Brown AND Caldwell
201 N. Civic Drive, #115
Walnut Creek, CA 94596-3864
tel: 925.937.9010
fax: 925-937-9026

Technical Memorandum 3.3

Design Criteria for Digester Modifications and Gas System Improvements

Prepared for: San Jose/Santa Clara Water Pollution Control Plant

Project Title: FOG Evaluation, Digester Rehabilitation and Gas Line Replacement

Project No: 136242-003

Technical Memorandum 3.3

Subject: Design Criteria for Digester Modifications and Gas System Improvements

Date: June 30, 2010 (Revised February 28, 2011)

To: Ravi Kachhapati, Project Manager

From: Steve Krugel, Senior Vice President, Project Manager

Rion Merlo, Ph.D., P.E., Project Engineer
Engineer in Responsible Charge, License No. C69030

Reviewed by: John Willis, Vice President
Perry Schafer, P.E., Senior Vice President
Lloyd Slezak, P.E., Vice President

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. EXECUTIVE SUMMARY

1.1 Purpose of Technical Memorandum 3.3

The purpose of this project is to identify the physical modifications to the San Jose/Santa Clara Water Pollution Control Plant's (WPCP) digesters that would be necessary to either put them back in service, or keep them in service for the next 20 to 30 years, and to do so in such a way that the modifications can accommodate any process alternative forecasted or recommended by the Master Plan. This technical memorandum (TM) forms the basis for that work by refining the alternatives to be considered, defining the flow and loads the digestion system will see, specifying the recommended loading rates, and estimating digester performance. Flows and loads will also consider the potential for a fully formed program for importing co-digestion feedstocks. Fats, oils and greases (FOG) and plant scum and grease are the principal feedstocks assumed. In addition, this TM will apply anticipated performance and project gas production volumes for each of the Master Plan alternatives.

1.2 Summary of Findings

The key findings from this effort are listed below.

- The current digester mixing system has resulted in a significant loss of active volume. Upgrading the mixing system would restore active volume and allow for higher VS loading.
- The current data collection is inadequate to determine digester loading. It is recommended that primary and secondary sludge sampling and flow methods are improved.
- The current volatile solids reduction (VSR) and gas production values are within range of typical municipal anaerobic digester processes.
- The current digester temperature varies depending on the time of year and between individual units. It is recommended that better temperature control is implemented to provide a more stable condition for the digesters.
- At current peak sludge flow and load, nine digesters are required to meet the 15-day hydraulic retention time (HRT) criterion plus two redundant digesters. Currently, eight digesters are in operation and have performed well. There is evidence that active volume in a given digester may be greater with eight digesters operating than with eleven due to potentially better mixing from hydraulic load and higher volatile solids (VS) load generating more gas, which contributes to mixing.
- At current loads, operation with five digesters would be possible based on the organic loading criterion. This would reduce the HRT below the 15-day Part 503 Class B criterion from the digesters, but additional stabilization in the lagoons would potentially qualify the lagoon-harvested sludge as Class B. Testing would be required to confirm this and discussions with regulatory authorities would be required to confirm acceptability of this classification with this strategy. Reduced HRT (below 15 days) would also risk odor formation in the sludge lagoons. This would require testing to determine the impact of odor from the lagoon at reduced HRT.
- It is likely that the WPCP will receive import materials in the future. It is recommended that the design basis that implements the design import materials is used for this project.
- It is possible to operate a digester with 30 percent of the VS loading originating from import materials. It is recommended that the two pilot digesters are designed for this condition.
- The Cambi™ process (primary and secondary sludge) would require the fewest number of digesters, but would require ancillary facilities for pretreatment. In addition, the gas peaking factors for this alternative

are the highest of all of the alternatives. Since there are no space constraints at the WPCP, designing for the Cambi™ process is not recommended.

- The digesters that are rehabilitated will most likely be operated as mesophilic digesters and be equipped with submerged fixed covers. However, the gas systems should be designed to allow for series thermophilic operation. This means that the gas system manifold would be sized for peak instantaneous gas flow rate for the system.
- The digesters that are rehabilitated should have sufficient heating for mesophilic conditions. However, the option to upgrade to thermophilic digestion in the future should be considered.
- The Master Plan recommends adding a new primary and secondary sludge fine screening facility. This project team concurs and supports this recommendation to further develop a fine screening facility project.
- It is recommended that the City determine the on-going ability to dampen diurnal peaks of solids loads within the liquid stream. If this is possible, the City should continue to optimize this practice. If this is not possible, thickened sludge blend tanks should be considered for sludge load equalization and blending.

2. INTRODUCTION

Technical Memorandum 3.3 (TM 3.3) is the first of a series of TMs to be provided under Service Order Number (No.) 1 for the WPCP FOG Program Evaluation and Enhancement Study, Pre-design Study of Digester Rehabilitation, Modifications and Gas Line Replacement, and Implementation Plan. The primary goal of Service Order No. 1 is to evaluate the 16 existing digesters and develop an implementation plan for digester modifications that rehabilitates digesters needed for reliable service through the 2030 planning period in a way that will not limit long-term options for future digestion processes that may be used at the WPCP. The number of digesters that will be modified will be determined based on the future digestion processes. In addition, some of the digesters could be dedicated to full-scale pilot testing.

This TM serves as the project deliverable for Task 3 of Service Order No.1. The primary purpose of this TM is to define the design criteria (i.e. digester loading, gas production, HRT, VSR) for each potential digestion alternative to be used in subsequent work of Service Order No. 1. In addition, the rationale that is used for cost estimates is presented. The flow and loading projections used for the design criteria were developed based on information from the WPCP Master Plan (Master Plan) that is being conducted in parallel with this project. The design criteria are developed for a range of quantity and quality of feedstocks including primary sludge; secondary solids; WPCP scum from influent sewers, primary clarifiers, and secondary clarifiers; FOG; and food and food processing waste. This TM also documents background information for the analyses in other tasks.

2.1 Goals and Objectives of Project

Our approach on this project is to identify the physical modifications to the digesters necessary to either put them back in service, or keep them in service for the next 20 to 30 years, and to do so in such a way that the modifications can accommodate any process alternative forecasted or recommended by the Master Plan. A significant element of this approach is to design all individual digester elements and auxiliary systems based on the ultimate or maximum capacity of each digester vessel. This provides the most flexibility going forward. By upgrading the digesters in a phased approach and maximizing the capacity of each digester, the City can determine the ultimate number of digesters to be upgraded based on the results of the Master Plan and projections of alternate feedstock acceptance. A first phase of upgrading some of the digesters can proceed immediately to address reliability and performance issues without needing to decide on the ultimate number of digesters needed. The remaining volume, if any, is what is available for alternative feedstocks, such as FOG and food and food processing waste.

2.2 Purpose and Content of Technical Memoranda for Service Order No. 1

The purpose and topics covered by TM 3.3 include the following:

- TM 3.3 – Design Criteria for Digester Modifications and Gas System Improvements – The primary purpose of TM 3.3 is to define the design and operational criteria for future digester operation, including defining digester process configurations that are relevant for possible future implementation. Historical data, computer modeling, and information from the Master Plan are used to develop the projected loadings for 2030 and the design criteria. Several different digestion alternatives are identified, and relevant criteria are developed for design. Finally, design considerations for alternative feed stocks, such as FOG, are presented.

Task 4 of Service Order No. 1 provides an analysis of the existing anaerobic digesters and evaluates and recommends options for digester modification/rehabilitation and gas line replacement. Task 4 work products include the following TMs:

- TM 4.1 - Structural Evaluation, Corrosion Protection and Concrete Rehabilitation – This TM evaluates the existing digesters to determine whether they can structurally accommodate steel, concrete, aluminum, or composite material fixed covers, including submerged and non-submerged fixed covers. The existing 16 digesters are evaluated by grouping them into one of two categories to conduct structural computer modeling. Results from a visual corrosion inspection of 5 digesters that are currently not in service are presented.
- TM 4.2 - Cover and Mixing System Selection – This TM compares steel, concrete, aluminum and composite material cover types for submerged and non-submerged fixed covers and evaluates new floating covers and rehabilitation of the existing floating covers including converting the floating covers to fixed covers for the existing 16 digesters. An important consideration of the cover selection and design is the type of mixing; and therefore, this TM also includes the evaluation of digester mixing.
- TM 4.3A – Digester Piping Gallery Ventilation and Drainage – This TM evaluates the adequacy of the existing ventilation system and drainage for the digester piping gallery. The results of the evaluation are compared to the Infrastructure Condition Assessment report prepared by CH2M Hill in May 2007. Recommendations for digester pipe gallery ventilation and drainage improvements are developed in this TM. The ventilation rates, and thus the recommendations, are dependent on the location of the digester gas piping (remain in pipe gallery or move above ground), which is evaluated in TM 4.4.
- TM 4.3B – Digester Heating and Mechanical Modifications – This TM evaluates the existing facilities and operational data, and identifies and recommends improvements to the heating system for both mesophilic and thermophilic digestion process options. The digester heating system has been noted by operations staff as a significant problem. Reported difficulties include maintaining digester temperatures throughout the complex.
- TM 4.4 – Gas Piping Connections/Modifications – This TM evaluates the existing gas piping system and recommends modifications for connecting new covers to the existing gas system; replacement of gas piping and appurtenances on the remaining digesters; removal of gas piping from tunnels; and connection of new gas piping to gas storage tanks and gas flares. The evaluations include pressure relief valve replacement, control valve type and locations, gas piping valve isolation locations, gas pressure monitoring requirements, condensation collection, gas flow metering type and locations, and gas sampling locations. The evaluation also determines the capacity required for the gas management system based on the maximum capacity of the digesters including high strength waste from FOG and/or food and food processing wastes, if accepted at the WPCP. The evaluation of the gas management system also includes an evaluation of the capacity of the existing gas flares, but does not include evaluation of alternatives for new gas storage tanks or waste gas flares.
- TM 4.5 – Electrical and Instrumentation/Control Systems – This TM estimates the power requirements based on existing power demand and the proposed new equipment (e.g. mixing, heating, etc.) based on the results of TMs 4.2, 4.3, and 4.4. The existing electrical equipment in the digester area is also reviewed with recommendations, if required, for replacement of electrical equipment, including motor control centers, conduit, and wire in conjunction with modifications to the 16 existing digesters.
- TM 4.6 – Struvite Formation and Control – Struvite is an operation and maintenance problem at the WPCP. This TM evaluates the historical formation of struvite in the WPCP digesters, and struvite control options that may be implemented in conjunction with modifications to the 16 existing digesters. Also, preventive measures and controlled stimulation of struvite precipitation at advantageous locations are evaluated in this TM. A chemical equilibrium model, U.S. EPA's MINTEQA2, is used to evaluate the various options for struvite control. In addition, commercial processes such as OSTARA™, are considered for struvite control. OSTARA™ is a nutrient recovery technology that precipitates struvite in a defined location in the solids treatment system so phosphorous and ammonia can be harvested and used as a "green fertilizer".

- TM 5.0 - The rehabilitation/modification recommendations from the TMs developed in Task 4 are summarized in TM 5.0. A project description and basis of design, along with miscellaneous project elements such as site grading, civil improvements, miscellaneous mechanical and electrical improvements, safety, maintenance access, and constructability, are included. The elements of the project description focus on those improvements necessary to provide reliable capacity without precluding any viable future digestion process options evaluated in the WPCP Master Plan.
- TM 7.1 – Task 7 will prepare a business case evaluation for upgrading the dissolved air flotation thickeners (DAFTs) to co-thickening of both primary and secondary sludge. This task was authorized on July 20, 2010.

Concurrently with the digester rehabilitation/modification pre-design study, a FOG Program Evaluation and Enhancement Study is completed in Task 2. The work product for Task 2 is a report, which includes the following:

- Source Control (FOG Control) Program
- Estimation of FOG Waste Volume
- Evaluation of FOG Waste Disposal Practices
- Evaluation of Alternate FOG Waste Disposal Options
- Evaluation of Current FOG Outreach Efforts
- Evaluation of FOG Related Grants and Loans
- Final Recommendations

2.3 TM 3.3 Organization

The general organization of this TM is as follows:

SECTION 1:	EXECUTIVE SUMMARY
SECTION 2:	INRODUCTION
SECTION 3:	REVIEW OF BACKGROUND INFORMATION
SECTION 4:	EXISTING FACILITIES OVERVIEW
SECTION 5:	HISTORICAL OPERATING DATA
SECTION 6:	OVERVIEW OF ALTERNATIVES
SECTION 7:	DIGESTER FEED FLOW AND LOAD DESIGN BASIS
SECTION 8:	DIGESTER LOADING AND OPERATIONAL DESIGN BASIS
SECTION 9:	SUMMARY OF DESIGN CRITERIA
SECTION 10:	BASIS OF COST ESTIMATES
SECTION 11:	NUMBER OF DIGESTERS REQUIRED – EXISTING AND FUTURE CONDITIONS
SECTION 12:	GAS PRODUCTION PROJECTIONS
SECTION 13:	SUMMARY OF FINDINGS
SECTION 14:	REFERENCES

2.4 Scope of Work (Task 3)

The scope of work for this task (Task 3) consists of the following elements:

- The following documents were reviewed:
  - Infrastructure Condition Assessment report prepared by CH2M Hill, May 2007
  - San Jose/Santa Clara Water Pollution Control Plant Scum Digestion Pilot prepared by Black & Veatch, March 2006
  - City of San Jose Integrated Waste Management Zero Waste Plan, Conversion Technologies and Facilities (Draft Report) prepared by HDR, October 2008 prepared for the City of San Jose Environmental Services Department
  - Digestion Coating Inspection Reports for 2003, 2004, 2005, and 2007, prepared by Jorge Reyes, Michael Noble, Robert Matz, and Paul Blach
  - San Jose-Santa Clara Water Pollution Control Plant Process Piping Assessment prepared by CH2M Hill, May 2008
  - San Jose/Santa Clara WPCP Electrical System Improvement Study prepared by YEI Engineers, October 2004
  - Facilities Condition Assessment Study prepared by Black and Veatch, August 1997
  - Existing On-line Operations Manual
- Obtain and review as-built information – As-built information consisting of drawings and specifications for the existing anaerobic digesters were reviewed.
- Develop Design Criteria for Digesters – Design criteria for the project are developed for a range of quantity and quality of feedstocks including primary sludge; secondary solids; WPCP scum from the influent sewer, primary clarifiers, and secondary clarifiers; FOG; and food and food processing wastes. Options for integrating pre-digestion treatment and thickening of feedstocks, which are being evaluated in the WPCP Master Plan, were considered in developing a potential range of feedstock quantity and quality, so that future pre-digestion and digestion process options are not precluded by the recommended digester modifications.
- The capacity of the existing 16 digesters was evaluated and a corresponding equivalent wastewater capacity (MGD of plant influent flow as a function of digester feed solids concentration) if all digesters were in service with adequate redundancy was estimated. The existing operating data from the WPCP was evaluated to assist with determining digester capacity. Annual average and peak sludge loadings are projected based the projected flows and loads from the Master Plan.
- Design criteria established in the TM include minimum hydraulic retention time and maximum volatile solids loading. Based on this analysis, the number of existing digesters that will need to be rehabilitated and in operation in the future for primary and secondary sludge was estimated. Available capacity for FOG and food and food processing wastes were also estimated.

2.5 Master Plan Coordination

Under separate contract and parallel to this project, a Master Plan for the WPCP is being developed. Several tasks in the Master Plan effort are related to the anaerobic digester facilities including developing overall planning goals and objectives, establishing reliability and redundancy criteria, review of historical WPCP operating data, and projection of flow and loads. Elements of the Master Plan that were available at the time of publication of this TM were reviewed and incorporated as appropriate.

