4	353	3350	0.11	3101	460	60.38	39.26	230	101
/15/00	Wednesday	36000	36.1	126.5	2.50	61	7.1	239	3000	0.08	2831	375	65.66	33.8	300	120
3/16/00	Thursday	36000	36.1	126.5	2.24	59	7.3	302	3300	0.09	3087	330	66.9	32.37	230	103
3/17/00	Friday	36000	36.1	127.0	2.29	59	7.3	277	3450	0.08	3255	325	66.78	32.37	300	131
3/18/00	Saturday	36000	36.1	127.1	2.34	57	7.5	214	3500	0.06	3349	390	na	na	na	na
3/19/00	Sunday	36000	36.1	126.1	2.30	58	7.4	202	3550	0.06	3407	350	na	na	na	na
3/20/00	Monday	51700	25.1	126.1	2.27	58	7.3	252	3500	0.07	3322	300	66.3	33.2	80	35
3/21/00	Tuesday	47000	27.7	128.0	2.24	58	7.2	265	3500	0.08	3313	310	64.46	35.01	40	18
3/22/00	Wednesday	47000	27.7	128.9	2.31	58	7.4	277	3450	0.08	3255	300	63.9	35.6	130	56
3/23/00	Thursday	47000	27.7	131.1	2.27	58	7.5	277	3550	0.08	3355	375	63.78	35.69	230	101
3/24/00	Friday	47000	27.7	131.3	2.28	58	7.4	302	3750	0.08	3537	400	64.42	36.05	230	101
3/25/00	Saturday	47000	27.7	130.8	2.12	58	7.4	340	3500	0.10	3260	370	na	na	na	na
3/26/00	Sunday	47000	27.7	130.7	2.55	60	7.0	375	2850	0.13	2585	375	na	na	na	na
3/27/00	Monday	47000	27.7	130.2	2.56	61	7.2	315	3000	0.11	2778	400	64.16	35.38	>16000	>6250
/28/00	Tuesday	64800	20.1	129.6	2.19	58	7.4	328	3450	0.10	3219	400	63.91	35.70	<20	<9
/29/00	Wednesday	64800	20.1	129.2	2.32	59	7.5	466	3550	0.13	3221	400	62.57	36.98	130	56
/30/00	Thursday	64800	20.1	127.7	2.38	59	7.4	328	3550	0.09	3319	390	65.50	34.05	130	55
/31/00	Friday	64800	20.1	128.0	2.20	58	7.4	466	3400	0.14	3071	370	65.31	34.37	40	18
/1/00	Saturday	55000	23.6	125.2	2.33	59	7.4	554	3350	0.17	2959	410	na	na	na	na
/2/00	Sunday	43200	30.1	126.7	2.48	61	7.2	252	3050	0.08	2872	325	na	na	na	na
/3/00	Monday	64800	20.1	126.5	2.36	60	7.1	277	3000	0.09	2805	400	61.9	38.5	>16000	>6780
/4/00	Tuesday	64800	20.1	127.7	2.29	59	7.3	731	3500	0.21	2984	375	63.43	35.64	<100*	<44
/5/00	Wednesday	64800	20.1	127.6	2.19	59	7.3	554	3400	0.16	3009	370	64.00	35.51	100*	46
/6/00	Thursday	64800	20.1	128.8	2.26	58	7.3	643	3500	0.18	3046	460	62.71	36.90	<100*	<44
/7/00	Friday	64800	20.1	127.4	2.12	59	7.2	680	3450	0.20	2970	620	na	na	<200	<94
/8/00	Saturday	64800	20.1	127.5	2.32	57	7.4	592	3450	0.17	3032	475	na	na	na	na

Samples were not taken during the temperature transition period.

/11/00	Tuesday	64800	20.1	127.0	2.22	60	7.2	680	3550	0.19	3070	370	[illegible]	[illegible]	<200	[illegible]
/12/00	Wednesday	64800	20.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3450	[illegible]	2917	300	[illegible]	[illegible]	230	[illegible]
/13/00	Thursday	64800	20.1	126.8	2.39	61	7.3	227	3050	0.07	2890	200	63.99	35.49	>160,000	>66946
/14/00	Friday	64800	20.1	127.0	2.25	57	7.4	630	3400	0.19	2956	150	na	na	<200	<89
/15/00	Saturday	64800	20.1	125.9	2.22	60	7.3	529	3400	0.16	3027	270	na	na	na	na
/16/00	Sunday	64800	20.1	125.1	2.41	60	7.3	466	3500	0.13	3171	330	na	na	na	na
/17/00	Monday	64800	20.1	124.2	2.19	59	7.4	113	3550	0.03	3470	200	67.84	31.33	<200	<91
/18/00	Tuesday	64800	20.1	123.2	2.14	59	7.4	277	3500	0.08	3305	210	67.7	31.77	<200	<93
/19/00	Wednesday	64800	20.1	123.5	2.30	59	7.4	403	3700	0.11	3416	225	66.93	32.49	<200	<87
/20/00	Thursday	64800	20.1	126.6	2.21	59	7.4	239	3500	0.07	3331	300	64.68	38.84	<200	<90
21/00	Friday	64800	20.1	125.9	2.16	59	7.3	265	3550	0.07	3363	310	64.46	35.01	<200	<93
22/00	Saturday	64800	20.1	125.5	2.18	60	7.3	315	3650	0.09	3428	310	na	na	na	na
23/00	Sunday	64800	20.1	125.3	2.25	59	7.4	290	3500	0.08	3295	300	na	na	na	na
24/00	Monday	64800	20.1	126.2	2.20	59	7.3	265	3500	0.08	3313	300	65.58	34	230	105
/25/00	Tuesday	64800	20.1	130.8	2.24	60	7.5	214	3650	0.06	3499	300	63.29	36.41	<200	<89
/26/00	Wednesday	81000	16.0	130.0	2.16	60	7.4	227	3550	0.06	3390	320	64.36	35.25	<200	<93
/27/00	Thursday	81000	16.0	127.3	2.19	60	7.4	403	na	na	na	310	64.49	35.15	<200	<91
/28/00	Friday	81000	16.0	129.1	2.13	60	7.4	315	3450	0.09	3228	310	na	na	<200	<94
/29/00	Saturday	81000	16.0	127.4	2.12	59	7.5	265	3550	0.07	3363	300	na	na	na	na
/30/00	Sunday	81000	16.0	127.9	2.15	60	7.4	315	3650	0.09	3428	280	na	na	na	na
/1/00	Monday	81000	16.0	128.7	2.20	60	7.4	214	3700	0.06	3549	300	64.88	34.71	<200	<91
/2/00	Tuesday	81000	16.0	128.7	2.85	68	7.4	290	3500	0.08	3295	290	65.22	34.5	<200	<70
/3/00	Wednesday	81000	16.0	127.2	2.17	60	7.4	265	3500	0.08	3313	300	66.08	33.54	<200	<92

APPENDIX IV.

DEFINITION OF SOME PARAMETERS

Date: February 22, 20000

From: Omar Moghaddam (Energy Management and Applied Research Group / WESD)
Y.J. Shao (TITP)

To: Lucy Joa, Manager, EMD

Re: **Thermophilic Startup Operations at TITP: Laboratory Analyses**

Thank you very much for taking the time to meet with us yesterday to discuss the laboratory work for the thermophilic digestion project. The assistance of the EMD is crucial for the success of this project, and we are most grateful that you are approaching it in the same spirit as when you participated in our previous projects. We appreciate all of your advice about the many aspects of the lab work with which we are not fully familiar and learn something new at the meeting. This will greatly improve the value of the results and final reports.