2.6 Acknowledgments

We offer our gratitude to the project team members from the City who provided valuable assistance in completing this evaluation. In particular, we wish to thank Mr. Ravi Kachhapati, Dr. Alex Ekster, Ms. Bhavani Yerrapotu, Mr. Dale Irkhe, Ms. Ting Ong, Mr. Steve Contreras, Dr. Issayas Lemma, Dr. Rong Liu and Mr. John Chien for their support in this effort and the WPCP staff who provided valuable insight during the site visits and project meetings.

3. REVIEW OF BACKGROUND INFORMATION

This section provides a discussion of the background information that was reviewed in developing this TM. Background information reviewed consisted of seven reports, WPCP existing on-line manual, and six as-built drawings and specification sets.

3.1 Previous Studies and Reports

The City provided seven reports that were reviewed as a part of the development of this TM and the TMs for Task 4. A brief summary of each of the reports, including relevance to the current work, is provided below:

3.1.1 Infrastructure Condition Assessment Report prepared by CH2M Hill, May 2007

This report provided a detailed assessment and evaluation of the condition of the WPCP's assets and facilities, organized by treatment process area including anaerobic digester and digester gas systems. Each asset in the process was identified, its functionality summarized, and location highlighted on a Main Processes Map provided in the report. At the conclusion of each process description, civil, architectural, structural, mechanical, and electrical condition of each asset was provided. Recommendations for repair and replacement projects were included in each section as well.

This report identified potential improvements for each of the digesters. A summary of the improvements as they relate to this project is provided in Table 3-1. Recommendations for gas collection and conveyance system improvements are summarized below.

Gas Collection and Conveyance

- Replace gas piping in tunnels and gas collection lateral from digesters, including valves, flame arrestors, moisture traps, seismic valves, flexible couplings, etc.
- Construct new redundant gas flare.
- Correct drainage around gas flares.

The information in this report provides background information for developing Technical Memoranda 4.1, 4.2, 4.3A, 4.3B, 4.4, and 4.5. This information, confirmed by site visits and analysis, form the basis for evaluating the existing facilities.

3.1.2 San Jose/Santa Clara Water Pollution Control Plant Scum Digestion Pilot, prepared by Black & Veatch, March 2006

This study provided a summary of the pilot study of a proposed process for the disposal of WPCP scum and addressed the feasibility and practicality of anaerobic digestion of scum. Comparing the digester performance between a digester with scum addition to the mixed sludge (Digester 7) and without scum addition (Digester 8) suggests that the scum can be successfully digested with anaerobic digestion. In addition, this report included a study investigating the addition of restaurant FOG to a digester. The viability of adding restaurant FOG to the digestion process was confirmed in the study. The study recommended a phased implementation plan and provided some estimated construction costs.

This report provides information on then current 2006 WPCP scum handling and disposal costs and potential design considerations for WPCP scum and restaurant FOG digestion in the existing digesters.

Table 3-1. Summary of Digester Improvements Recommended in the Infrastructure Condition Assessment Report prepared by CH2M Hill, May 2007

Potential Improvements	Digester 1	Digester 2	Digester 3	Digester 4	Digester 5	Digester 6	Digester 7	Digester 8	Digester 9	Digester 10	Digester 11	Digester 12	Digester 13	Digester 14	Digester 15	Digester 16
Replace digester cover		√		√	√	√										
Replace digester mixing system	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Improve digester heating system	√	√	√	√	√	√						√	√	√	√	√
Improve drainage, grading, and hardscaping (pavement improvements around digester)	√	√	√	√	√	√	√	√	√	√	√					
Replace corroded handrails and stairs	√	√	√	√	√	√	√	√								
Replace MCC B and associated transformer	√	√	√	√												
Improve lighting, lighting panels and control stations with corrosion resistant cabinets	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Replace copper control wiring (Switches RP1 and RP2 to S800 Remote I/O)	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Replace MCC V and associated transformer and lighting panel									√	√	√					
Improve water pressure at remote digesters												√	√	√	√	√
Replace MCC Y1, MCC Y2, and associated transformer and lighting panel												√	√	√	√	√

3.1.3 City of San Jose Integrated Waste Management Zero Waste Plan, Conversion Technologies and Facilities (Draft Report) prepared by HDR, October 2008

This report evaluated developing renewable energy from portions of municipal solid waste streams, including food and food processing waste, using conversion technologies or alternative technologies. New facilities and new technology will be needed to reach the City's goal of 75 percent diversion by 2013 and zero waste by 2022. An overview of conversion technologies was provided in this report. The overview included thermal processing and biological processing where anaerobic digestion is considered.

This report also provided recommendations of viable alternatives for further consideration. Included in the recommendations is high and low solids anaerobic digestion operation. The next logical steps for the City as it pertains to anaerobic digestion of alternative feedstocks are to evaluate FOG as an additional feedstock incorporated into the digesters and wait and see how the technologies develop at other facilities for incorporating municipal solid waste as a feedstock.

This report is still in the draft stage and in the initial stages of the City's evaluation; and therefore, does not provide significant information for this pre-design study.

3.1.4 Digestion Coating Inspection Reports for 2003, 2004, 2005, and 2007, prepared by Jorge Reyes, Michael Noble, Robert Matz, and Paul Blach

All of the digesters except for Digester 2 were inspected in these reports. These reports provide the results of corrosion and coating surveys and the inspection of the interior bottom and the walls of each floating cover attic space. The inspections consisted of measuring the dry film thickness of the cover coatings and a visual inspection for corrosion, delaminating of coatings, and bubbling defects. The interior concrete walls were also inspected for cracks, concrete spalling, and other surface defects. These reports contain coating dry film thickness readings, recommendations for corrective action, and an estimated life expectancy of the coatings for each of the digesters.

Task 4.1 of Service Order No. 1 includes a corrosion inspection of the five digesters currently not in service: Digesters 2, 4, 5, 6, and 8. The information in the above referenced report provides additional information on Digesters 4, 5, 6, and 8 along with information on those digesters that could not be physically inspected under Task 4.1 because they were in operation.

3.1.5 San Jose-Santa Clara Water Pollution Control Plant Process Piping Assessment prepared by CH2M Hill, May 2008

This study developed a database for process piping 8-inches and greater at the WPCP. The database was used to conduct a risk analysis and identification of key piping systems that may require replacement. The risk analysis results were based on the database information and WPCP staff interviews. The risk analysis used three objectives in ranking and prioritizing process piping for replacement. These objectives were probability of failure, trigger factors or performance related issues, and severity of consequences of failure. The piping systems identified with the highest relative risk were digester gas, sanitary sewer force mains, secondary effluent, blended gas, raw sewage, natural gas, waste sludge, and chlorinated effluent, with digester gas piping having the highest ranking. An approach for inspection of the digester gas piping was developed in this study.

The information in this report provides background information for TM 4.4, which evaluates the digester gas piping system and its potential relocation.

3.1.6 San Jose/Santa Clara WPCP Electrical System Improvement Study prepared by YEI, Inc., October 2004

This report documents the electrical system at the WPCP, and includes a facilities assessment, power system analysis, overall system redesign, equipment replacement prioritization, schedule and costs, and a cogeneration feasibility study. Specifically, this document addresses operations and maintenance issues associated with the electrical power distribution system, an investigation of the cable feeder, an evaluation of the substations and generators, a harmonic analysis of variable frequency drives, adequacy of insulation, an assessment of the protective relay system, an evaluation of the main and load center switchgears, and an assessment of the cogeneration equipment, including generators and engines. Recommendations for each area were developed into projects and prioritized. Costs and scheduling were included as part of the project development.

The information provided in this report is for the larger components of the electrical system; and therefore, has limited value to the digester project, which has smaller electrical components. The relevant information in this report to the digesters will be used as background information in developing TM 4.5.

3.1.7 Facilities Condition Assessment Study prepared by Black and Veatch, August 1997

This report is a comprehensive condition assessment of the WPCP facilities. An assessment of each asset is provided as part of its respective treatment process and is displayed on a Main Processes Map at the beginning of each section. For each treatment process section, the study addresses the facility history, a description of the structure and equipment, the investigation and testing completed to date, the current asset condition, cost estimates, and recommendations. Photos of each asset are provided in the assessment to display condition issues.

Understanding this assessment, along with the CH2M Hill Infrastructure Condition Assessment (May 2007) study, gives important details related to the condition and maintenance of the assets at the WPCP facilities. The information in this report provides background information for developing TM 4.1, 4.2, 4.3A, 4.3B, 4.4 and 4.5. This information, confirmed by site visits and analysis, form the basis for evaluating the existing facilities.

3.1.8 Existing On-line Operations Manual

The On-line Operations Manual provides standard operating procedures, sampling protocol and schedules, process schematics, equipment information, design data, alarm conditions, and emergency response procedures for the digestion facilities. The information contained in the On-line Operations Manual is used in Section 2 of this TM to provide background information on existing facilities.

3.2 Existing As-built Drawings and Specifications

The existing as-built drawings and specifications were reviewed to obtain an understanding of the existing WPCP digester facilities. Site visits were conducted to confirm as-built information. The following existing as-built drawings and specifications were reviewed.

1. Contract Drawings for Construction of Sewage Treatment Works, Volume 1 and 2, Brown and Caldwell, December 1, 1954 (specifications not provided).
2. Contract Drawings for Construction of San Jose Sewage Treatment Works Plant Additions 1960-1, Brown and Caldwell, July 1960.
3. Sewage Treatment Works Improvements, Division D, Primary Treatment – Sludge Digestion – Site Development, Consoer, Townsend & Associates, 1961.
4. Water Pollution Control Plant Improvements, Stage IIB, Consoer, Townsend & Associates, 1966.
5. Contract Documents for the Construction of Intermediate-Term Sludge Processing Facilities, Volume 3, JM Montgomery Consulting Engineers, Inc. and CH2M Hill, April 1983 (specifications not provided).
6. Contract Documents for the Construction of First Stage Expansion Sludge Processing Facilities, Volume 2, JM Montgomery Consulting Engineers, Inc. and CH2M Hill, May 1985 (specifications not provided).

4. EXISTING FACILITIES OVERVIEW

The digestion facilities, along with the feedstocks and the facilities associated with the feedstocks are described in this section.

4.1 Feedstocks

Thickened primary sludge and thickened waste activated sludge (TWAS) are currently fed to the digesters. Plant scum and grease are not fed to the digesters but hauled offsite to a landfill. Figure 4-1 shows the flow metering and sampling locations for the existing feedstocks.

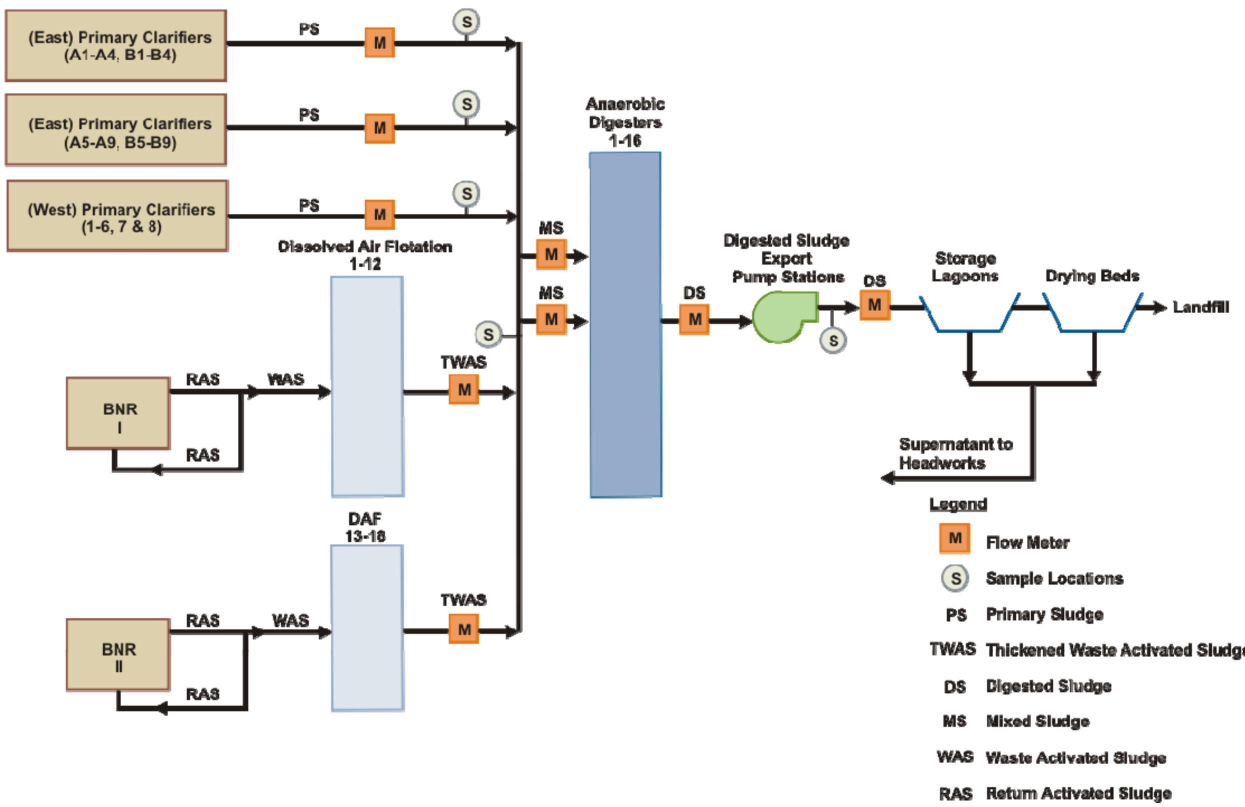


Figure 4-1. Solids treatment flow metering and sampling locations

4.1.1 Primary Sludge Feedstock

The primary sludge feedstock is the settled solids from the primary clarifiers. The WPCP has two sets of primary clarifiers: the east primary settling tanks (primary clarifiers) consist of 18 tanks, which are divided into two sets of primary clarifiers, and the west primary settling primary clarifiers consist of eight tanks. The west primary clarifiers were recently put into service.

The primary sludge is thickened in the primary clarifiers. The thickened primary sludge concentration averages approximately 3.9 percent total solids (TS) with a range from 1 percent to 9 percent TS. Data for the primary sludge pumps is provided in Table 4-1.

Table 4-1. Primary Sludge Pump Data		
Parameter	Unit	Data
East Primary Tanks		
Number of sludge pumps	--	14
Type	--	Progressive Cavity
Design capacity, each	gpm	250 @ 50 psig TDH (4 pumps) 100 @ 52 psig TDH (10 pumps)
Power, each	hp	15[a]
West Primary Tanks		
Number of sludge pumps	--	3
Type	--	Progressive Cavity
Design capacity, each	gpm	250 @ 50 psi TDH
Power, each	hp	15

Source: San Jose/Santa Clara Water Pollution Control Plant On-line Operations Manual

[a] Motors hp verified in O&M manual. Motor oversized for 100 gpm service condition.

The primary sludge pumps convey primary sludge to the blended sludge header pipe upstream of the digesters, where primary sludge is blended with TWAS before being fed into the digesters. The TS information is recorded as three separate samples with combined samples for the two sets of east primary clarifiers and one sample for the west primary clarifiers. The combined primary sludge flow from each battery of primary clarifiers is measured by magnetic flow meters.

4.1.2 Waste Activated Sludge Feedstock

The secondary aeration tanks and secondary clarifiers (BNR I) and the nitrification tanks and nitrification clarifiers (BNR II) operate in parallel to provide secondary and advanced treatment for the WPCP. Settled sludge from the secondary clarifiers is withdrawn using vacuum-type rotating collectors. Waste activated sludge (WAS) is pumped from the return activated sludge (RAS) well to DAFT units for thickening. Information on the WAS pumps is summarized in Table 4-2. WAS flow and solids concentrations are measured and recorded for each secondary and nitrification battery prior to sludge thickening.

Table 4-2. WAS Pump Data		
Parameter	Unit	Data
Secondary Clarifiers (BNR I)		
Number of WAS pumps	--	4
Type	--	Horizontal centrifugal
Design capacity, each	mgd	2.5 @ 30 ft TDH
Power, each	hp	20
Nitrification Clarifiers (BNR II)		
Number of WAS pumps	--	6
Design capacity, each	mgd	0.25 (4 pumps) 1.4 (2 pumps)
Power, each	hp	5 (4 pumps) 25 (2 pumps)

Source: San Jose/Santa Clara Water Pollution Control Plant On-line Operations Manual

The purpose of the DAFT units is to thicken WAS from the secondary and nitrification clarifiers. The DAFT process comprises 16 rectangular concrete tanks with chain and flight mechanisms to collect floating and settled sludge. Typically, the west tanks (Numbers 1 through 12) receive WAS from the secondary system (BNR I), while the east tanks (Numbers 13 through 16) receive WAS from the nitrification system (BNR II). The TWAS from the system typically has a concentration of 3.5 to 4.0 percent TS. Polymers are not used to increase thickened solids concentration or capture. The TWAS is conveyed to the blended sludge header pipe upstream of the digesters, where primary sludge is blended with TWAS before being fed into the digesters. The East and West DAFT tanks contain individual flow meters and TWAS sampling occurs on the combined flows from the East and West DAFT tanks as shown in Figure 4-1. Plant staff has reported that the TWAS flow meters have not been accurate; therefore, these flow rates are not used in subsequent analyses. Data and original design criteria for the DAFTs are summarized in Table 4-3. Operational data from 2006 to 2007 are also summarized in Table 4-3. Solids capture rate average approximately 98 percent in these two years which indicate good solids capture in the DAFTs.

Table 4-3. DAFT Design Data [a] and Operational Data (2006-2007) [b]

Parameter	Unit	Data
DAFT Design Data[a]		
Total number of tanks		16
West DAFTs		12
East DAFTs		4
Surface area, each	sf	1640
Solids loading rate, maximum	lb/sf/hr	0.42
Hydraulic loading rate, average flow	gpm/sf	3.4 (Original design criteria)
Detention time, average flow	hr	0.23 (Original design criteria)
Thickened sludge pumps		
Number	--	6
Type	--	Progressive cavity
Capacity, each	gpm	400 gpm at 70 feet TDH (3 pumps) 700 gpm at 92 feet TDH (3 pumps)
Historical Operational Data (2006 to 2007 annual averages)[b]		
DAFT Influent Loading	lb/day	133,000
DAFT Influent Loading, maximum month	lb/sf/hr	0.36[c]
DAFT Influent Loading, average	lb/sf/hr	0.22[c]
TWAS TS Content	percent	3.56
Capture Rate	percent	98

[a] *Source: San Jose/Santa Clara Water Pollution Control Plant On-line Operations Manual*

[b] *Source: Data from information provided by City for Master Plan*

[c] *Maximum monthly load for years 2000 through 2007. From Master Plan Task No.3, Draft Project Memorandum No. 4, July, 2009.*

4.2 Plant Scum and Grease

The primary clarifiers use chain and flight scrapers to collect settled sludge and floating scum. Rotating scum troughs at the end of each tank receive and convey the floating scum to scum pumping stations. Two scum pumping stations collect scum from the primary clarifiers and convey it to the scum handling building. The scum handling building includes a septage receiving station, two scum thickeners, and an odor control scrubber. The scum from the primary clarifiers is thickened prior to offsite landfill disposal.

Other WPCP scum sources include secondary clarifier scum and plant influent scum. Scum from the secondary and nitrification clarifiers is routed to a scum pumping station where the scum is pumped to the 84-inch influent line. Scum at the WPCP is also collected in the sewer upstream of the headworks area, which is also landfilled offsite.

4.3 Anaerobic Digestion Facilities

This section discusses the facilities associated with anaerobic digestion.

4.3.1 Anaerobic Digesters

The anaerobic digesters receive thickened primary sludge from the primary clarifiers and thickened secondary sludge from the DAFT process. The system uses a conventional high-rate, mesophilic anaerobic digestion process to reduce VS, produce digester gas, and reduce pathogens in the sludge. The digested sludge is conveyed to the Digested Sludge Export Pumping Station (DSEPS) where it is pumped to the WPCP's Residual Solids Management facilities.

There are 16 cylindrical tank, anaerobic digesters with floating covers, gas-mixing systems, and pumped heating loops. Currently, eight digesters (Digesters 9 through 16) are in operation. Data on the digesters and original design criteria is included in Table 4-4. Each digester has a separate heating system installed at ground level outside the respective digester. Each digester's heating loop includes one concentric tube heat exchanger that transfers heat generated from the cogeneration engines and/or boilers to the digested sludge recirculation line.

4.3.2 Anaerobic Digester Mixing

A portion of the digester gas is returned to the digesters through gas compressors to provide mixing. Each digester is equipped with one liquid ring gas mixing compressor having a design capacity of 200 cubic feet per minute (cfm) at 21 pounds per square inch, gauge pressure (psig) and a 30-horsepower (hp) electric motor (Source: San Jose/Santa Clara Water Pollution Control Plant Online Operations Manual). The Infrastructure Condition Assessment Report prepared by CH2M Hill in May 2007 indicated that the mixing systems in all of the digesters should be replaced. TM 4.2 further discusses the issues with the existing mixing systems and provides an evaluation of new mixing systems with recommendations.

4.3.3 Active Digester Volume

Active digester volume refers to the available volume for a well incorporated slug of feed to reside in close proximity to active microorganisms and for close to the average time of the other feed solids. Active volume can be decreased by poor mixing, grit accumulation, struvite, other debris and scum accumulation, and by lower digester operating level. The existing gas mixing system is undersized compared to typical recommended design standards (this issue will be discussed in TM 4.2) and the digesters have a history of heavy grit and debris accumulation. For these reasons, it is anticipated that the digesters are operating at an active volume well below their maximum potential. This issue is discussed in detail in Section 8.2 of this TM.

Table 4-4. Anaerobic Digesters at Original Design Conditions [a]		
Parameter	Unit	Data
Total Number of Digesters	--	16
Digesters 1 through 3		
Diameter	ft	100
Average sidewater depth [b]	ft	25[b]
Volume, each digester [c]	MG	1.64[c]
Digesters 4 through 16		
Diameter	ft	110
Average sidewater depth [b]	ft	34.2[b]
Volume, each digester [c]	MG	2.67[c]
Solids retention time @ mean peak week	days	16.4 (original design criteria)
Dry total solids loading rate @ mean peak week	lb/day	657,000 (original design criteria)
Volatile solids loading rate @ mean peak week	lb/day	460,000 (original design criteria)[b]
Volatile solids loading rate @ mean peak week	lb VS/cf/day	0.10 (all 16 digesters in operation)

[a] *Source: San Jose/Santa Clara Water Pollution Control Plant On-line Operations Manual*

[b] *Based on "Normal Water Surface" elevation reported in Operations Manual*

[c] *Volume includes the bottom cone portion of the digester: Assumes 11 foot deep cone on large digesters and 10 foot cone on small digesters. See Table 8-1 and Section 8.2 for discussion of active digester volume.*

[d] *Note that the original design VS content was 70 percent, and the actual VS content has historically been approximately 80 percent.*

4.3.4 Sludge Heating and Sludge Recirculation System

The heat exchangers and hot water recirculation pumps were designed to maintain the sludge temperature at 95 to 100 degrees Fahrenheit (F) to maintain proper mesophilic anaerobic digestion conditions. Each of the 16 digesters is equipped with a concentric tube heat exchanger with a rated capacity of 900 gallons per minute (gpm) sludge recirculation and 180 to 250 gpm of heated water. Each of the 16 digesters includes a 1.5-hp hot-water recirculation centrifugal pump with a capacity of 180 gpm at 23 feet total dynamic head (TDH) (Source: San Jose/Santa Clara Water Pollution Control Plant On-line Operations Manual). The heated water loop is a two-pipe direct return system.

The WPCP staff has indicated that maintaining temperatures, especially in the colder months and at the far end of the heated water loop is difficult. This impacts Digesters 9 through 16 the most. TM 4.3B provides a detailed analysis of the sludge heating system, the problems associated with the existing system, analysis of mesophilic and thermophilic heating requirements, and recommendations for heating system improvements.

4.3.5 Digester Gas

Gas produced in the anaerobic digesters is collected and conveyed to the gas storage, blending, and compression systems using a network of pipes installed in tunnels throughout the digester complex. Each digester is equipped with gas collection piping that includes a flow meter, a flame arrestor, pressure relief valve, moisture trap, and isolation valves. Flexible hoses connect the digester floating cover with the gas piping. Digester gas is stored in a steel tank that has a water sealed gasholder cover. The tank equalizes gas flow to better match consumption by the cogeneration engines. The storage tank is located near the scum handling facilities. The gas blending and compression system, housed in the sludge control building, delivers a mixture of digester gas, landfill gas, and natural gas to cogeneration engines. TM 4.4 discusses in further detail the digester gas management system.

4.3.6 Piping Galleries

The piping galleries are underground tunnels that contain piping for primary sludge, thickened sludge, digested sludge, hot water supply and return, digester gas, as well as various ancillary piping systems. These tunnels are discussed in further detail in TM 4.3A, Digester Piping Gallery Ventilation.

5. HISTORICAL OPERATING DATA

A review of historical data is provided in this section. The DSEPS flow meter data was used to determine digester HRT. The primary sludge loadings were determined using primary clarifier TSS removal data. The secondary sludge loading was determined using the DAFT flow (determined by subtracting the DSEPS flow from the primary sludge flow) and the plant reported DAFT concentration.

5.1 Digester Loading

Figure 5-1 presents the historical VS loading to the digesters. Figure 5-2 presents the same loadings divided by the active volume of digesters in service. The historical 7-d running average VS loadings ranged from 0.04 to 0.13 pounds VS per cubic foot per day (lb VS/cf/day). The recent increase is because the number of digesters in service has been reduced from 11 to 8.

Historically, recommended maximum design digester loading criteria for a well mixed mesophilic digester ranged between 0.12 to 0.16 lb VS/cf/day, which indicates the WPCP digesters are not overloaded at the current condition. Under ideal conditions, mesophilic digesters are capable of loadings well above even these values. However, in municipal wastewater digesters, varying peak loads, imperfect mixing, varying substrate characteristics, high ammonia concentrations, inhibitory effects from other compounds, and the potential for slug loads of other destabilizing or toxic compounds make conditions less than ideal and require prudent conservatism.

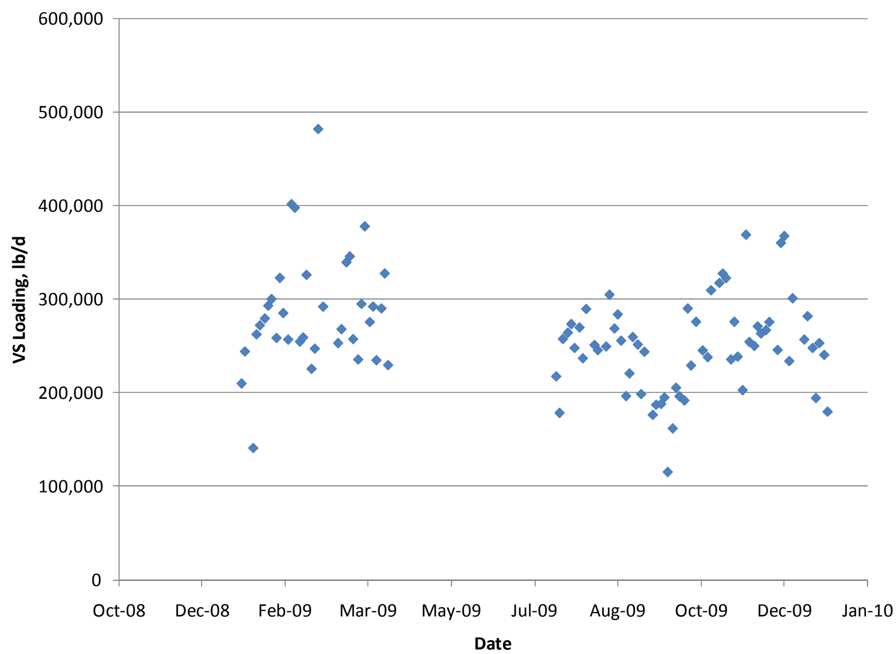
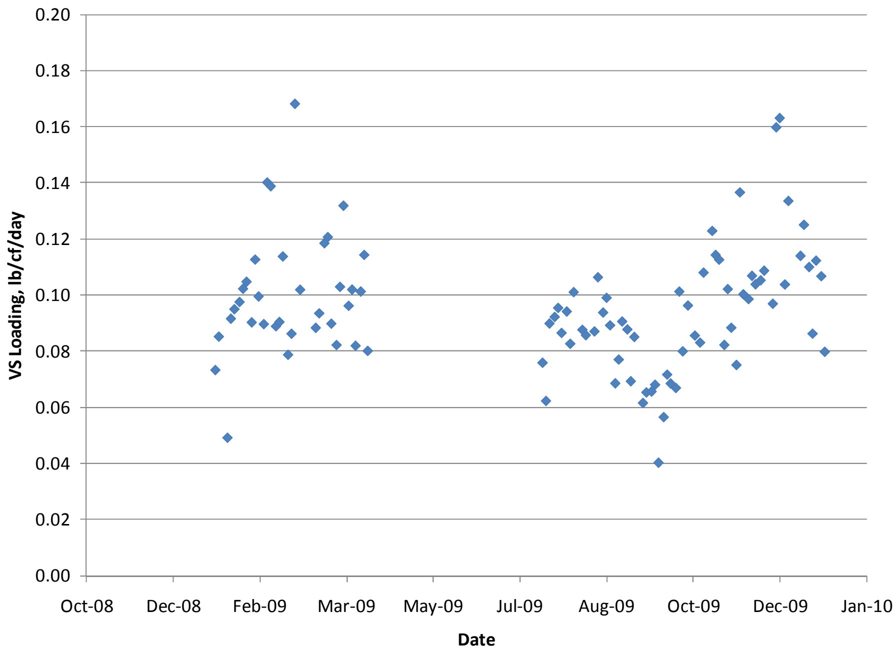


Figure 5-1. Summary of historical VS loading



Note: Assumes an existing active digester volume of 2.11 MG (Digesters 4-16) and 1.23 MG (Digesters 1-3) from Table 8-1.

Figure 5-2. Summary of historical normalized VS loading

5.2 Digester Temperature

Temperature is important in determining the rate of digestion and providing optimum conditions for microorganism growth. Maintaining a stable operating temperature is also important, as the bacteria in the digester are sensitive to temperature fluctuations. Conversion of VS and subsequent gas production is most efficient at about 95 to 98 degrees Fahrenheit (F) for mesophilic digestion. Mesophilic operation above 95 degree F is mandatory for plants wishing to meet the EPA Part 503 criteria for a Process to Significantly Reduce Pathogens (PSRP). However, San Jose is not required to meet the temperature criteria of 95 degrees F in the digesters, because the digesters are followed by lagoons and drying beds, where Class A pathogen criteria are met.

Good operating practice avoids temperature changes greater than 2 degrees F per day to minimize stress on active microorganism and to help maintain stable conditions for optimum growth. Daily temperature fluctuations in excess of 2 degrees F were observed in the San Jose digesters in the data from 2006 through 2007 (Table 5-1). Depending on the digester, daily temperature fluctuations above two degrees F occurred between 0 to 8 percent of the time in those two years. Digester 7 seems to be the digester with the most temperature fluctuations. Temperature fluctuations are typically due to limitations in the heating loop control, changes in digester feed, poor mixing, and exceeding the capacity of the heating system. The most likely cause of the Digester 7 fluctuations is limitations in the heating loop. This is further addressed in TM 4.3B – Digester Heating and Mechanical Modifications.