The list of parameters in our previous document was collected from a number of papers and reports about previous laboratory studies and full-scale implementations of thermophilic anaerobic digestion. We recognized that some of them would not be necessary for successfully starting the process at TITP but included them because we thought that observing them would have potential scientific value. Our rationales for the specific parameters and other comments are as follows.

Parameter 7 (protein) was included because we believed that it could be useful to measure the supply of nitrogenous material that could produce additional NH_3--N (parameter 8) and other components of TKN (Parameter 9), and a previous study gave us the impression that there was a chemical test for total protein, comparable to the aggregate tests for other classes of compounds, such as VFAs. If we are mistaken in this impression, there is no need to pursue the subject further, since we do not know of any specific proteins to look for. If such a test is possible, and circumstances permit performing it, it would be done on samples of the incoming blended sludge.

Item 6 on the list, measurements of the concentrations of individual VFAs in the digester contents, would probably be useful primarily as a diagnostic if the process failed to start properly or suffered an upset later. For example, a number of authors report that a buildup of propionic acid is linked to inhibition of one of the important pathways to methane. Since you pointed out that fermentation after the sample is drawn would distort the results, if the acid concentrations are to be monitored then provisions will have to be made to cool the samples as soon as they are obtained. Since room temperature for humans is refrigeration for thermophilic microbes, it may not be necessary to cool the samples all the way to $4^{o}C$, so adequate cooling probably will be easy to achieve.

Parameter 4 (ORP) would be measured in the digester contents, and, like the individual acid concentrations, probably would be significant primarily for efforts to understand a slow startup or process upset. One of the important methanogenic reactions is the reduction of CO_2 to methane by autotrophic methanogens, and only occurs when the ORP is below about -350 mV. Hence, we expect that insufficiently negative ORPs would be associated with low or absent methane production, and would like to verify this, if possible.

Parameters 8 and 9 (NH_3--N, and TKN) indicate the nitrogenous component of the potential fertilizer value of the biosolids, and are to be measured in the wet cake. Toxicity issues are also noted.

Likewise, item 16 (metals) shows whether the biosolids meet the metals specifications of the exceptional quality standard, and could be a significant aspect of the health and safety of the biosolids even when meeting the metals standard is not required, so measuring the metals would also be done in the wet cake.

Since the TITP influent has substantial quantities of oil and grease from the greasy food industry wastes from its service area, we believe that parameter 17 (oil and grease) should be measured in the digester contents to provide insight if there are problems with scum or foaming. Oil and grease may also be significant for the effect of the biosolids on soil, so eventually there should be at least one measurement on the wet cake, but this may not have to be done until the process is started and stabilized.

We agree that Parameter 12 (TOC) is not important if TSS and VSS measurements are made, so it should be dropped from the list.

Parameters 20 and 21 (biomass activity and microanalysis) were included based on recommendations from faculty members at UCLA (Professor Ahring who has also reviewed and commented on the other parameters). We will get further specifics from her and will let you know as soon as possible what, if anything, is to be done about these items.

As we rely so heavily on assistance from the EMD laboratories and appreciate the depth of your knowledge of chemistry and microbiology, we will be happy to share our data and discuss the results with you for any insights that you would be willing to provide. We will certainly incorporate your contributions in our work, city reports, any papers or conference presentations that emerge from this project. We hope to meet with you again on a more or less regular basis to discuss the progress of the project and the scientific interest of the results.

For your comments and questions, plesae call Reza Iranpour of the Applied Research Group at (310) 648-5280.

CC: EMD Staff
Christine Gardner
Chokoufe Marashi
Ioannice Lee
Ron Cressey
Sumitra Roy-Burman
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Martin Ruiz

For Information
V. Varsh
G. Garnas

APPENDIX V.

PROTOCOLS
(Distributed in February, 2000)

Date: 2/23/2000

From: Omar Moghaddam, Energy Management and Applied Research
Y. J. Shao, TITP

To: Distribution

The enclosed document is the draft plan (5th revision) for starting thermophilic digestion at TITP. It is presented with details based on extensive discussions with plant managers, engineers, and operators at TITP, Environmental Monitoring Division (EMD) management and staff, and outside experts, including Professor Ahring of UCLA. It is currently expected that the first option in this plan will be used, with no more than minor modifications from the description here. **Related sketches are attached to exhibit the exact steps to be performed in the field.** Two other options are also included for perspective on the range of alternatives that have been considered or used by others.

For questions and comments, please call Reza Iranpour of Applied Research Group (ARG) at 310-648-5280 or Hi-Sang Kim of TITP at 310-732-4715.

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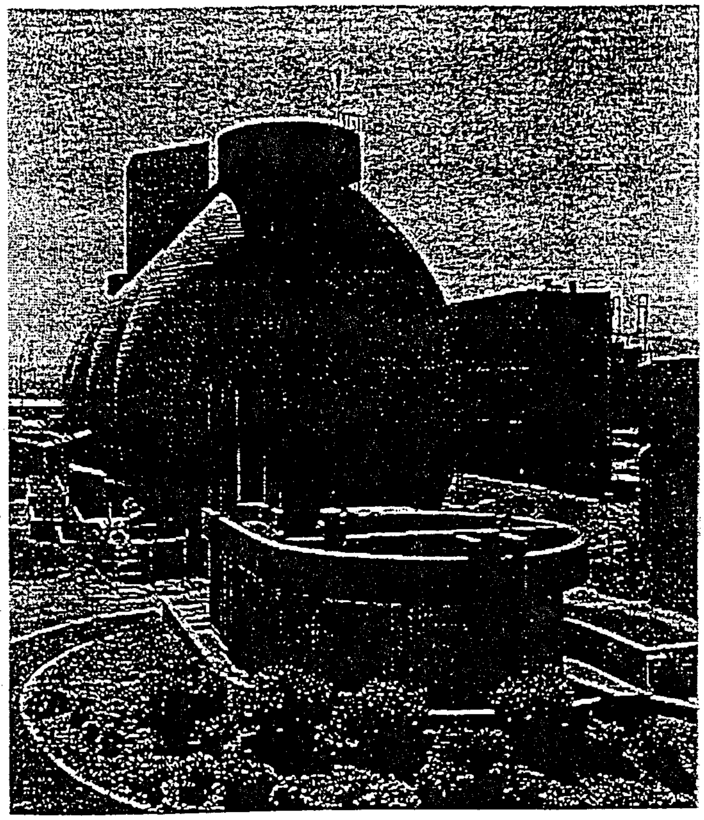
Class "A"Biosolids
Terminal Island Treatment Plant



Startup Process and Protocols
February 2000

Applied Research Group and TITP

Bureau of Sanitation
City of Los Angeles

Introduction

If certain parameters are adjusted and changes in operating procedures are made, sludge digestion at TITP can produce biosolids meeting USEPA Class A standard. This document presents a plan for a project to test operational methods for producing these high-quality biosolids.

Biosolid Standards

In 1993 USEPA developed a set of standards to protect public health and the environment from the adverse effects of contamination in biosolids. This resulted in 40 CFR, Part 503, which specifies that for biosolids to be in Class A, and hence suitable for unrestricted use, the following condition must be met: (please note References 1 and 2)

1. The concentration of fecal coliform in the biosolids must be less than 1,000 most probable numbers (MPN) per gram total solids (dry-weight basis).

2. The concentration of Salmonella sp. bacteria in the biosolids must be less than 3 MPN per 4 grams of total solids (dry-weight basis).

3. And one of the following conditions must be met:
   a) For a temperature T in degrees Centigrade that is at least 50°C, digestion time D in days is at least

$$D = 50{,}070{,}000/10^{0.14T}, \qquad (1)$$

   except that if T >67°C then D is always at least 30 minutes.

   Note that for temperatures between 50°C and 67°C Equation 1 implies a five-fold reduction in time for each 5°C rise in temperature, as in the following table:

Table 1: Class A Temperature/Time Combinations

Temperature, °C	Temperature, °F	Time
50	122	5:0 days
55	131	1.0 day
60	140	4.8 hours
65	149	1.0 hour
67	153	30 minutes

b) Biosolids are subjected to pH > 12.0.

c) Microbiological testing verifies that enteric virus concentration is less than 1 focus-forming unit (ffu) per 4 grams of total dry solids, and helminth ova concentration is less than 1 ovum per 4 grams of total dry solids.

d) One of the Processes to Further Reduce Pathogens (PFRP) is carried out. (These are specified processes of composting, heat drying, heat treatment, thermophilic aerobic digestion, beta-ray irradiation, gamma-ray irradiation, and pasteurization)

e) A treatment that has been certified PFRP-equivalent is carried out.

For comparison, the Class B standard for biosolids is far less stringent, mandating a fecal coliform concentration below 2,000,000 MPN per gram total solids, or a Process to Substantially Reduce Pathogens (PSRP), such as anaerobic digestion for 15 days at 35°C, or a certified PSRP-equivalent process.

Exceptional Quality (EQ) Biosolids

To characterize biosolids that meet low-pollutant and Class A pathogen reduction (virtual absence of pathogens) limits and that have a reduced level of degradable compounds that attract vectors. Once the requirement (EPA/832/R-93/003) are met, EQ biosolids are considered a product that is virtually unregulated for use, whether used in bulk, or sold or given away in bags or other containers.

Risk Assessment Basis of the Part 503 Rule

The biosolids risk assessment process involved selecting representative pathways by which humans, animals, and plants could become exposed to pollutants of concern that can be present in biosolids (EPA/832-B-93/005).

Land Application Requirements

All biosolids applied to the land must meet the *ceiling concentrations for pollutants*, listed in the first column of Table 2-1(EPA/832/R-93/003)

The ceiling concentrations are maximum concentration for 10 heavy metals pollutants in biosoilids, specifically, arsenic, cadmium, copper, chromium, lead, mercury, molybdenum, nickel, selenium, and zinc. Figure 2-3 and Table 2-2 summarizes the option for meeting pollutant limits and pathogen and vector attraction reduction requirements for land application.

Pollutant limits for inorganic pollutant (10 heavy metals) and organic pollutants were calculated for each of the exposure pathways evaluated for the land application, surface disposal, and incineration risk assessments using the parameters and algorithms discussed in Chapter.4(EPA/832-B-93/005). The numerical results of these calculations are shown in Tables 10, 12, and 14 of same reference. Table 2-3 summarizes the regulatory requirements for different types of biosolids(EPA/832-B-93/005).

Process Modifications at TITP

Although the results of early efforts to use thermophilic anaerobic digestion of sludge have given it a bad reputation in the United States, in recent times it has been developed in Europe into a highly reliable and effective process (Ahring, 1994, 1996). Recent US experience has also been highly successful, and this international effort has found values of pH, total volatile fatty acids (VFAs), alkalinity, etc. that indicate satisfactory operation of the process, so stable operation will be recognized by the attainment and maintenance of values close to the desired ones. Hence, the thermophilic digester will have to be carefully monitored for pH, alkalinity, VFA production, and the degree of VS destruction that actually occurs, to verify that the conditions are right for methane production to be maintained at a high level, without exceeding the pH tolerance or other metabolic limits of the methanogens.

In this exercise is one of the digesters at TITP is to be used as a thermophilic digester to achieve Class A biosolids. The test program is planned so that the established mesophilic digestion will continue during startup of the thermo process, so that the plant's normal operation will not be disturbed. The recommended startup plan is presented with details based on discussions with plant managers, engineers, operators, and many outside experts, including a consultant from Brown and Caldwell and several anaerobic digestion researchers who are currently at UCLA. It also incorporates the results of an extensive survey of the research literature.

Feeding the thermophilic digester is to be performed in draw and fill mode, so that no incoming sludge enters the digester until all outgoing sludge has been removed. The digester is mixed by the recirculation and gas mixing systems, so a fraction of each new charge may be withdrawn at the next extraction, and hence the Part 503 requirement for pasteurization at the temperature of the thermo reactor must be met under the minimum residency conditions set by the draw and fill schedule. The standard EPA recommendation implies that at 55°C feedings cannot be more frequent than once a day, but at 57°C twice a day should be possible, according to Equation 1. However, it is widely recognized that for thermophilic digestion this recommendation is much too conservative, because the digester culture appears to produces proteases or other substances enhancing pathogen kill, so that drawing and filling can be done several times a day at 55°C. Bacteriological testing will be needed to verify that pasteurization is being accomplished and to tune the process, since minimizing the operating temperature obviously reduces heat loss and heating costs.

Heat Transfer Considerations

a) *Stable Operation* The draw and fill operation requires temperatures around 55°C. The heat required to raise the incoming sludge to this temperature is in the range of (2.5-3) x 10^6 BTU/hr, depending on variations in the raw sludge temperature, the ambient air temperature, and the chosen final temperature. As the heat value of current digester gas production is around 6.9×10^6 BTU/hr, and the new process is expected to produce more gas, this heat supply appears sufficient to heat the incoming sludge in the absence of measures to recover heat from the thermophilically digested sludge, despite all losses in the power generator engine system.

As the liquid recirculation system on each side has two pumps, each with a rated capacity of 500 gpm. Or. 720,000 gpd, running both pumps continuously (or at their maximum duty cycle) will probably be sufficient to recirculate the contents of one digester about once per day. Given the draw and fill mode of operation described above and the need to mix the contents well for both temperature equalization and completion of the digestion process, it will be necessary to determine the recirculation rate that produces adequate mixing.

b) *Startup* As noted above, a major consideration of this project is that plant compliance with operating standards should not be compromised. Hence, the present meso digestion process must be continued until it is clear that the plant's full sludge production can be fed into the thermo digester. Owing to the configuration of the plant's piping, recirculation pumps, and heat exchangers, there is essentially only one way to do this.

To obtain rapid heating of the sludge in the thermo digester, use of the recirculation system and the heat exchangers begins as soon as the first day's load has been put into the thermo digester. It is also necessary to maintain a heat supply to the two meso digesters while the thermo digester is being filled and the thermo culture is being established. It is not practical to heat both a meso and a thermo digester on the same side of the complex with the same recirculation system, so the two meso digesters must be on the other side of the complex from the thermo digester. Hence, if, for example, Digester 1 is to be the thermo digester, then at the time of the beginning of the test Digesters 3 and 4 must be the ones used for the meso process.

Once the sludge in the thermo digester becomes deep enough for efficient heat transfer from steam injection, this method of heat input will be used instead of the heat exchangers, to reduce the risk of fouling the heat exchangers, which is common when they are used to heat sludge to these higher temperatures for prolonged periods. The time to shift to steam injection is another detail that will be determined by consultation with plant personnel.

As a portion of the plant's sludge production is diverted to fill the thermo digester, the retention times in the meso digesters will rise above the present twenty days. This is acceptable, since it will probably increase, at least slightly, the VS reduction factor, and is not expected to affect the ability to meet the Class B standard.