Seasonal fluctuations are also important to consider. If changes are made gradually, microorganisms can adapt to tolerate new operating temperatures, but reduced temperatures will reduce performance, specifically volatile solids reduction and gas production. Plots of historical digester temperatures are presented in Attachment C. Figure 5-3 presents one representative plot for digesters 13 through 16 and shows historical seasonal fluctuations in digester temperature. Average temperatures during this period were approximately

95 degrees F, while low cold weather temperatures were typically around 93 degrees F and warm weather temperatures were typically around 97 to 98 degrees F. In 2008, plant operations began increasing the digester temperature control set point. Through 2009 and early 2010, average temperature for all digesters was approximately 97 degrees F and fluctuated between 93 and 100 degrees F (Figures 5-4 and 5-5). As will be discussed in Section 8.4 and Attachment B, stable operation at these two temperatures can result in a 2 percentage point difference in VSR and a comparable and compounding difference in specific gas production.

Table 5-1. Historical Digester Annual Average Operating Temperature, degrees F

Digester Number	Year 2006	Year 2007	Percent Occurrence of Daily Temperature Change > 2°F (2006–2007)
1[a]	94.6	96.2	0.5
2[b]	---	---	---
3	94.8	95.2	2.5
4[b]	---	---	---
5[c]	96.9	---	0
6[b]	---	---	---
7[d]	95.9	105.4	8.1
8[c]	96.2	---	0
9	95.3	95.8	0
10	95.6	95.7	0.4
11[e]	---	95.6	0
12[f]	95.2	94.8	0
13[g]	95.5	95.2	0.6
14[h]	95.4	95.6	0.3
15	94.8	95.1	0.9
16	95.8	95.7	0.6

Source: Data from information provided by City for Master Plan.

[a] Digester 1 was out of service through November 2006.

[b] Digesters 2, 4, and 6 were out of service.

[c] Digesters 5 and 8 were out of service from December 2006 through December 2007.

[d] Digester 7 was out of service September 2006 through August 2007.

[e] Digester 11 was out of service all of 2006 and January and February of 2007.

[f] Digester 12 was out of service from mid-September to mid-October 2007.

[g] Digester 13 was out of service for most of October 2007.

[h] Digester 14 was out of service from mid-October to mid-November 2007.

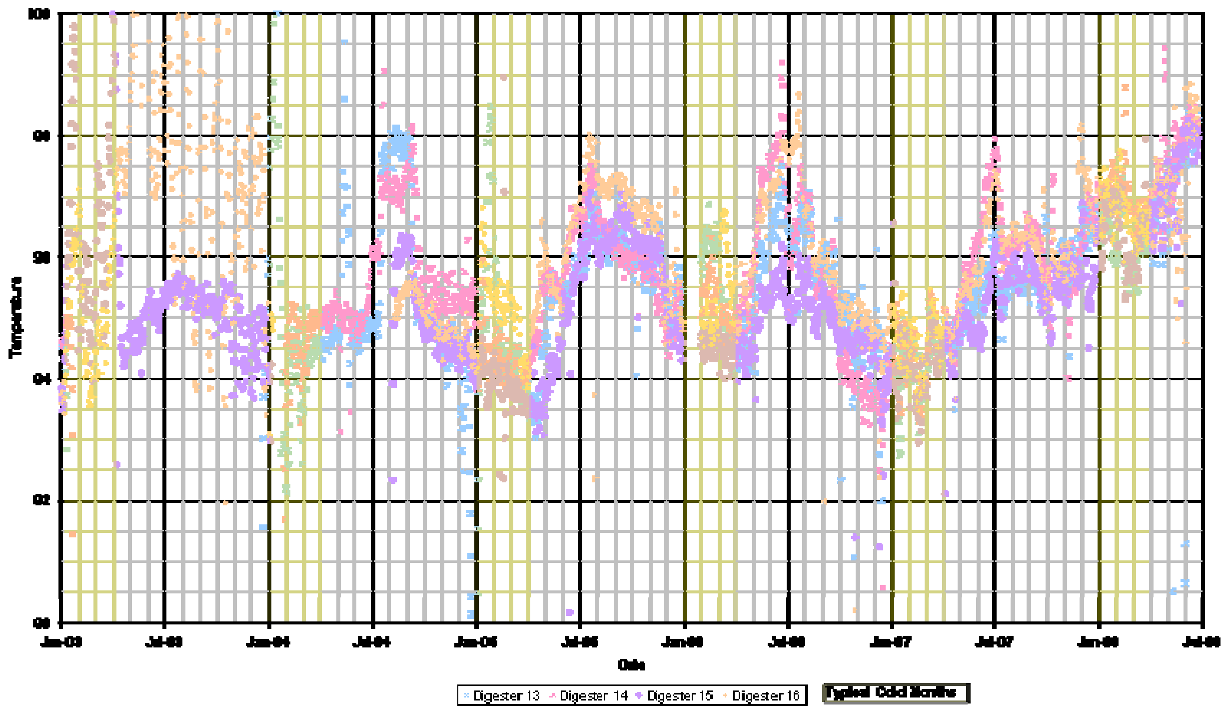


Figure 5-3. Historical digester operating temperatures for Digesters 13 through 16

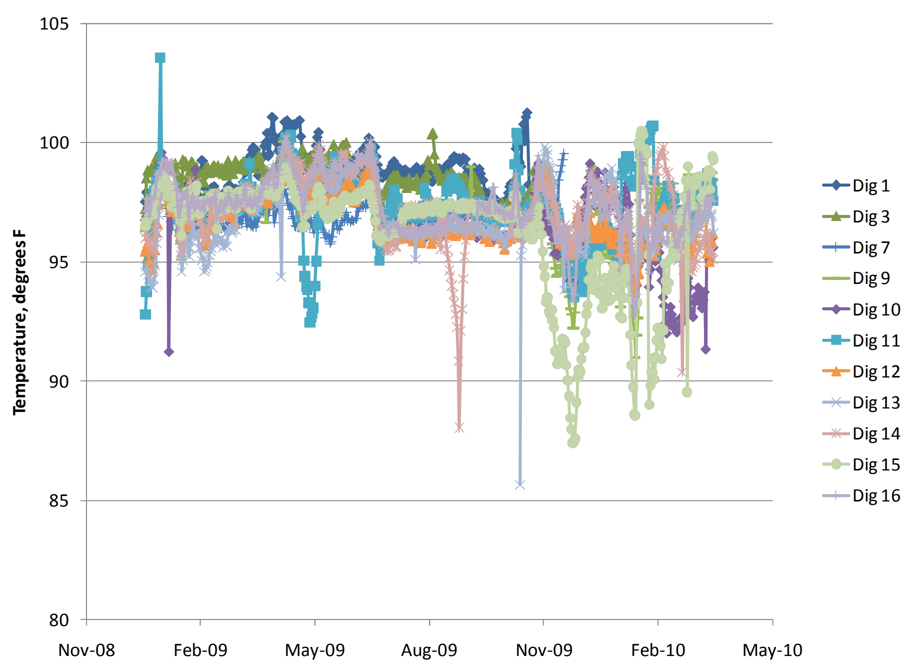


Figure 5-4. Historical digester operating temperatures.

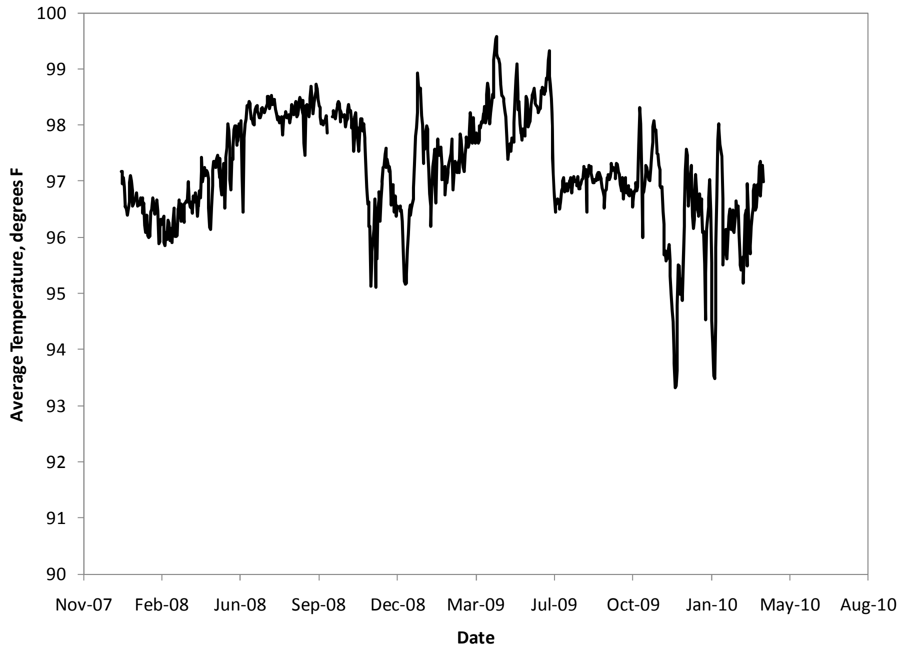
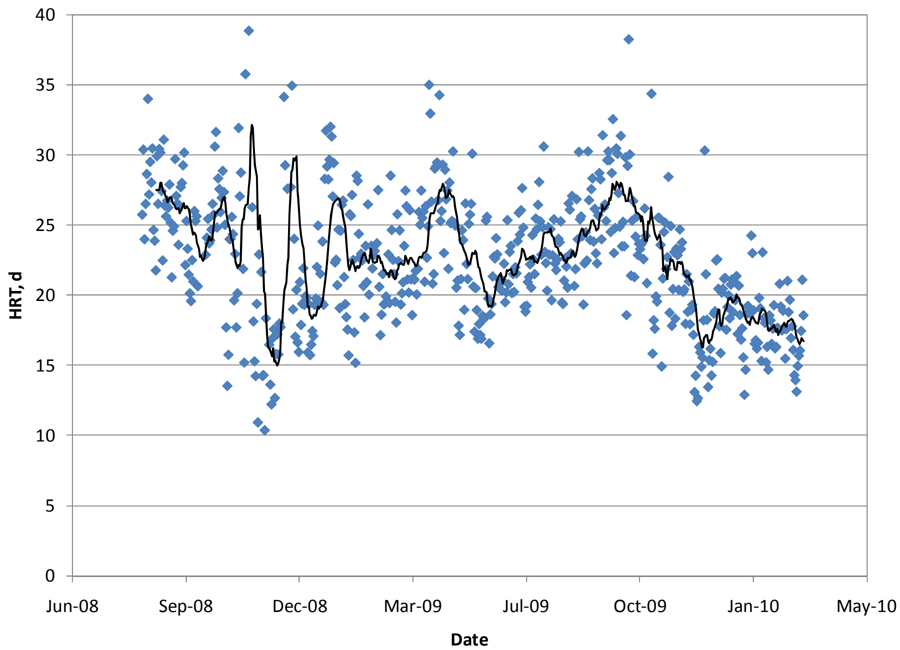


Figure 5-5. Average digester temperatures.

5.3 Digester Hydraulic Residence Time (HRT)

For digesters without recycle as is the case with San Jose's digesters, HRT and solids residence time (SRT) is the same. Therefore, this TM uses HRT. Figure 5-6 presents the historical HRT values. The 14-d average HRT values have ranged from 15 to 32 days. The recent decrease is HRT is because only 8 digesters are in service. Recommended design digester solids HRT ranged between 15 to 20 days at peak loadings. In addition, a minimum 15 day HRT is required if production of Class B biosolids is desired. These HRTs indicate adequate detention time for treatment at current capacity, assuming that the mixing system provides effective use of tank volume. However, as is discussed in TM 4.2, Cover and Mixing System Selection, the existing mixing system does not appear to effectively mix the entire tank volume.



Note: Assumes an existing active digester volume of 2.11 MG (Digesters 4-16) and 1.23 MG (Digesters 1-3) from Table 8-1.

Figure 5-6. Historical digester HRT (Black line represents 14-d running average)

5.4 Volatile Solids Reduction

VSR can be calculated using either the Van Kleeck method or the mass balance method. For digesters that have a significant level of grit deposition, the mass balance method is recommended. Figures 5-7 and 5-8 present the VSR using the Van Kleeck and mass balance methods, respectively. The Van Kleeck method calculation yields significantly lower VSR values than the mass balance method.

VSR values for plants in California receiving combined primary and WAS feedstock can average between 50 and 60 percent. To correct for the disparity between the mass balance and Van Kleeck calculated values, a method was developed to adjust to a "true VSR" based on correcting for loss of fixed solids through deposition in the digester. This analysis is discussed in Attachment A and estimates an average "true VSR" in the San Jose digesters for the period of July 19 through November 12 of 2009 at 54 percent. This analysis of historical digester performance indicates that the VSR values at the WPCP are typical (see Attachment A). In addition, a BioWin model of the digesters was calibrated and validated for this same period (Attachment B). The model results correlate with the adjusted VSR values after considering and adjusting for active digester volume. The results of the analyses in Attachment A and Attachment B indicate that with conventional mesophilic digestion, greater VSR at a given HRT and temperature may not be possible at the WPCP based on the comparison to other plants with similar high liquid stream SRTs.

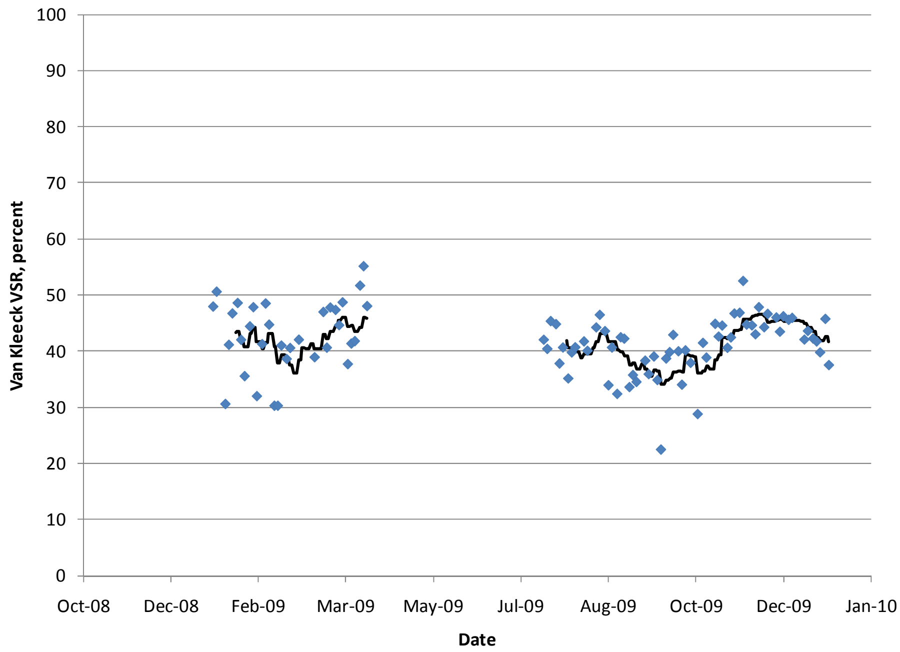


Figure 5-7. Historical VSR using the Van Kleeck method (Black line represents 14-d running average)