Once the transition is complete, the meso digesters will continue operating until some future time when sufficient confidence has been gained to adopt thermophilic digestion as the sole method.

Notes for Permanent Operation

If evaluation of the results of this test leads to permanent adoption of this process, we strongly recommend installation of a sludge-to-sludge heat exchanger. This will recover large amounts of heat that will have to be removed by the recirculation system on the mesophilic side during the test, and hence will ease the task of cooling the thermophilic solids for storage and dewatering. Cost estimates for the test and for purchase and installation of the sludge-to-sludge heat exchanger will be prepared.

Parameters to be monitored

The following list of parameters is suggested for monitoring the chemical state of the digestion process, based on previous startups at other plants and consultation with various experts. Further experience may show that once operation is established some of the parameters may be eliminated entirely. All parameters are to be measured using the procedures in the latest edition of *Standard Methods*.

1. Temperature (^{o}C)
2. pH
3. Alkalinity (as mg $CaCO_3$/L)
4. Oxidation/Reduction Potential (ORP) (volts)
5. Total VFAs (as mg acetic/L)
6. VFA composition: concentrations of acetic, butyric, propionic and pentanoic acids (as mg acetic/L)
7. **Total Protein Concentration (mg/L)**
8. **Total Kjeldahl Nitrogen (TKN) (mg/L)**
9. **NH_3–N (mg/L)**
10. **Total Solids (TS) (mg/L)**
11. **Volatile Solids (VS) (mg/L)**
12. **Total organic carbon (TOC) (mg/L)**
13. Biogas Flowrate (L/hr)
14. CH_4 content of biogas (%)
15. CO_2 content of biogas (%)
16. **Heavy or toxic metals: Pb, Cr, Cd, Hg, etc. (g/L)**
17. **Oil and grease (mg/L)**
18. Fecal coliforms (MPN/gm dry VS) (thermophilic effluent and storage tank effluent)
19. 19 *Salmonella* (MPN/gm dry VS) (thermophilic effluent and storage tank effluent)
20. Biomass activity
21. Sludge for microbiological analysis

The suggested frequencies of measurement appear in Table 1.

Table 2: Suggested Monitoring Frequencies

Parameter	Startup	Stabilization	Operation
1.Temp	4/day	Daily	daily
2.pH	Daily	Daily	weekly
3. Alk	Every other day	Weekly	weekly
4. ORP	Every other day	Weekly	weekly
5. VFAs	Daily	Daily	weekly
6. Individual acids	2/day	2/day	daily
7. Total Protein	Weekly	Weekly	weekly
8. TKN	Weekly	Weekly	weekly
9. NH_3—N	Weekly	Weekly	weekly
10. TS	Daily	Daily	weekly
11. VS	Daily	Daily	weekly
12. TOC	Daily	Weekly	weekly
13. Gas flow	Daily	Daily	weekly
14. CH_4	Daily	Daily	weekly
15. CO_2	Daily	Daily	weekly
16. Metals	Weekly	Weekly	weekly
17. O & G	Weekly	Weekly	weekly
18. Coliforms	Every other day	every other day	weekly
19. *Salmonella*	Every other day	every other day	weekly
20. Biomass activity	Every other day	every other day	weekly
21. Micro analysis			

Note: *Parameters designated for weekly measurement are considered to have sufficiently low importance that a less frequent measurement schedule, such as two or three times a month, would be acceptable to meet limitations of budget or laboratory capacity. Parameters 7, 8, 9, 12, 16, and 17, which are only measured weekly, are the most likely candidates for elimination from the measurement program at some later time.*

Biomass activity testing should be performed by???

Two samples should be taken from test reactor for microbiological analysis???

Tentative Startup Plan for Option 1: No Seed and Complete Fill with Mesophilically Digested Sludge (Please note a Attached sketch)

The following startup plan assumes that Digester 1 is to be the thermo digester. It is presented with details provided by plant managers, engineers, and operators, and it is currently expected that this plan will be used, with no more than minor modifications from the description here. The sludge level values are relative to a reference line approximately 26.3 feet above ground level. Hence, the recommended levels around 58 feet represent filling the digester to its full working capacity, with the sludge surface approximately 84.3 feet above ground level, so that removal and dewatering of thermophilically digested sludge begins soon after feeding begins.

Transfer of Sludge From Digesters 3 and 4 to Digester 1

As soon as Digester 1 is purged and emptied to lowest level possible, start transferring digested sludge from Dig 3 and 4 to Dig 1. No centrifuge operation during the transfer (about a week). Notify BIOGRO about hauling interruption. There are two ways we can transfer digested sludge to Dig 1. Operation decides which method they prefer to use.

a) By gravity via transfer line - we have to be very careful in using this method. The transfer valves need to be partially open to prevent creating vacuum in Dig 3 or 4, triggering the vacuum relief valves to open, admitting air into the digesters. Negative pressure must not be allowed to happen. During the transfer of digested sludge the gas dome pressure of Digester 3 and 4 must be closely monitored. If the pressure indicates a decreasing trend, secure the transfer and resume transfer when the pressure is back to normal, 8.5 inches W.C. Note that pressure transmitters for Digester 3 and 4 are located on the 8" line downstairs. The actual digester pressure in the domes may be different.

b) By recirculation pump via crossover valve - this is the safest way to transfer digested sludge from 3 and 4 to Dig 1. However, we could not feed and heat digesters 3 and 4 and transfer at the same time.

1. During the transfer of sludge the level in Digesters 3and4 must not fall below 52 feet to meet the RMP requirement.

2. Stop transferring when the level in Digester 1 reaches 58 feet and immediately get sludge sample to test for the parameters in the table of frequencies. You may resume

dewatering sludge from Digester 3 and 4 as long as we meet the temperature and volatile solid reduction requirements.

Heating and Mixing of Digester

4. Heat digester 1 to 130 °F using the boiler and the heat exchanger and put gas mixing compressor in service. Gas mixing during startup will be continuous and will be reduced when digestion process is stable. Make sure Mix Sludge Feed Valve 1 is closed and Mix Sludge Feed Valve 2 is open (this will ensure the steam is injected under sludge surface). Maintain the temperature at 128 – 131 °F.

5. During the heating period samples will be taken according to the table, as in step (3).

Feeding digester 1

6. Feed Digester 1 5,000 gal /day for 3 days when the temperature has reached 130 °F. Feeding of the Digester 1 will be done during day shift. Evaluate the sampling results for Digester 1 before proceeding to next step (7). If the volatile solids destroyed is over 38 %, dewater sludge to maintain digester level at 56' – 60' range. From this point on take gas samples daily from Digester 1 and test for H_2S.

7. Increase feed to Digester 1 to 10,000 gal /day for 3 days (5,000 gal during Day shift and 5,000 gal during swing shift). Evaluate sampling results before proceeding to next step (8). Dewater sludge to maintain level 56' – 60' range if the percent volatile solid destroyed is over 38 %.

8. Increase feed to Digester 1 to 15, 000 gal/day for 3 days (5,000 gal each shift). Evaluate sampling results before proceeding to next step (9). Dewater sludge to maintain digester level at 56' – 60' range if the percent volatile solid destroyed is over 38 %.

9. Increase feed to Digester 1 to 20, 000 gal/day for 3 days (10,000 gal during day shift, and 5,000 gal each during swing and graveyard shifts). Evaluate sampling results before proceeding to next step (10). Dewater sludge to maintain digester level at 56' – 60' range if the percent volatile solid destroyed is over 38 %.

10. Increase feed to Digester 1 to 25, 000 gal/day for 3 days (10,000 gal each during day and swing shifts, and 5,000 gal during graveyard shift). Evaluate sampling results before proceeding to next step (11). Dewater sludge to maintain digester level at 56' – 60' range if the percent volatile solid destroyed is over 38 %.

11. Increase feed to Digester 1 to 30, 000 gal/day for 3 days (10,000 gal each shift). Evaluate sampling results. Dewater sludge to maintain digester level at 56' – 60' range if the percent volatile solid destroyed is over 38 %.

12. Make sure tests are being performed

13. TITP and App Res. and UCLA and WESD staff evaluate the entire pilot test.

Tentative Startup Plan for Option 2: No Seed and Partial Fill Initially with Mesophilically Digested Sludge (option not expected to be chosen)

As noted above, when sludge consumption in the thermo digester is below daily production from primary and secondary treatment, the rest of the sludge goes to the present meso process, which is maintained until the thermo process reaches full operation. The following possible startup plan assumes that Digester 1 is to be the thermo digester. Since it is not anticipated that this option will be used, it is presented in much less detail than Option 1.

1. Load 900,000 gal of mesophilically digested sludge (the full output from the two meso digesters for a little more than a week) to start filling Digester 1, with heating to 55°C by the heat exchangers and recirculation system, as in the Heat Transfer Considerations section.

2. Ferment with recirculation and fill by intermittent feeding with raw sludge until the VFA concentration stabilizes at or below 1 g/L with a HRT decreasing from 30 days according to the following rule. First, feed only when the VFA concentration is below 2 g/L. This is expected to involve intervals of two to four days at first, but daily feedings will probably be possible after about 10 days or two weeks. Second, maintain an HRT of 30 days for the first 30 days or more, depending on gas production and VFA concentration, and then decrease the HRT by 5 days for each 10 elapsed days until it reaches the desired 10 days, 60 days or more after the beginning of the startup period. (Note that the HRTs and duration's of operation at these HRTs

are subject to adjustment based on further consultation before the beginning of the project, and on laboratory monitoring of digester parameters during startup. The schedule can be adjusted to accommodate many variations, including a prolonged period of operation at an HRT of more than 10 days so that a flow can be maintained to the meso digesters.)

As the thermo culture is established, a transition is eventually made to operation with all the sludge going to the thermo digester. The first feedings after the initial loading are small, only a few thousand gallons, but once significant gas production begins it becomes important that filling the digester should be completed in a timely manner, to avoid overloading the thermophilic culture while minimizing the risk of having a large headspace containing a potentially explosive gas mixture for a prolonged period. It is tentatively anticipated that the first few feedings will be 10,000-20,000 gallons each, and that 40,000 gpd will be fed once daily feedings start. The feed rate may be raised higher if it becomes necessary to complete digester filling rapidly, but the schedule described here is expected to complete the filling in about two weeks, a short enough period not to compromise safety.

This schedule, including the HRT reductions after filling is completed, is intended to balance feeding speed and culture acclimation with a filling rate that maintains headspace safety. It is based on information from European experts who have extensive experience with achieving smooth and relatively fast startups of thermophilic processes, and also on discussions with North American experts. The schedule also maintains a modest flow to the meso digesters. However, the detailed feeding plan remains to be determined based on further consultation with plant personnel.

Once the digester is full, a feed rate of 40,000 gpd with draw-and-fill operation would establish an HRT of 30 days until the HRT was reduced to 25 days, as described above. The feed rates for HRTs of 25, 20, 15 and 10 days evidently would be 48,000 gpd, 60,000 gpd, 80,000 gpd, and 120,000 gpd. If the HRT is 10 days, all the raw sludge goes to the thermo digester, but any higher HRT implies that a portion of the raw sludge is still being sent to the meso digesters.

Tentative Startup Plan for Option 3: Using a Seed (option not expected to be chosen)

As noted above, when sludge consumption in the thermo digester is below daily production from primary and secondary treatment, the rest of the sludge goes to the present meso process, which is maintained until the thermo process reaches full operation. The following possible startup plan assumes that Digester 1 is to be the thermo digester. Since it is not anticipated that this option will be used, it is presented in much less detail than Option 1.

1. Load 400,000 gal of thermophilically acclimated seed sludge to start filling Digester 1, with heating to 55°C by the heat exchangers and recirculation system, as in the Heat Transfer Considerations section. As this is approximately 1500 tones, the logistics of transportation from the supplier of the seed require careful analysis: refrigeration is not needed, but highway and railroad weight limits imply that if all the seed travels by the same mode of transportation then it will occupy at least 50 tank trucks or at least 20 railroad tank cars.

Ferment with recirculation and fill by intermittent feeding with raw sludge until the VFA concentration stabilizes at or below 1 g/L with a HRT decreasing from 30 days according to the following rule. First, feed only when the VFA concentration is below 2 g/L. It is expected that daily feedings will probably be possible almost immediately after loading, because of the abundant thermo culture, which will need only a little acclimation to the new feed. Second, maintain an HRT of 30 days for the first 30 days and then decrease the HRT by 5 days for each 10 elapsed days until it reaches the desired 10 days, 60 days after the beginning of the startup period.

As the thermo culture is established, a transition is made to operation with all the sludge going to the thermo digester. Significant gas production is expected soon after loading, so then it becomes important that filling the digester should be completed in a month or two, to avoid overloading the thermophilic culture while minimizing the risk of having a large headspace containing a potentially explosive gas mixture for a prolonged period. It is tentatively anticipated that the first few feedings will be 13,000-15,000 gallons each, and that 40,000 gpd will be fed at the start of daily feedings. The feed rate may be raised to 70,000-80,000 gpd if it becomes necessary to complete digester filling rapidly.

This schedule, including the HRT reductions after filling is completed, is intended to balance feeding speed and culture acclimation with a filling rate that maintains headspace safety while still maintaining a modest supply to the meso digesters. As noted in Option 1, it is based on information from European experts. However, the detailed feeding plan remains to be determined based on further consultation with plant personnel.

Once the digester is full, a feed rate of 40,000 gpd with draw-and-fill operation would establish an HRT of 30 days until the HRT was reduced to 25 days, as described above. The feed rates for HRTs of 25, 20, 15 and 10 days evidently would be 48,000 gpd, 60,000 gpd, 80,000 gpd, and 120,000 gpd. By the time that the HRT was reduced to 10 days, all the raw sludge would go to the thermo digester.

Precautions/Safety Requirements

1. All participants in the project shall meet regularly to coordinate their activities.
2. All valves and gates leading to digesters not in service shall be closed and properly tagged.
3. The safety coordinator for the plant is to be consulted to ensure compliance with all other applicable safety procedures.

Notes and Comments

A. Establishment of a stable thermophilic population would occur faster if a seed culture could be obtained from an operating thermophilic digester. Also, room temperature (20^{o}-$25^{o}C$) is in effect refrigeration for organisms that need temperatures of 45^{o}-$60^{o}C$ for growth, so transport or storage of a seed culture for several days or weeks would not impair viability.

B. A preliminary calculation indicates that operation of one of the Terminal Island digesters at $55^{o}C$ will increase the heat loss through its walls by at least 100%, compared to the present mesophilic operation.

C. Many authors (e.g., Aitken and Mullenix (1992); Streeter, et al. (1997); Volpe, et al.) report experiences that argue for heating a digester to its thermophilic operating temperature as quickly as possible (preferably several degrees per day). The capacity of the heat exchangers in either loop at TITP is great enough that the full flow of 120,000 gpd will be heated to the necessary temperature in a few hours, and the process of filling the thermo digester guarantees that operation will start at the full operating temperature.