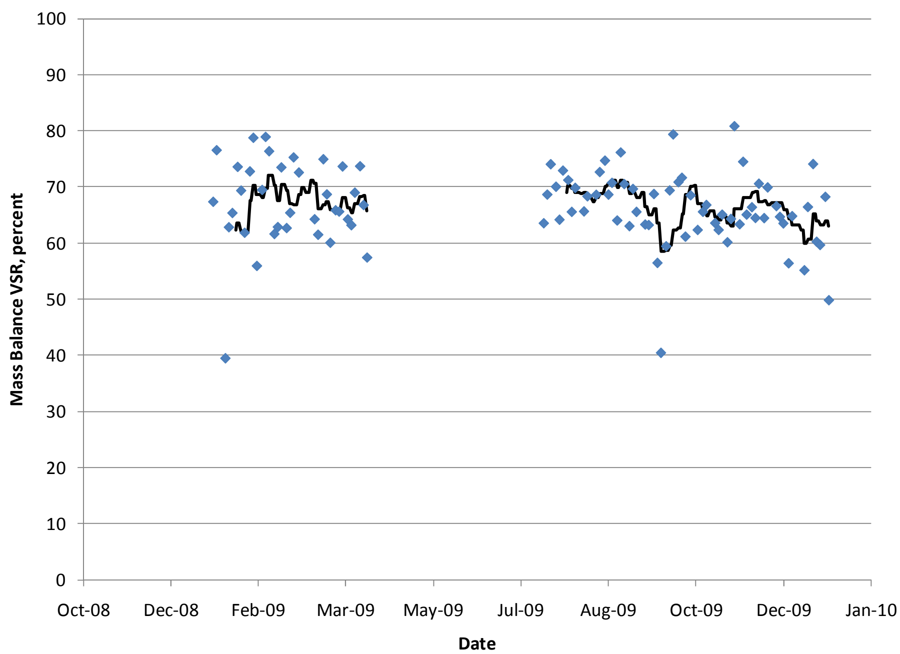


Figure 5-8. Historical VSR using the mass balance method (Black line represents 14-d running average)

Figure 5-9 presents the mass balance VSR versus HRT for the period from July through December 2009. During the month of November, digesters were being taken off line as plant staff transitioned from 11 to 8 digester operation. The VSR increases with increasing HRT as expected in the range from 15 to 25 days. However, above 25 days a steep decline in VSR is shown. An ideal digestion system would be expected to continue VSR improvement as HRT increases, but at a decreasing rate of improvement. The gas mixing system is assumed to apply the same mixing energy per tank as HRT increases. A plausible explanation for this trend is a change in other mixing contributions, resulting in actually lower active volumes at higher HRT. At any point in time, liquid sludge is being pumped into the digesters, which is one source of mixing energy. The unit energy input is greater at shorter HRT, assuming a constant feed rate. In addition, there is lift associated with gas production within the digester. At higher organic loading rates (assumed at low HRT), there is a higher gas production per unit volume and, therefore, greater inherent mixing energy from gas production. The added mixing energy, even if marginal, may improve active volume sufficiently to improve contact between the microorganisms and the food, thus improving performance. Once you drop below a certain mixing energy, more dead zones are created, reducing contact and short circuiting, thus lower VSR. This is consistent with the findings of the active volume analyses conducted and discussed in Attachment A. With 11 digesters in service, the active volume per digester was estimated at 2.00 million gallons (MG), whereas with 8 digesters in service, the estimated active volume per digesters was 2.36 MG. If this hypothesis holds true, it appears that with existing mixing systems and loads, performance is optimum in the 25 day HRT range. Above that, VSR deteriorates rapidly and should be avoided.

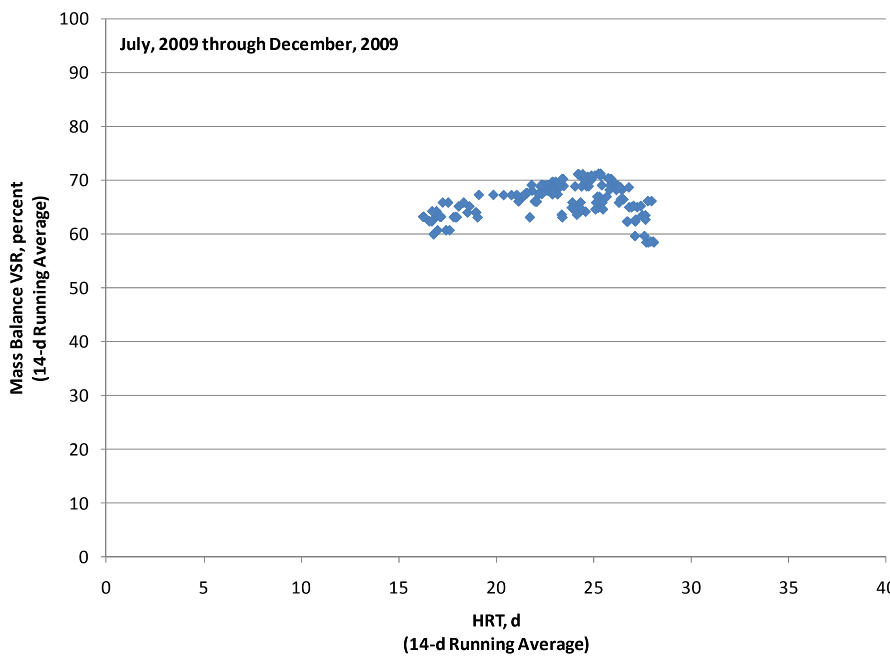


Figure 5-9. Historical VSR using the mass balance method versus HRT

5.5 Digester Volatile Fatty Acid-to-Alkalinity Ratio

The digestion process produces volatile fatty acids (VFAs) as an intermediate digestion product as well as producing alkalinity in the form of ammonium bicarbonate. Digester bacteria, specifically the methane producing bacteria, are sensitive to pH, with the optimum methane production occurring at between pH 6.8 and 7.2, however many mesophilic digesters operate very well at pH values up to 7.5 and above. High digester alkalinity and low VFA concentration are indicator conditions that foster stable pH conditions. Mesophilic digester alkalinity typically ranges from 2,000 to 5,000 mg/L and digester VFAs range from 50 to 300 mg/L for well-operating mesophilic digesters.

The VFA-to-alkalinity ratio has traditionally been used as an indicator of digester health, monitoring the balance required between VFAs and alkalinity. Increases in this ratio to 0.3 or 0.4 indicate upset conditions; a ratio below 0.2 indicates good digester health. The pH and VFA-to-alkalinity ratio provided for all WPCP digesters in Table 5-2 indicate that for all digesters, the pH and VFA-to-alkalinity ratio are well within recommended and accepted operating criteria. The small variations in these parameters are normal among a group of digesters and are indicative of slight variations in feed content and history, active volume, and mixing and temperature variations. These data from 2006 to 2007 are an indication that the digesters are in good health.

Table 5-2. Historical Digester Annual Average Operating Characteristics, 2006-2007

Digester Number	Alkalinity, mg/L as $CaCO_3$	VFA Concentration, mg/L as CH_3COOH	VFA/ Alkalinity Ratio	pH
1[a]	2,703	136	0.05	7.3
2[b]	--	--	--	--
3	2,648	130	0.05	7.3
4[b]	--	--	--	--
5[c]	3,131	132	0.04	7.4
6[b]	--	--	--	--
7[d]	2,996	102	0.03	7.4
8[c]	2,989	122	0.04	7.4
9	2,884	105	0.04	7.4
10	2,926	121	0.04	7.4
11[e]	2,799	110	0.04	7.3
12[f]	2,956	121	0.04	7.4
13[g]	2,878	113	0.04	7.3
14[h]	2,728	94	0.03	7.4
15	2,884	102	0.04	7.3
16	2,827	111	0.04	7.3

Source: Data from information provided by City

[a] Digester 1 was in service from mid-November through December 2006 only.

[b] Digesters 2, 4, and 6 were out of service.

[c] Digesters 5 and 8 were in service through September 2006 only.

[d] Digester 7 was in service through September 2006 only and then from mid-June through December 2007.

[e] Digester 11 was out of service all of 2006 and January 2007.

[f] Digester 12 was out of service from mid-September to mid-October 2007.

[g] Digester 13 was out of service for most of October 2007.

[h] Digester 14 was out of service from mid-October to mid-November 2007.

5.6 Gas Production and Co-generation

The WPCP receives fuel for operating the plant engines from three sources: digester gas from the onsite anaerobic digesters, landfill gas from the nearby Zanker Landfill, and natural gas purchased from Pacific Gas and Electric (PG&E). Digester gas production data in thousand cubic feet (kcf) per month (mth) as well as natural gas and landfill gas utilization data per month were obtained for year 2006 and are summarized in Table 5-3. Digester gas accounts for approximately 30 percent of total gas energy used at the WPCP.

Table 5-3. Digester Gas Production and Co-Generation, Year 2006								
Month	Natural Gas Volume (kcf/mth)	Digester Gas Volume (kcf/mth)	Landfill Gas Volume (kcf/mth)	Total Gas Volume (kcf/mth)	Natural Gas Energy Purchased (kTherms) [a]	Digester Gas Energy Produced (kTherms) [a]	Landfill Gas Energy Provided (kTherms) [a]	Total Gas Energy Used (kTherms) [a]
January	30,434	40,934	37,609	108,977	307	246	192	745
February	31,342	38,604	35,673	105,619	317	232	182	731
March	31,534	42,102	42,524	116,160	318	253	217	788
April	28,698	38,126	36,429	103,253	290	229	186	705
May	33,114	38,838	41,814	113,766	334	233	213	780
June	37,747	33,157	44,544	115,448	381	199	227	807
July	40,363	33,280	29,065	102,708	408	200	148	756
August	36,253	33,080	41,727	111,060	366	198	213	777
September	41,804	36,329	30,701	108,834	422	218	157	797
October	35,215	36,145	36,966	108,326	356	217	189	762
November	29,589	40,557	36,013	106,159	299	243	184	726
December	30,777	46,616	27,546	104,939	311	280	140	731
Total	406,870	457,768	440,611	1,305,249	4,109	2,747	2,247	9,105
% of total	31%	35%	34%	100%	45.1%	30.2%	24.7%	100%

[a] Natural gas energy production of 1,010 BTU/CF; Digester gas energy production of 600 BTU/CF; and landfill gas energy production of 510 BTU/CF
Source: Data from information provided by City for Master Plan

Figure 5-10 presents the recent gas production. In general, there has been an increase in digester gas production, which corresponds to increased digester loading.

Typical specific gas production rates from anaerobic digesters are approximately 12 to 18 cubic feet of gas produced per pound of VS destroyed. Higher values are associated with high primary-to-secondary sludge ratios, high grease loads, and lower SRTs in liquid stream treatment processes producing short SRT waste secondary sludge.

Figure 5-11 presents the normalized gas flows (specific gas production) based on VSR using the mass balance calculation approach. For the period from July through November of 2009 when 11 digesters were in service, values typically ranged from 7 to 15 cf/lb VS destroyed. The average value for that period was calculated 12.6 cf/lb VS destroyed. However, as discussed above in Section 5.4, a method adjusting the VSR to a “true VSR” value was developed (Attachment A) and, using this adjusted VSR, the average specific gas production for this period was estimated to be 15.4 cf/lb VS destroyed. This is well within the range of typical values discussed above and is indicative of normally functioning digesters.

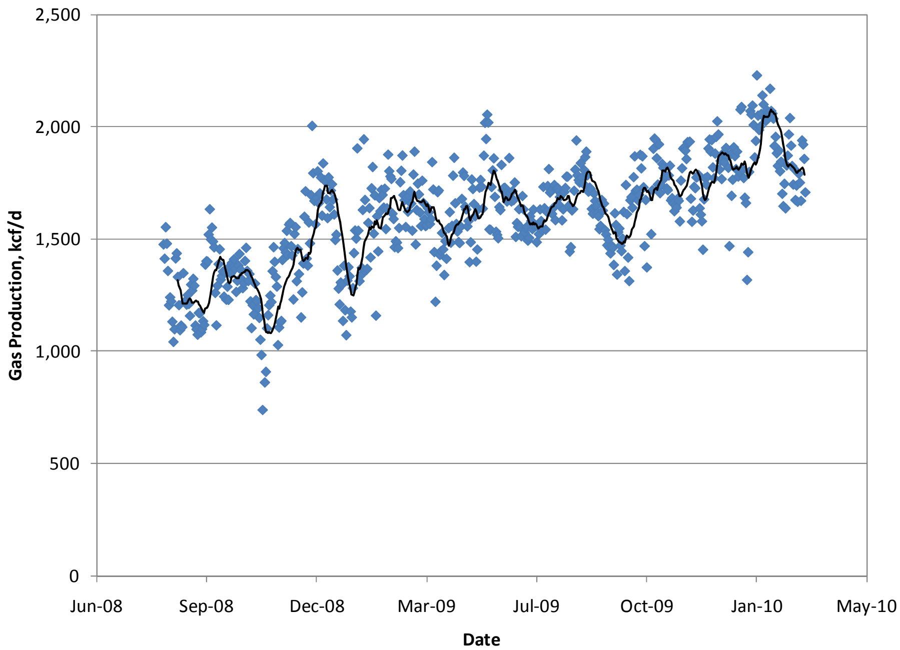


Figure 5-10. Historical gas production (black line represents 14-d running average; data adapted from blend gas meters and flare gas meters).

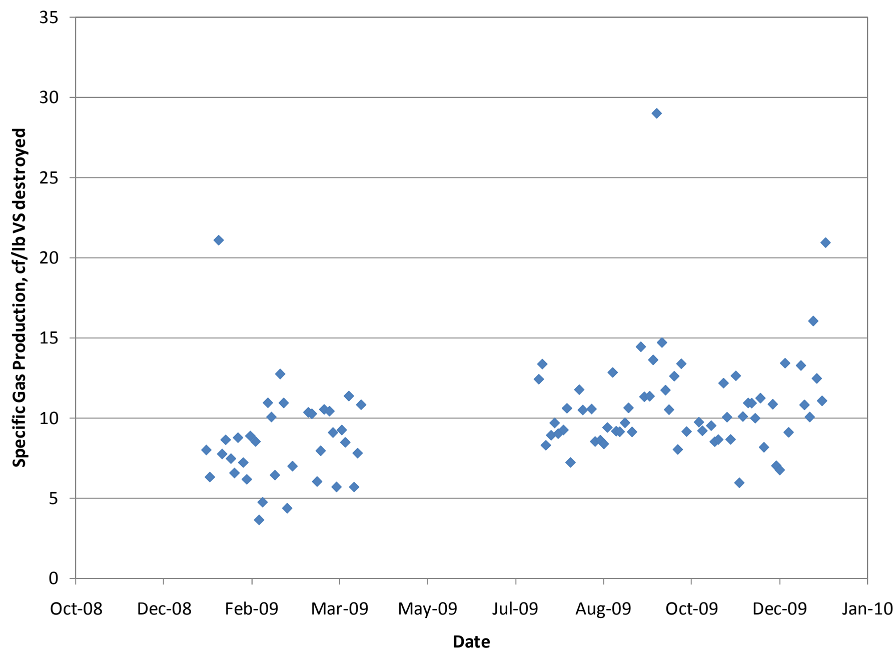


Figure 5-11. Historical normalized gas production (data adapted from blend gas meters and flare gas meters).

Another issue with the digester gas is hydrogen sulfide (H_2S). Figure 5-12 shows that the historical digester gas H_2S concentration has typically been below 200 parts per million (ppm) but the H_2S concentration began increasing in August 2008 to over 200 ppm. It is recommended that the H_2S concentration be below 200 ppm for operation in cogeneration facilities and to reduce corrosion. The reason that the H_2S may be increasing in the digester gas is that ferric chloride ($FeCl_3$) addition in the collection system for odor control at one of the pumping stations has been reduced or eliminated (personal communication between Perry Schafer and Dale Irkhe). The result is that the H_2S that previously reacted with the $FeCl_3$ is now contained in the digester gas at increased levels. TM 4.4 on the Gas Management System and TM 4.6 on the Struvite Control discuss this in further detail.