D. We believe that the plant's plumbers and other staff will be able to perform all necessary construction for the test, so that hiring an outside contractor will not be necessary.

References

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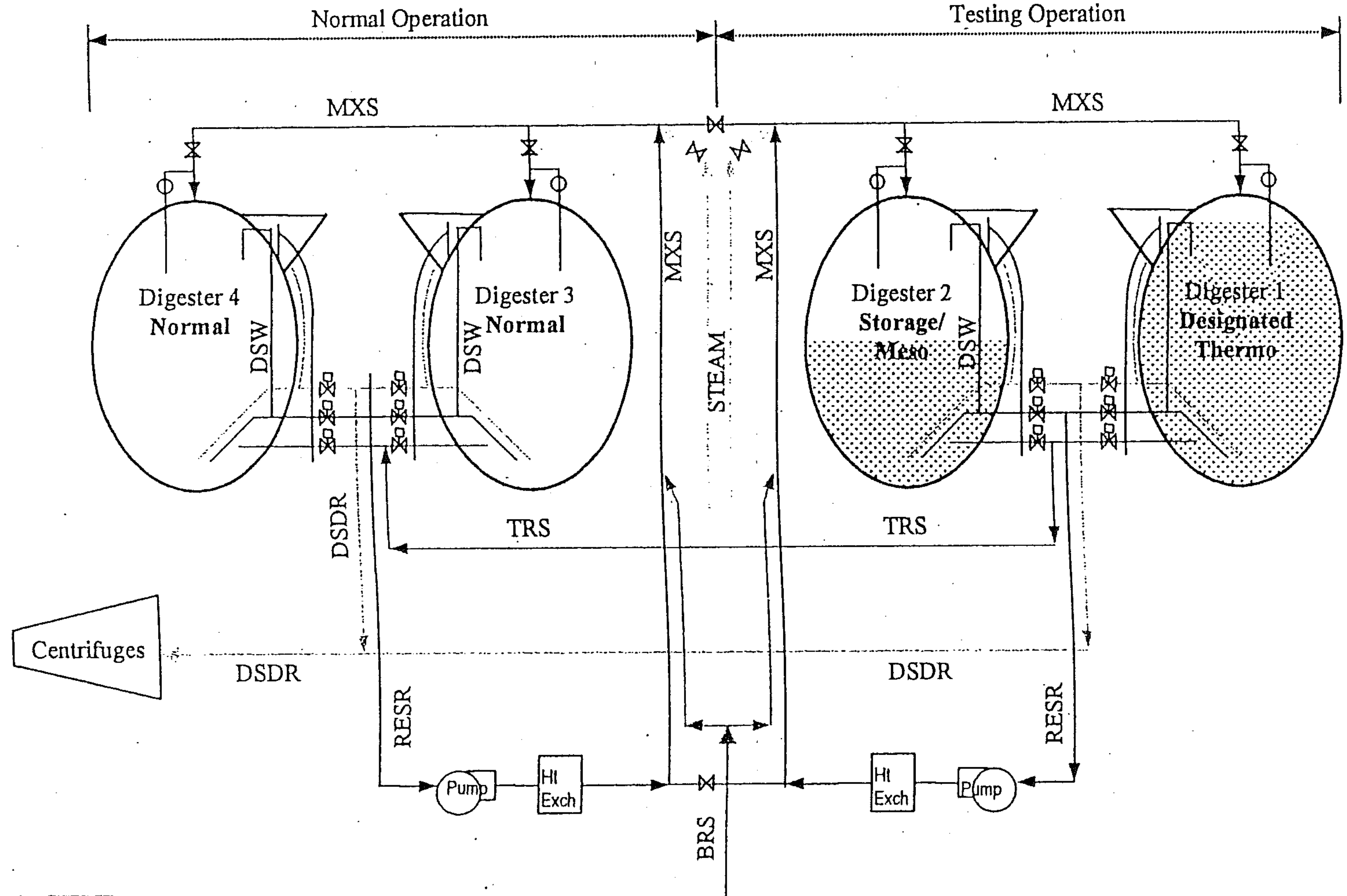
TITP Process Flow Diagram of Digester Operation

Base Sketch



LEGEND

- DSDR - Digested Sludge Drain 8"
- BRS - Blended Raw Sludge 8"
- RESR - Recirculation Sludge Return 8"
- TRS - Transfer Sludge Line 8"
- MXS - Mixed Sludge 8"
- HPE - High Pressure Effluent 4"
- DSW - Digested Sludge Withdrawal
- SCDR - Scum Drain
- SPDR - Supernatant Drain
- SPW - Supernatant Withdrawal

VALVE LEGEND

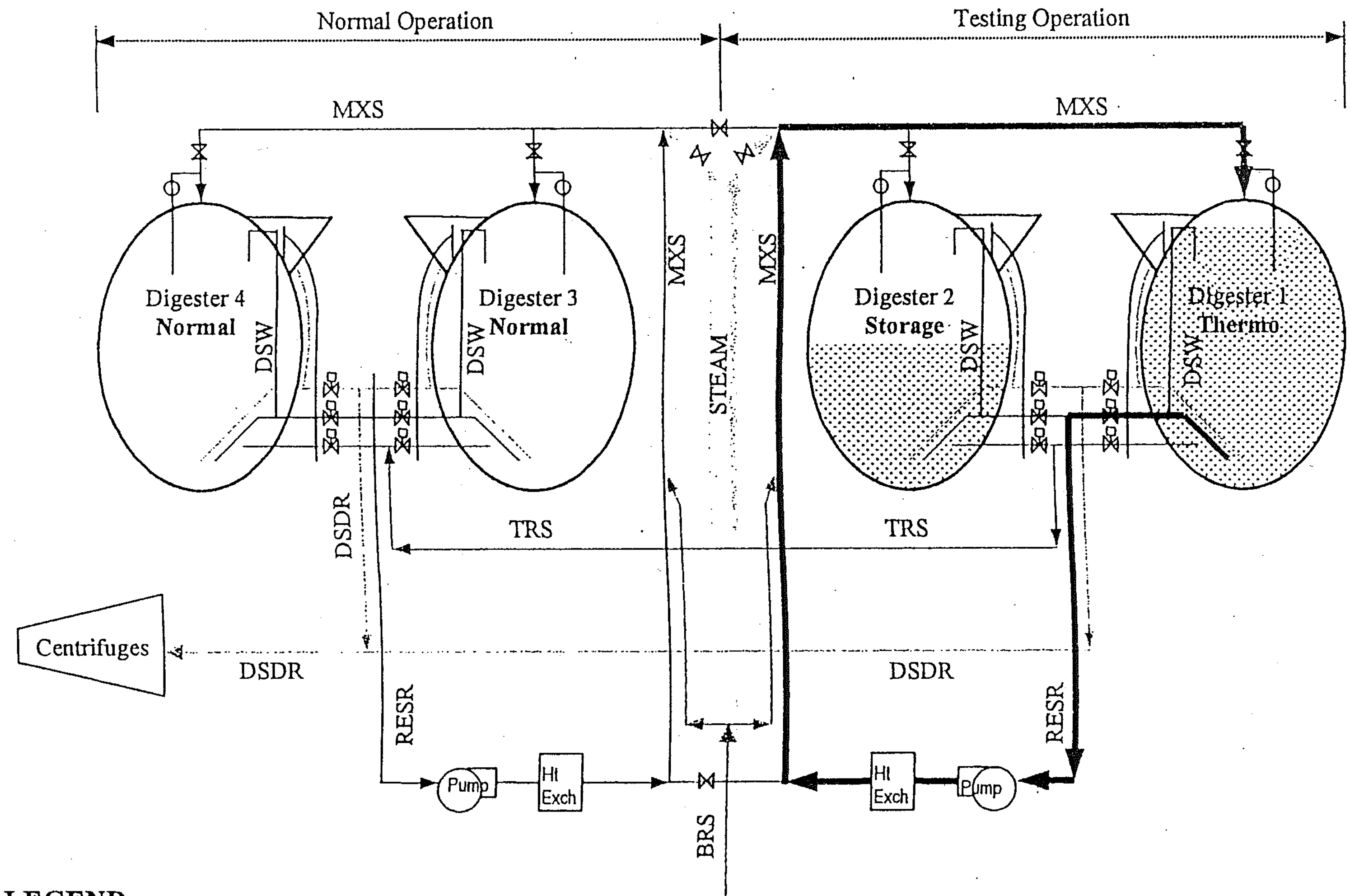
- Plug Valve Flanged Motor Operated
- Plug Valve Victaulic Flanged
- Angle Gate Valve Screwed Plan

Process Highlights

D1
D2
D3
D4

TITP Process Flow Diagram of Digester Operation

Current Configuration



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SPDR - Supernatant Drain
SPW - Supernatant Withdrawal

VALVE LEGEND

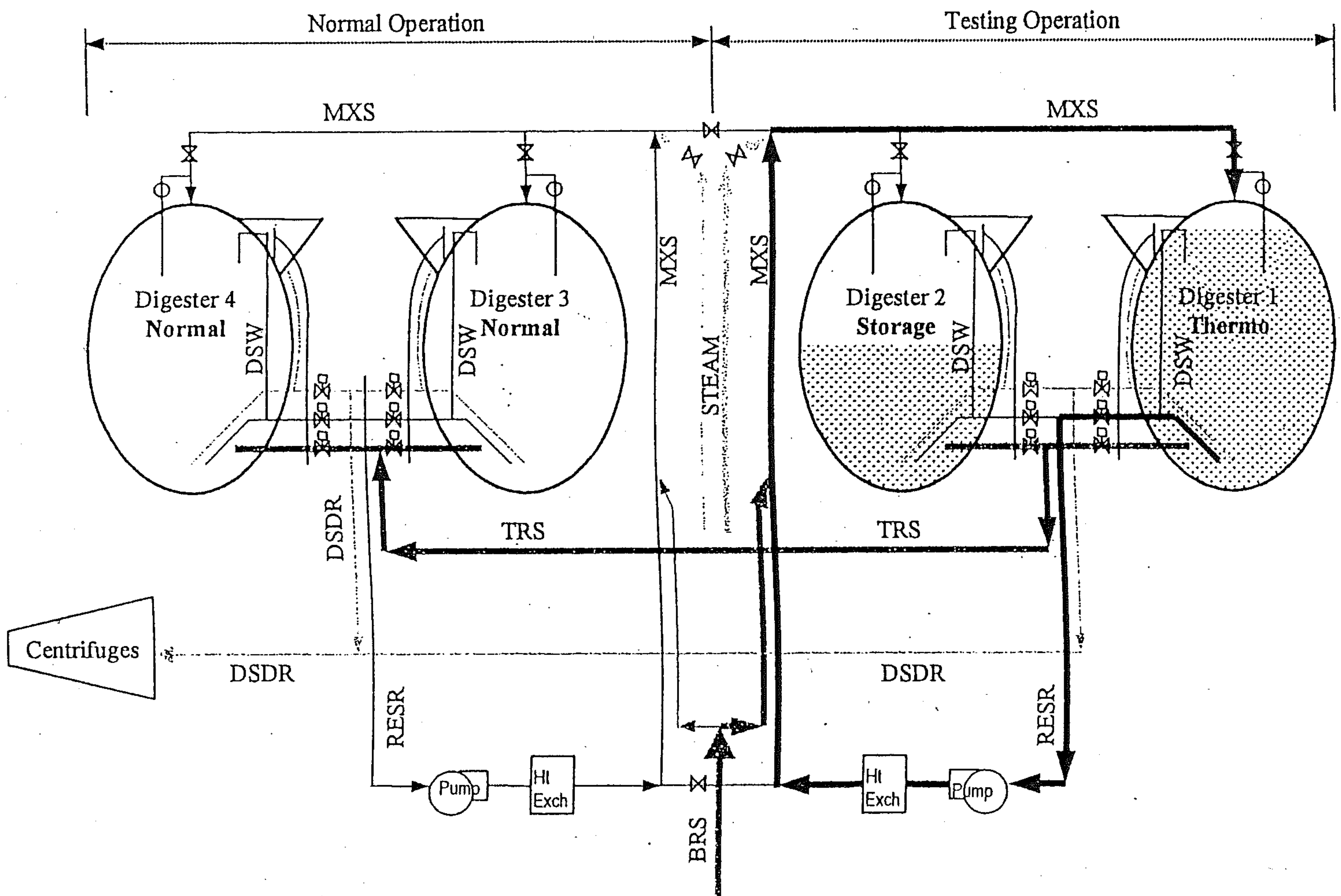
Plug Valve Flanged Motor Operated
Plug Valve Victaulic Flanged
Angle Gate Valve Screwed Plan

Process Highlights

D1 Heating sludge to 135F
D2 Raw sludge storage
D3 Normal operation
D4 Normal operation

TITP Process Flow Diagram of Digester Operation

Configuration #1



LEGEND

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SCDR - Scum Drain
SPDR - Supernatant Drain
SPW - Supernatant Withdrawal