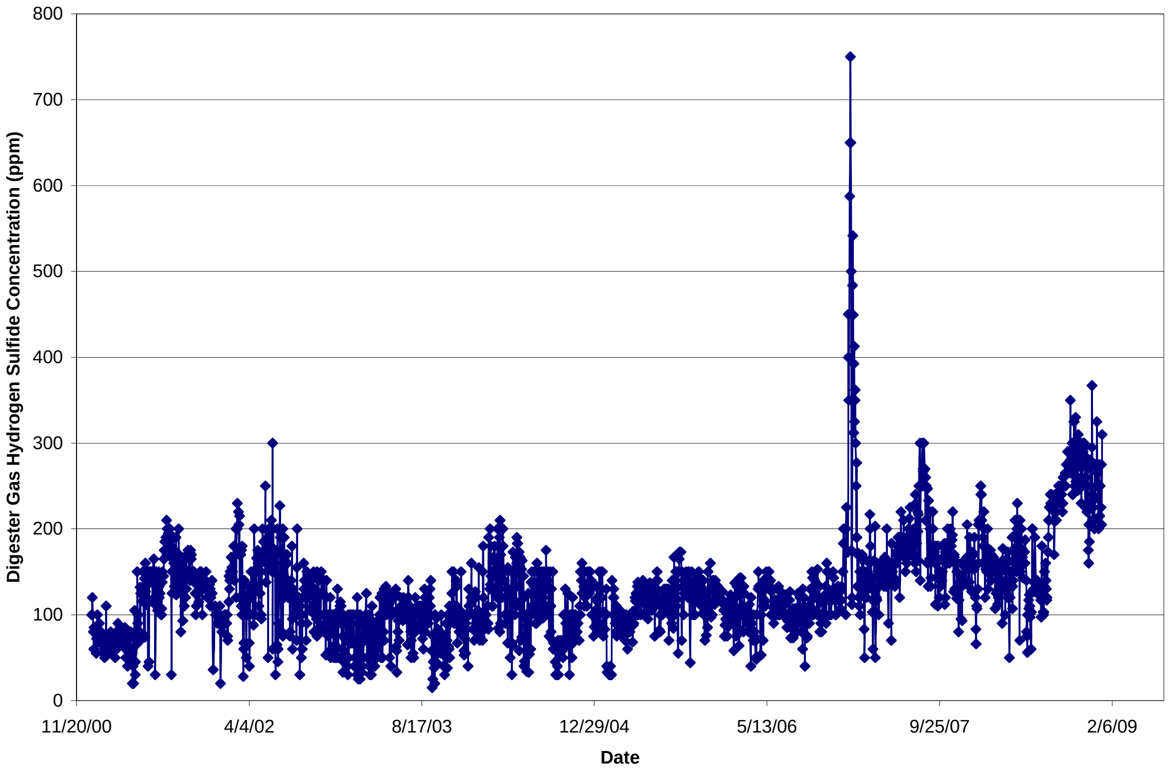


Figure 5-12. Historical daily digester gas H_2S.

6. OVERVIEW OF ALTERNATIVES

This section provides an overview of the alternatives that will be considered as a part of the project. The alternatives that are included are adapted from the Master Plan. Additional sub-alternatives and pre-processing options to improve digestion performance have been included in the discussion for consideration.

6.1 Review and Refinement of Master Plan Alternatives

Six alternatives were developed for the Master Plan (Master Plan Project Memorandum 5.2) that included four different approaches to anaerobic digestion, summarized in Table 6-1. In addition to the alternatives presented in Table 6-1, additional sub-alternatives have been included in the project to address potential for different tank configurations and feed sludge concentrations that could lead to different individual reactor loadings and gas production potential. The list of all alternatives considered in this project is presented in Table 6-2. Table 6-2 presents the digester feed sludge TS concentration for each alternative. The alternative of continuing with the existing digesters with no mixing upgrades is also included. For this alternative, a lower active volume is assumed. The existing primary sludge and TWAS blended feed concentration to the anaerobic digesters is approximately 3 to 4 percent TS. As part of this project, a study is currently underway (TM 7.1) by Brown and Caldwell to determine the cost-effectiveness of converting the existing DAFTs to co-thickening service for both primary sludge and WAS. This could increase the thickened solids to as high as 7 percent TS. Alternative average TS concentrations of 3.5 and 5.5 percent are included in Table 6-2 for evaluation, representing the conditions of current and potential future upgraded thickening systems, respectively. For the Cambi™ system, TS concentrations for 6.5 percent TS (WAS only) and 9.5 (primary sludge and WAS) are assumed.

Table 6-1. Summary of Master Plan Alternatives

Alternative	Master Plan Alternative
Mesophilic Digestion	1, 2, 6 and 7[a]
Cambi™ (WAS Only)	3
Cambi™ (Primary and WAS)	4
Thermophilic Digestion	5

[a] *Master Plan mesophilic alternatives vary with respect to post digestion processing*

Table 6-2. Summary of all Alternatives

Alternative	Sub-Alternative	Feed Sludge Concentration, percent TS
Existing (Mesophilic Digestion)	No Mixing Improvements	3.5
Mesophilic Digestion	Complete Mix	3.5
Mesophilic Digestion	Complete Mix	5.5
Mesophilic Digestion	Series	5.5
Cambi™ (WAS Only)	None	6.5
Cambi™ (Primary and WAS)	None	9.5
Thermophilic Digestion	Complete Mix	5.5
Thermophilic Digestion	Series (Extended Thermophilic, TPAD, Batch Class A)	5.5
Preprocessing with Mesophilic Digestion	Many	5.5

6.2 Conventional Mesophilic Digestion

Conventional mesophilic is the current sludge stabilization process used at the San Jose/Santa Clara WPCP. This stabilization process has the longest operational history of all the process options. The advantages of conventional mesophilic digestions are a Class B product can be produced with a minimal amount of additional testing, methane is generated for beneficial use, and the expected performance can be easily predicted from the existing digester operation and from other similar facilities. Mesophilic digestion typically operates in the range of 95 to 98 degrees F. While this process operates efficiently, the degradation rates are relatively low when compared to thermophilic digestion. This lower biological degradation rate results in lower VSR, lower gas production, and a higher mass of solids for disposal relative to a thermophilic process.

If mesophilic digestion is continued as the digestion process, the digestion system would include the following:

- Mesophilic digesters operated in parallel using the existing tanks (and possibly new tanks depending on the design solids) with a minimum HRT of 15 days at peak 2-week loadings to meet EPA's Class B Biosolids product
- Potential upgrades to digester mixing, heating, and gas systems to resolve existing limitations

In addition, new raw sludge blend tanks sized for approximately eight to twelve hours of storage at peak day loads may be included (see further discussion below).

This alternative is the least complex from the perspective of system modifications and upgrades, but also would result in the lowest digestion performance from the perspective of potential VSR and gas production.

6.3 Cambi™ Mesophilic Digestion

The Cambi™ process is a thermal hydrolysis process that can be used for primary sludge, secondary sludge, or both. If all feed sludge is treated through the Cambi™ process, the digested sludge is considered a Class A product. The Cambi™ process is preceded by thickened sludge blend tanks and raw sludge screening and dewatering. The dewatered sludge cake is fed into a batch hydrolysis vessel, where it is subjected to high heat (320 degrees F) and pressure (100 psi). The Cambi™ hydrolysis units are typically fed up to 18 percent TS raw sludge cake, thus reducing the heating demand. The pressure is released in a flash tank, which helps destroy pathogens and breakdown the cell structure of the bacteria in the sludge (see discussion of disintegration technologies below). Following hydrolysis, the hydrolyzed sludge is diluted to provide approximately 6 percent TS for secondary sludge treatment systems and 10.5 percent TS for blended primary and secondary sludge before pumping through cooling heat exchangers along with 3 to 4 times the flow of recirculated digested sludge prior to being fed to the digester. At 10.5-percent TS, ammonia toxicity can impact digester stability. For this study, a maximum concentration of 9.5 percent TS is assumed. Cambi™ recommends that the sludge be digested at high mesophilic temperatures, usually about 104 degrees F. The high feed solids content reduces the digestion tank volume required, and subjects the digester to very high organic loading rate and limitations on ammonia concentration within the digester. The reduced tank volume is one of the key advantages of this process purported by the manufacturer along with the production of a Class A biosolids if both primary and secondary sludge are treated. Another key advantage is a well stabilized and easily dewatered product (typically 30 to 35 percent solids concentration is achievable).

The Cambi™ process digestion system would include the following:

- New blending tanks sized for approximately eight to twelve hours of storage are recommended to blend feedstocks and equalize flows to the hydrolysis units
- New 5-mm sludge screening system (e.g. Parkson StrainPress™ or similar) to clean solids prior to hydrolysis
- New raw sludge dewatering units to achieve 18 percent TS
- New cake hoppers and cake feed system
- New Cambi™ thermal hydrolysis process units
- New hot, hydrolyzed sludge pumping and sludge feed distribution system
- Steam generation for Cambi™ heating
- Sludge dilution, recirculation, and effluent or air cooling systems to cool hydrolyzed sludge prior to feeding to the digesters
- Mesophilic digestion using the existing tanks. Mixing upgrades would be required over and above other considered processes to be capable of mixing 5 to 6 percent TS concentration in the digesters. Gas system upgrades to accommodate high gas rates from heavily-loaded digesters.

This alternative presents the potential for the highest feed concentration and the highest digester loading. Therefore, Cambi™ would require the lowest number of digesters of all the alternatives. This alternative would involve the most complex issues of any of the digestion alternatives for sludge transfer and heating and would require completely new systems.

6.4 Thermophilic Digestion

Thermophilic digestion takes place at elevated temperatures, typically from 125 to 135 degrees F. Although thermophilic microbes can perform outside this range, optimum thermophilic digester performance is typically found in this range and most commonly at temperatures around 131 degrees F (55 degrees C). Predominant microbes at these temperatures have a significantly higher growth rate than mesophilic bacteria. Consequently, thermophilic digesters can perform well at higher organic loadings and shorter HRTs than mesophilic digesters. Thermophilic digestion offers other advantages over mesophilic digestion at comparable HRT, including greater VSR resulting in greater digester gas production, less product solids to handle, and the potential for a Class A product. The major disadvantage of thermophilic digestion over mesophilic digestion is that there is higher heat demand resulting in higher energy costs and a more complex mechanical system. The higher energy cost can be overcome if waste heat from cogeneration or other waste sources is available or if a heat recovery system is installed to extract heat from the outgoing sludge for return to the feed sludge. For this alternative, there are four thermophilic sub-alternatives that will be considered.

6.4.1 Complete Mix Thermophilic

Thermophilic digesters can be operated in a complete mix configuration similar to conventional mesophilic digestion. In this configuration, all digesters are operated in parallel, each being fed the same load. In this configuration, since thermophilic digesters have much higher loading rate limits than mesophilic digestion, capacity is usually controlled by HRT limits to achieve the 15-day Class B biosolids requirement or to achieve a desired level of product stability.

6.4.2 Series Thermophilic

There are several alternatives that have been applied for series thermophilic digestion to meet various process objectives. The principal alternatives are extended thermophilic, temperature phased anaerobic digestion (TPAD), and batch processing to achieve Class A biosolids. The following sections describe these systems.

6.4.2.1 Extended Thermophilic

This option is a staged thermophilic digestion option with the goal of achieving a Class A biosolids product and/or enhancing overall digester VSR performance. As with series mesophilic digestion, improved VSR has been shown when reactors are configured in series. In addition, with proper sizing of thermophilic stages, a Class A biosolids product can be achieved. Although this configuration does not strictly meet the time/temperature requirements of Alternative 1 of EPA's 40 Code of Federal Regulations (CFR) 503, the ability of successive stages to break pathogen bleed through inherent in any complete mix system has proven these systems are capable of keeping pathogen levels low. This configuration would require designation as Class A under Alternative 3 or 6 of EPA's Part 503 regulations.

6.4.2.2 Temperature Phased Anaerobic Digestion (TPAD)

This option is a staged digestion option with two distinct temperature phases. The temperature phases are generated by digesting sludge in two different sets of tanks arranged in series operation. The first phase is the thermophilic phase, which typically operates at 131 degrees F and an HRT of between 5 and 8 days.

Following the thermophilic phase is a mesophilic phase operated at an HRT of 10 to 12 days. By phasing the digestion process, the advantages of thermophilic digestion are gained plus the ability to "polish" the VFA concentrations, improve VSR, and reduce odors in the final mesophilic phase are realized. The thermophilic digestion process is typically characterized by high biogas production rates, VSR (65 to 70 percent), and significantly enhanced pathogen kill. Given that most of the VSR occurs in the thermophilic phase, organic loading to the mesophilic phase is not limited in this system.

6.4.2.3 Batch Class A

This option is a staged digestion option with the goal of achieving a Class A biosolids product from digestion by meeting the time/temperature requirements of Alternative 1 of EPA's 40 Code of Federal Regulations (CFR) Part 503. It can be combined with any of the other thermophilic configurations. Following a first stage thermophilic phase are three or four thermophilic batch tanks, which operate in a parallel fill, hold, and draw schedule as shown in Figure 6-1. At an operating temperature of 55 degrees C, typical of the thermophilic stage, the batch tanks must allow for a total of 24 hours of hold time according to Alternative 1; therefore, with a four-tank configuration, each tank requires a retention time of 0.5 days at peak day load. The batch tanks are typically operated at the same temperature as the thermophilic phase to maintain biological stability; therefore, the sludge will continue to digest and add to the overall volatile solids reduction of the system.

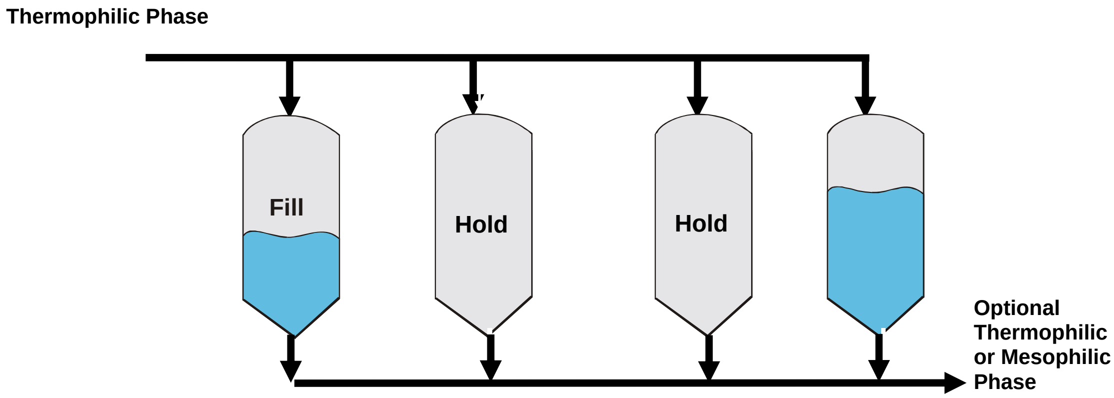


Figure 6-1. Thermophilic batch tanks.

6.4.3 Thermophilic Digestion Design Considerations

The additional biological activity associated with thermophilic digestion presents several process and design considerations beyond those with conventional mesophilic anaerobic digestion. The principal additional considerations include:

- Higher Loading Rates – The higher loading rates to a thermophilic system, particularly the first stage in a series configuration will require larger feed piping, feed pumps, and heat exchanger capacity than conventional mesophilic anaerobic digestion to accommodate higher flow rates.
- Elevated Gas Production Rate – Thermophilic bacteria have a faster growth rate than mesophilic bacteria. As a result of this enhanced activity, the biogas generated from the digester increases. The gas system must be designed to address the higher production rate during peak loading periods.
- Moisture in Gas – Thermophilic gas has increased saturation potential and moisture content due to higher temperatures over mesophilic gas. This can seriously effect gas use equipment. The impact of moisture in the biogas can be mitigated using gas cooling and condensation for moisture removal.
- Volatilization of Odorous Compounds – In stand-alone thermophilic digestion, increased ammonia and VFAs cause a stronger, but shorter lived odor than mesophilic sludge. This can be an issue in dewatering and potentially at biosolids use sites. This is addressed by cooling the digested sludge or polishing in a second phase mesophilic digester to reduce volatilization and VFAs. The mesophilic stage consumes additional VFAs and the intermediate cooling step reduces volatilization. Odor containment of the dewatering facilities is also practiced.
- Ammonia Release – Additional ammonia is released as a byproduct of the catabolism of proteins during the volatile solids reduction process. In general, a 20 percent improvement in VSR will increase released ammonia by 20 percent. Plants with a nitrification requirement can be challenged due to the elevated ammonia levels returned to the plant in sidestreams. Sidestream treatment has proven to be a cost-effective approach as well as treatment with existing liquid stream aeration assuming sufficient capacity is available. Note that this issue is true of any enhanced digestion alternative that improves VSR, including sludge disintegration.