VALVE LEGEND

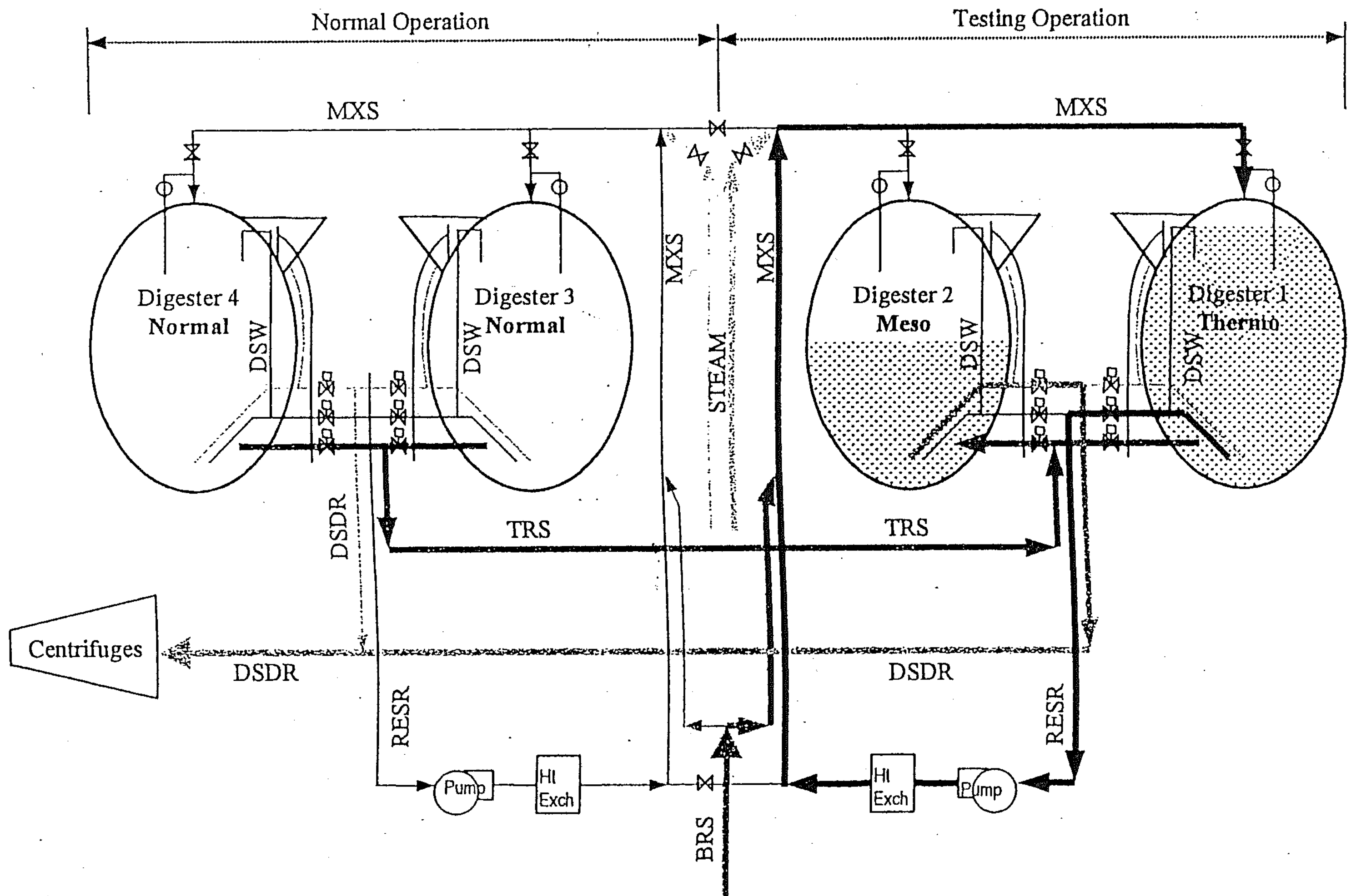
Plug Valve Flanged Motor Operated
Plug Valve Victaulic Flanged
Angle Gate Valve Screwed Plan

Process Highlights

D1 Maintain Heat (135F), sludge withdrawal using D2 for cooling
D2 Draw down sludge and redirect to 3 or 4
D3 Normal operation
D4 Normal operation

TITP Process Flow Diagram of Digester Operation

Configuration #2



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- SPDR - Supernatant Drain
- SPW - Supernatant Withdrawal

VALVE LEGEND

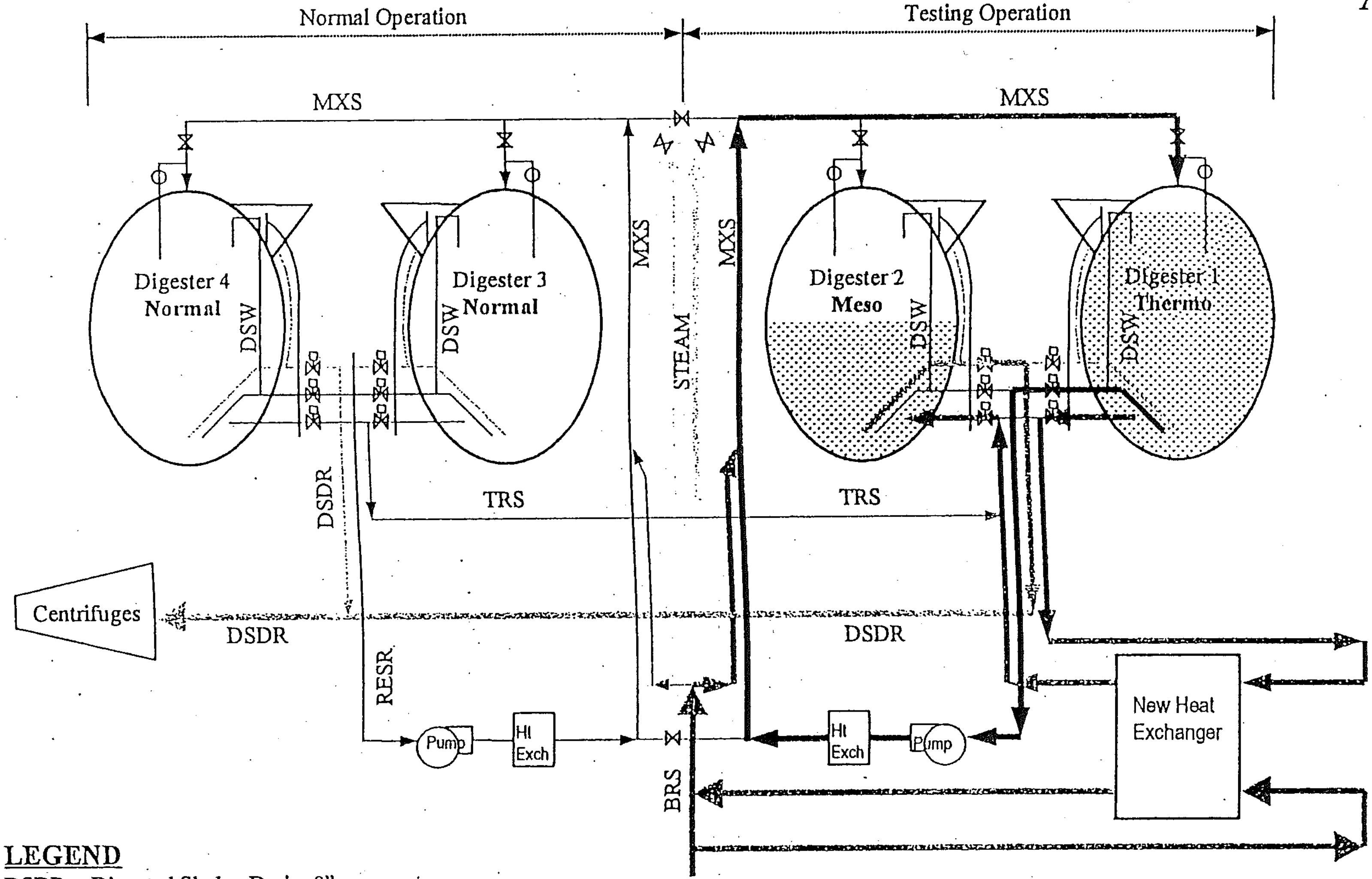
- Plug Valve Flanged Motor Operated
- Plug Valve Victaulic Flanged
- Angle Gate Valve Screwed Plan

Process Highlights

D1 Maintain Heat (135F)
D2 Transfer sludge from 1 to 2 using 3 or 4 for cooling
D3 Normal operation
D4 Normal operation

TITP Process Flow Diagram of Digester Operation

Configuration #3
Alt. #2



LEGEND

- DSDR - Digested Sludge Drain 8"
- BRS - Blended Raw Sludge 8"
- RESR - Recirculation Sludge Return 8"
- TRS - Transfer Sludge Line 8"
- MXS - Mixed Sludge 8"
- HPE - High Pressure Effluent 4"
- DSW - Digested Sludge Withdrawal
- SCDR - Scum Drain
- SPDR - Supernatant Drain
- SPW - Supernatant Withdrawal

VALVE LEGEND

- Plug Valve Flanged Motor Operated
- Plug Valve Victaulic Flanged
- Angle Gate Valve Screwed Plan

Process Highlights

D1 Maintain Heat, Thermophilic (135F)
D2 Transfer sludge from 1 to 2 using heat exchanger and blended sludge for cooling
D3 Normal operation
D4 Normal operation