The complete mix thermophilic digestion options would include the following:

- Thermophilic digesters operated in parallel using the existing tanks (and possibly new tanks depending on the design solids) with a minimum HRT of 15 days at peak 2-week loadings to meet EPA's Class B Biosolids product
- Upgrades to digester mixing, heating, and gas systems to resolve existing limitations and increase heating and gas system capacity

In addition to these modifications, the series thermophilic digestion options would also include the following:

- New blending tanks sized for approximately eight to twelve hours of storage may be included to help control batching time and initial OLR.
- First stage thermophilic digestion using existing tanks
- For Class A digestion only: New batch reactor tanks, each with a 0.5 day detention time at peak day sludge feed rates
- Second stage thermophilic or mesophilic digestion using existing tanks
- Modifications to sludge feed system to accommodate higher flow rate into and between staged digesters and additional heating requirements for feed sludge and cooling requirements between stages.

Because of the high energy requirements associated with heating the sludge to thermophilic temperatures, it is recommended that the thickened sludge feed rate concentration be a minimum of 5.5 percent TS. Thickening improvements would be required to meet this requirement. In addition, if sufficient waste heat is not available for heating, heat recovery from thermophilic sludge is recommended to maintain energy demand similar to that of mesophilic digestion. This alternative would involve more complex sludge transfer and heating issues than mesophilic digestion, but far less complexity than with the Cambi™ alternative.

6.5 Preprocessing with Sludge Disintegration and Mesophilic Digestion

Methods for the enhancement of wastewater sludge stabilization can be achieved through a variety of mechanisms including process conversion (i.e. mesophilic to thermophilic), improved operating conditions (heating, mixing, etc.) or through the addition of sludge disintegration technologies for preprocessing prior to digestion. These technologies, unlike previous mentioned approaches, have a specific goal of breaking down the sludge floc matrix into more readily degradable components rather than manipulating the digester environment directly. Reported impacts on the digestion process by sludge disintegration technologies range from increased biogas, increased volatile solids reduction, reduced solids production, elevated ammonium-N in the recycle, reduced process heating requirements, and reduced sludge viscosity. The effects of sludge disintegration have been reported to extend beyond the digestion process into the dewatering and sludge disposal efforts, manifesting as increased optimum polymer dose, increased cake solids content and reduced cake odors as measured by organic sulfur. It should be noted that these are all effects similarly reported for enhanced digestion processes such as thermophilic digestion.

There are a variety of technologies under development or currently in the market place for the purpose of increasing the degradability of sludge during digestion. Alternative approaches use high heat and pressure, electrical current, chemical disintegration, and mechanical shearing. Although not typically discussed as a sludge disintegration technology, acid hydrolysis (acid/gas phased digestion) is included in this category as it is a pre-digestion (pre-methanogenic phase) process used for enhanced hydrolysis of the sludge. While the operative technologies may vary, the application approach is fairly uniform in that almost all technologies pretreat waste activated sludge prior to digestion, as it is commonly thought that WAS is the most refractory portion of the solids entering the digester. Waste activated sludge is primarily constituted of bacterial mass, extracellular polymeric substances (EPS), and captured debris.

Currently, the most notable commercially available technologies include, but are not limited to:

- *OpenCel^tm*: a technology that applies an electrical current to a pipe containing thickened WAS prior to digestion. The current induces the cells to lyse and rupture through a process similar to electroporation. The lysis of the cell releases the contents to the surrounding environment where it is degraded and converted to biogas.
- *Microsludge^tm*: The Microsludge process uses a combination of high pressure homogenization and caustic pretreatment to disintegrate WAS prior to digestion. WAS is screened and combined with sodium hydroxide prior to homogenization. The homogenization process occurs by passing the sludge through an impactor ring at a pressure of 12,000 psi. The immediate reduction in pressure results in hydrodynamic cavitation, which lyses and damages cells. Further degradation occurs as the material impact the impactor ring on exiting the nozzle.
- *Crown® Disintegration Technology*: The crown system sold by Siemens is another technology that utilizes hydrodynamic cavitation to disrupt cells and sludge floc. This process works at a pressure of approximately 175 psi to generate the disruptive forces. The sludge passes through the nozzle a minimum of three times prior to discharge to the digester.

The Cambi™ process is a sludge disintegration process, but is discussed separately above (Section 6.3) because of the more dramatic impact that the overall process has on the solids processing flow scheme, including pre-dewatering and the much higher loaded digesters proposed by Cambi™.

Mechanistically, all sludge disintegration technologies look to improve digestion through cell lysis and particle disruption. Cell lysis releases intracellular materials allowing it to be degraded by surviving organism, while particle disruption is thought to improve the hydrolytic rates by increasing available surface area. Sanders et al. 2000 and Vavilin et al. 1996 have put forth two different models for hydrolysis both of which incorporate available surface area into the hydrolysis rate equation. These researchers believe that the available surface area for hydrolytic bacterial growth and extracellular enzyme access to substrate has a direct impact on the observed hydrolysis rate; increased available surface area increases the rate.

On average, disintegration technologies have been reported to achieve approximately 20 percent increase in digestion VSR and biogas production. For conservatism in this study, we will assume the same improvement as thermophilic digestion (12 percent, overall). Some vendors have claimed much higher than this in some instances, but caution is recommended as much of the reported data have not been independently substantiated. It should be noted that observed performance can deviate significantly from facility to facility. Therefore, it is recommended that utilities pilot test technologies before full implementation. It is fair to say that disintegration technology is an emerging technology as it is not as yet widely applied, processes are being improved, and new alternatives are emerging.

Sludge disintegration technologies have high operational costs and their economics is at best unclear, especially in areas with high electrical costs. Cost effectiveness is also dependent on having a high-value beneficial use of the biogas generated as a result of treatment and high biosolids disposal costs to benefit from the process reduction in sludge mass.

6.6 Other Pre-Processing Options to Improve Digestion Performance

6.6.1 Raw Sludge Thickening

As discussed above, currently primary sludge is thickened in the primary clarifiers and secondary sludge is thickened in the DAFTs. Average raw sludge feed concentration to the digesters ranges from 3 to 4 percent total solids. This is a low feed concentration compared to typical digesters and results in more digester volume required to meet HRT criteria than is typical. As discussed above, as part of this project (TM 7.1), Brown and Caldwell is currently investigating enhancing the thickening process by combining primary and secondary sludge prior to co-thickening in the existing DAFTs. This has the potential for increasing average solids concentrations to the 5 to 6 percent range (typical), possibly as high as 7 percent. Alternative average TS concentrations of 3.5 and 5.5 percent are included in this TM for evaluation, representing the conditions of current and potential future upgraded thickening systems, respectively.

Ultimately, the City will weigh the costs of the DAFT upgrade against the cost of upgrade and operation of additional digesters. DAFT conversion to co-thickening may require upgrades to sludge pumping, DAFT air saturation systems, bottom sludge withdrawal, and may require covers and an odor treatment system. A separate analysis of upgrades that would be required to convert the DAFTs to co-thickening is currently part of the analysis being conducted for TM 7.1.

In addition to reducing the digestion volume required, improved thickening would reduce the digested feed sludge heat required in direct proportion to the improved TS concentration. Improving feed sludge concentration from 3.5 to 5.5 percent will reduce heating requirements (excluding digester tank shell losses) by 35 to 40 percent. With thicker sludge feed, the OLR to individual digesters will go up and gas laterals leading to the main gas header will have to be upsized. Increased TS concentration in the feed from 3.5 to 5.5 percent TS will increase digested sludge concentration from about 2 to about 3 percent TS. Mixing systems in the range of 2 to 3 percent digested sludge concentration are well proven and will likely not require a horsepower adjustment to accommodate this slight increase in solids concentration. In addition, gas holdup (retention of gas bubbles in the digester contents) will not appreciably change in this concentration range. The capital and O&M costs for the potential DAFT upgrade will be weighed against the costs and benefits of digester upgrades with and without thickening in TM 5.1.

6.6.2 Sludge Load Equalization and Blending

Transfer of sludge from liquid stream processes (primary and secondary clarification) is variable due to a number of factors including treatment plant influent flow and load rates, wasting rates of the secondary system, primary sludge pumping rates, and primary and secondary thickening capacity. Means of dampening those fluctuations, particularly diurnal fluctuations, can help reduce load peaks on downstream unit processes including thickening; sludge screening; pumping; digester heating; digester gas conveyance, treatment, and use systems; and with some plants, dewatering.

Diurnal peaks can be dampened either through liquid stream solids inventory control or through post thickening storage. Currently at the San Jose WPCP, secondary sludge wasting rates are controlled through an SRT control system that can be set to waste consistently throughout a given day. Primary sludge is thickened in the primary clarifiers and is pumped on a relatively consistent basis based on XX. It may be practical to continue this practice, albeit at lower TS concentrations in the primary clarifiers, to even out sludge loads to co-thickening if the WPCP implements that process in the future. If both primary and secondary sludge load removal from the liquid stream can be controlled to dampen diurnal peaks, downstream storage is not required.

If sludge load removal from the liquid stream cannot be controlled to dampen diurnal peaks in the future, thickened sludge blend tanks could be beneficial for all of the digestion options. Optimum digester process operation and overall process stability are dependent on the process selected and is a function of how it is operated. Several factors influence process stability including temperature, mixing, and solids loading. The incorporation of a sludge blend tank improves the overall process stability by providing a means to homogenize multiple solids streams (primary and secondary sludge, FOG including plant scum and grease, and potentially food and food processing wastes); and thus, a consistent sludge feed to the anaerobic digesters. This is particularly important during peak loading conditions such as diurnal load peaks, peaks when reducing primary or secondary solids inventories, or peaks from irregular co-digestion feedstock deliveries. A thickened sludge blend tank provides an ideal location to incorporate FOG and food and food processing waste.

As stated above, transfer of sludge from liquid stream processes (primary and secondary clarification) is variable due to a number of factors. Thickened sludge blend tanks are sized to dampen the variations from sludge transferred from these processes. The dampening effect helps produce a constant feed rate to the digesters throughout a day, which allows for a more even distribution of the load to multiple digesters and reduces the fluctuation in the metabolic state of the microorganisms digesting the sludge, leading to more stable operation. In addition, constant feed rate of sludge will facilitate consistent gas production, a major advantage for the operation of cogeneration systems.

The added benefits of a thickened sludge blend tank are not limited to process stability alone. It can also positively impact the equipment used to operate the digesters. Pumps, heat exchange systems, and piping can be sized and operated under less variable flow conditions through a more constant loading regime. Thickened sludge blend tanks are typically sized to provide eight to twelve hours of storage at peak day flow. If operated properly, this dampens diurnal loads during the peak day. Two tanks are usually recommended to allow staff to take one tank out of service for cleaning and maintenance. A pump mixing system is also typically recommended to circulate the sludge within the thickened sludge blend tank to produce a homogeneous feed. Each of the tanks should be designed with steep sloped cone bottoms leading to a bottom withdrawal point to promote efficient solids removal. This configuration also allows easy cleaning and removal of solids from the tank. The headspace of the thickened sludge blend tanks is typically connected to an odor control system to manage headspace gases during filling.

It is recommended that the City determine the on-going ability to dampen diurnal peaks of solids loads within the liquid stream. If this is possible, the City should continue to optimize this practice. If this is not possible, thickened sludge blend tanks should be considered for sludge load equalization and blending.

6.6.3 Primary and WAS Sludge Screening

The San Jose WPCP currently has 5/8-inch opening coarse screens for influent liquid stream flow at the headworks. While these screens remove the majority of the coarse material from the influent stream, a significant quantity of non-degradable, recognizable material still passes through to the various treatment processes. Plant staff has reported significant maintenance time is required to remove this material from various downstream equipment and processes. Plant staff has also reported rags (meeting minutes, June 21, 2010) are causing significant maintenance problems around the digesters. In addition, recognizable debris accumulates in the digesters and is a significant fraction of removed grit during digester cleaning. This debris will also cause significant difficulty with any future efforts to market biosolids products. Fine screening, with 5 to 6 mm (approximately 1/4-inch) openings, is typically used in the industry for removing debris from biosolids and would be expected to significantly improve materials removal.

Fine screening was evaluated in the Master Plan (Master Plan Project Memorandum 5.1) from a planning level perspective for two potential streams at the WPCP: 1) the influent stream (following coarse screening), and 2) the primary sludge and WAS streams. Master Plan recommends implementing fine screening (5-6 mm openings) on primary sludge and WAS at the DAFT facility to improve plant operations. While the current maintenance issues on the liquid treatment processes will likely not be improved with this facility, it will benefit the solids treatment processes. In addition, the final biosolids product will be of a much higher quality (essentially free of nuisance materials), which will potentially increase its market value and disposition options. The MP estimated a capital cost for this facility of approximately $4 million, one tenth the cost of implementing full liquid stream screening.

The Master Plan used a step-type screen for costing the sludge screening facility; however, other technologies such as the Parkson StrainPress™ (or equivalent) are in wide and successful use for sludge screening throughout the industry and should be considered in detailed design.

As stated above, the Master Plan recommends adding a new sludge fine screening facility. This project team concurs and supports this recommendation to further develop a fine screening facility project.

6.7 Co-Digestion with Alternative Feedstocks

The City of San Jose is evaluating a co-digestion program using excess digester capacity at the WPCP. Interest is growing rapidly across North America to use available digester capacity to increase gas production and increase plant revenue from tipping fees associated with accepting alternative waste products. Food and food processing waste, FOG, and other organic waste addition are all being implemented in an ever-expanding array of plants. Implementing such programs requires careful attention to waste characteristics, system capacities and loading rates, degradation/gas production rates, and potential secondary impacts on biosolids and the plant liquid stream.

In addition to impacts on the capacity of the plant's digestion system, the technical and economic feasibility of co-digestion of wastes at the WPCP depends on several site- and plant-specific issues. Co-digestion will depend on the ability of the community to generate, collect, and deliver waste to the plant on a sustainable basis as influenced by source control, solid waste ordinances and collection systems, and FOG management ordinances and enforcement. Another consideration that could be of importance in the future is competition with other facilities for FOG.

The following critical success factors are important to consider when implementing and optimizing a co-digestion program:

- Evaluation of the organic waste composition and/or biochemical methane potential (BMP)
- Evaluation of waste chemical composition and potential effects on digestion biology, liquid stream performance, or biosolids quality
- Selection of the best available waste streams through ranking organic waste sources, based on availability, BMP, digester capacity utilization, pre-processing requirements, and potential revenue
- Evaluation of maximum organic loading rates under co-digestion
- Identification of synergistic effects of different organic waste streams
- Identification and evaluation of inhibitory effects of organic wastes or potential by-products
- Delivery and feed timing and product preparation and blending.

Achieving the above-listed critical success factors should result in a sustainable, stable, and beneficial co-digestion program. However, the addition of co-digestion substrates to digesters is not always straightforward. Digesting or co-digesting grease and other organic substrates with wastewater sludges within the WPCP digestion system needs to be evaluated from many perspectives, including the long-term vision and goals of the waste acceptance program. For instance, some researchers have proposed digesting non-sludge materials in separate digesters (i.e., food-waste-only digesters). When source quantities and deliveries are highly reliable, and if tank capacities match the needs, then there could be advantages to segregated processing and potentially alternative end product disposal. However, such situations normally do not exist at wastewater plants, and there can also be performance advantages to co-digesting organic wastes with wastewater sludge.

Not only can the addition of different co-digestion substrates to the digesters increase gas production through their degradation, but it can also improve the digestion of the exiting sludge through synergistic effects. Current literature has indicated anecdotal evidence of increased gas production and sludge solids destruction with the addition of FOG to digesters, which may be evidence of these synergistic effects between the wastes being digested. In this case, the improved digestion or synergistic effect is thought to be due to an improvement in the carbon, nitrogen, and phosphorus ratios of the system. A host of other constituents may also become important depending on waste blends. Each specific waste may, by itself, be deficient in some critical substrate, nutrient, or compound, which is plentiful in another type of feedstock. Combining multiple wastes during digestion—rather than a monosubstrate approach—can remove limiting nutrients or substrates stimulating the microflora of the digester, resulting in greater methane production and solids destruction than if digested alone. The increase in biological activity can reduce the amount of digested biosolids material for dewatering and ultimate disposal, an additional cost savings. Research on the synergistic effects of alternative waste streams during digestion is continuing and the latest information will be used to make reasonable assumptions for this project.

Potential feedstock materials for biogas enhancement at the WPCP include: FOG, food and food processing waste, and source-separated food wastes. FOG refers to commercial sources of FOG, such as FOG collected from grease traps or grease interceptors at restaurants. Potential quantities and characteristics of these wastes will be described in greater detail in Section 7.

Acceptance of co-digestion feedstock should be able to be accomplished within the existing air quality and Regional Water Quality Control Board permits, but these agencies should be contacted before implementation. California Environmental Quality Act requirements would be required to construct new receiving facilities.

Adequate staffing would be required for successful implementation of FOG or food and food processing waste facilities at the WPCP. A staffing study, which is not part of this project, should be completed to determine additional staff requirements and costs if a co-digestion program in one of several optional forms is to be implemented.

6.7.1 Feedstock Receiving and Preprocessing

Waste acceptance and pre-processing must be considered when starting a co-digestion program. The physical properties of the substrate along with the level of contamination with undesirable materials, such as silverware, glass, rocks, and/or plastics can have a significant impact on the process, especially when high-grade biosolids products are to be produced.

Receiving FOG at the plant for feeding to the digesters requires accommodation of a number of logistical issues. The FOG must be screened to remove unwanted recognizable debris or debris such as rocks that can damage equipment. In addition, the FOG needs to be heated to assure pipeline transport without line plugging. Finally, a receiving storage tank(s) needs to be provided to unload delivery trucks and buffer the load to allow close to constant feed to the digesters. A typical FOG receiving and processing facility schematic is shown in Figure 6-2.

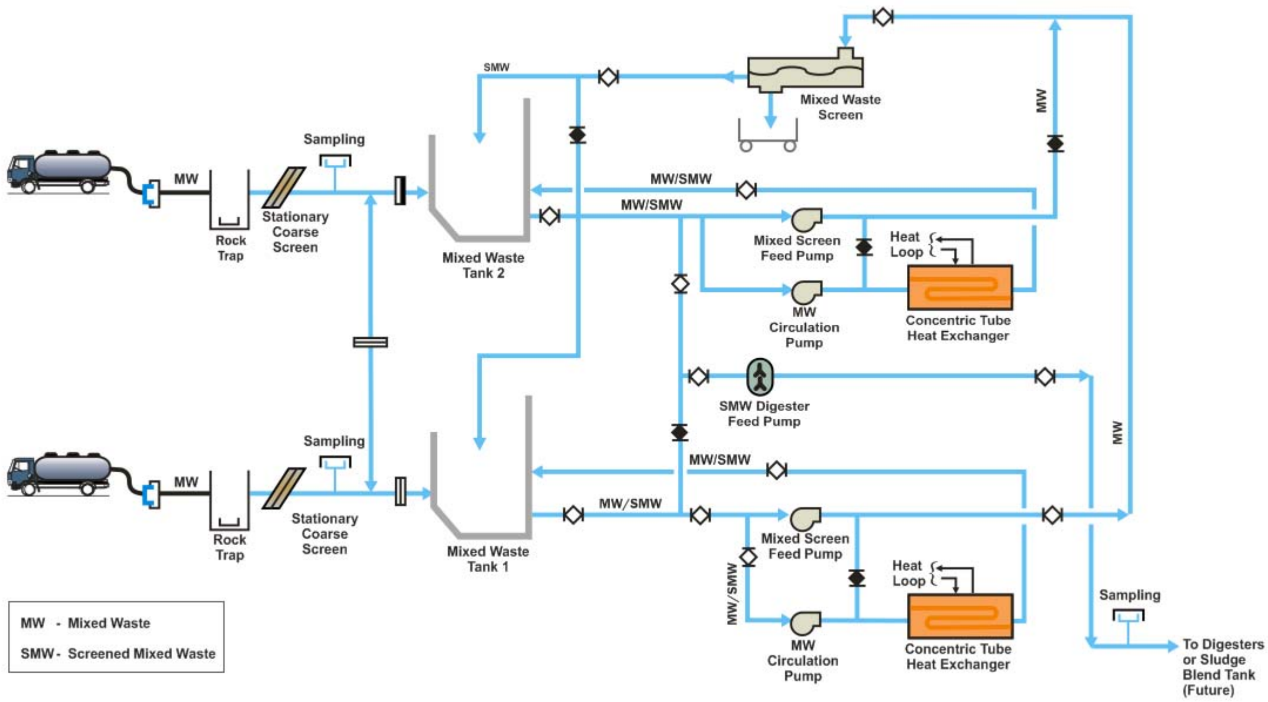


Figure 6-2. Typical FOG waste and receiving and processing station process schematic.

Source-separated food wastes are defined as materials originating from residential and commercial sources such as residences, restaurants, and grocery stores. Source separated food wastes must be pre-processed prior to anaerobic digestion. Source-separated food waste pre-processing consists of sorting, pulping (grinding) and dilution to develop a product that can be pumped, screened, and classified to remove unwanted material, and mixing to create a homogenous product suitable for feeding into an anaerobic digestion system. Pre-processing is often accomplished by a solid waste collection agency or private solid waste company. Pre-processing may need to or would best occur at a site away from the WPCP because inclusion of a "tipping floor" triggers regulation by the California Integrated Waste Management Board as a solid waste facility. Quality control of the sorted and screened material is a key consideration in the pre-processing step. It is recommended that the material be diluted to a maximum of 10 percent TS to make sure that it can be pumped and more easily incorporated into the digestion facilities.

Industrial food processing wastes can come from a host of industrial sources and in a variety of strengths and characteristics. Typically, food processers control (pre-process) these wastes at the production facility prior to disposal or trucking to a co-digestion facility.

Figure 6-3 shows a process schematic for a typical source separated food and food processing waste receiving facility at a wastewater treatment plant. This receiving facility assumes that any source separated food waste has been pre-processed offsite as described above and that it is the cleaned diluted food waste pulp that is delivered to the plant for digester feed. Food processing wastes are assumed to be received directly by the wastewater receiving facility as food processing waste generators are assumed to control waste quality prior to delivery.

The receiving facilities can include the following items:

- Monitoring or tracking system for food and food processing wastes
- Hopper or quick connect coupling for receiving waste
- Grinding facilities with food waste transport pump
- Receiving/storage tank with heat exchanger, metering system, and food waste feed pump
- Sampling locations
- Odor containment and control
- Spill containment

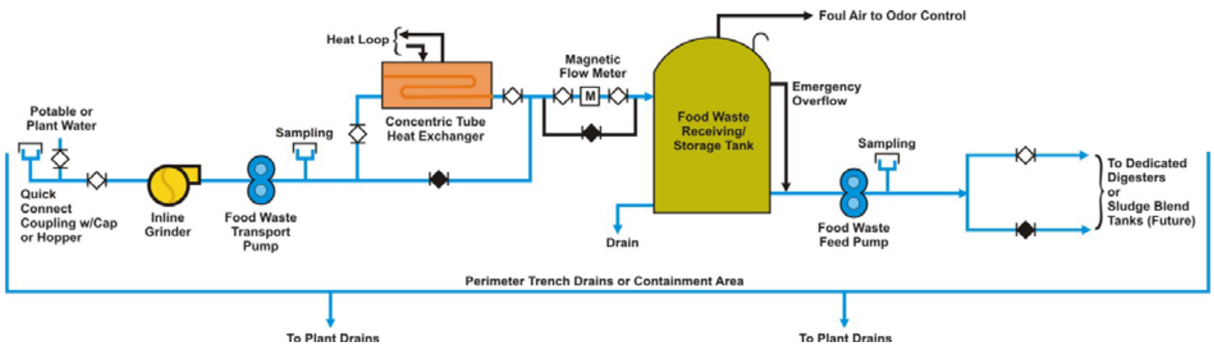


Figure 6-3. Typical food and food processing waste receiving station flow schematic.

Depending on the moisture content of the received food waste, the waste material can be received at the plant either in a hopper or with a quick connect coupling. An inline grinder to pulverize the material (or a screening facility) followed by a positive displacement food waste transfer pump should be provided. Depending on the material's moisture content, water may need to be added to the waste to achieve the desired digester feed concentration, typically about 10 percent TS. The liquid could be potable water or other liquid food processing wastes if an organic product is desired after digestion or it could be plant water if an organic product is not desired. Potable water would be required if separate digestion facilities are provided for an end product that meets organic status.

With either the FOG or food waste receiving station, the receiving tank(s) should be sized to provide sufficient storage to allow a homogenous material to be fed to the dedicated co-digestion digesters, a future sludge blending tank, or directly to all digesters. Each of these options would drive different criteria for the receiving tank sizing. Included with the receiving tanks is a heat exchanger. The heat exchanger is recommended to make the feedstock easier to pump and to pre-heat the material prior to digester feed. The food waste is pumped by a positive displacement pump and monitored by a flow meter to accurately control the volume being fed to the digesters.

It is recommended that a method to monitor or track the feed stock be provided at the receiving facilities. This could be a key card system for approved haulers that tracks time and quantity of waste received. A video monitoring system could also be provided for extra security.

Sampling locations should be provided following transport and feed pumps. The first sampling location allows for sampling of individual waste received at the WPCP while the second sampling location allows for sampling of the feed to the digesters.

Odors will be a concern at the receiving tank. The head space of the receiving tank should be connected to an odor control system. One option suggested has been to connect the receiving tank to the digester gas management system. However, if the receiving tank is connected to the digester gas management system, all the receiving facility components would be in a classified area requiring explosion proof equipment. This arrangement is not recommended.

The entire area for the receiving facilities should be within a spill containment area. The containment area would then be drained back to the plant headworks downstream of influent sampling facilities.

6.7.2 Co-Digestion Process Impacts

This section discusses the impacts to the digestion facilities if FOG, source separated food and food processing wastes are received at the WPCP. Included in this section is a discussion of digester operation, digester mixing, and digester gas management.

Digester Operation. As discussed in Section 8.3, a maximum FOG loading to the digesters of 30 percent of total VS load is recommended to prevent digester operational problems. Most significantly, digester foaming issues have arisen at higher loads. In addition, it is imperative that the FOG be well blended with sludge feed and that feed rates are kept as uniform as possible to prevent slug loads that can destabilize the digester.

When considering digestion of source-separated food waste, a separate food waste digester is an important option to consider. The EBMUD report (Gray et. al., March 2008) on food waste digestion suggests an organic loading rate as high as 550 lb-VS/1000-cf-day could be supported due to its ease of degradation. A big benefit is if this digester does not fall under the Class A/B regulations, then a higher load and lower HRT can be considered (~10 days). Therefore, if the City further develops a food waste/digestion program in the future, highly-loaded, separate food waste-only digestion should be considered.

With food waste co-digestion, the digester operation is dependent on the end product desired. If a post digestion certified organic product is desired for the food waste, completely separated facilities would be required because sanitary waste cannot be exposed to the material for organic certification. This would require dedicated digesters for the food waste. Section 11 discusses the number of digesters required for co-digestion with FOG and remaining digesters would be available for food and food processing waste.

If a certified organic product is not needed, then the food waste can be blended with the other feedstocks prior to the digesters to provide a consistent feedstock. The best location to accomplish this is at a future sludge blending tank. However, a dedicated receiving station would still be required for the food and food processing waste.

Digester Mixing. Good digester mixing is vital to any anaerobic digester, but it is particularly important to one receiving significant quantities of FOG. FOG is highly and rapidly degradable and imparts a significant point load when introduced to the digester. Inefficient mixing can cause dead zones within the digester and apply the heightened load from FOG to isolated active areas of the digester. This can quickly cause destabilization and cause irregular gas surges when the internally stored load is eventually folded into active volume. In addition, mixing is important to control foaming when heavy FOG loads are applied.

Food and food processing waste can pose challenges to digester mixing depending on the feedstock moisture content. At solids concentration greater than six percent within the digester, mixing becomes difficult with conventional digester mixing technologies such as draft tube mixers and pumped mixing system. This is a principal reason to recommend that the food waste feed to the digester be diluted to a concentration of less than 10 percent solids content. This will result in the concentration in the digesters being maintained below six percent after volatile solids destruction.

Digester Gas Management System. One of the main advantages of alternative feedstocks for co-digestion is that significant amounts of biogas can be generated. The digester gas management system will need to be sized to account for this additional gas. Section 12 presents projections of gas production with and without co-digestion.

7. DIGESTER FEED FLOW AND LOAD DESIGN BASIS

This section provides an overview of the flows and loads that are used for the project. A planning period from 2010 to 2100 was presented in the Master Plan. The planning period recommended for this project is to 2030, which is reasonable for a phased approach for construction projects.

7.1 Primary and Secondary Sludge Loads

Table 7-1 summarizes the projected loadings for the primary and TWAS sludge. These data are adapted from the Master Plan. The primary sludge loadings are determined using the projected raw influent TSS loadings and assuming a 61 percent TSS removal across the primary clarifiers. The secondary sludge loadings were determined using the primary effluent BOD loading and converting to sludge production using BioWin predicted yield (i.e. lb TS/lb BOD fed and lb VS/lb BOD fed).

Table 7-1. Design Basis for Primary and Secondary Sludges at 2030

Parameter	TS content, lb/d	VS Content, lb/d	Flow at 3.5 % TS, gpd	Flow at 5.5 % TS, gpd
Primary Sludge Loading				
Annual Average	232,700	197,800	-	-
Peak Month	295,100	250,900	-	-
Peak 2 Week	326,500	277,500	-	-
Peak Week	338,300	287,600	-	-
Peak Day[a]	357,700	304,000		
TWAS Loading				
Annual Average	144,600	108,200	-	-
Peak Month	202,700	151,600	-	-
Peak 2 Week	210,400	157,400	-	-
Peak Week	219,400	164,100	-	-
Combined				
Annual Average	377,300	306,000	1,292,600	822,500
Peak Month	497,800	402,400	1,705,400	1,085,200
Peak 2 Week	536,900	434,900	1,839,300	1,170,500
Peak Week	557,600	451,600	1,910,200	1,215,600
Peak Day	577,100	468,100	-	-

[a] Peak day loadings are calculated using peak day primary sludge production and peak week secondary sludge production. Peak week secondary sludge production is used because a peak day loading event would not impact secondary sludge production due to the long SRT (i.e. >6 days).

7.2 Alternative Feedstocks Loads

This section discusses feedstocks for the anaerobic digesters. The existing feedstocks are primary sludge and TWAS. Potential future feedstocks included in this analysis are FOG, including plant scum and grease, and food and food processing wastes.

7.2.1 Fats, Oils, and Grease

FOG collected from grease traps or grease interceptors at restaurants is often referred to as "brown grease" and is a viable gas enhancement feedstock, because it is already collected in trucks and hauled to disposal locations.

As part of Service Order No. 1 (Task 2), EEC, a subconsultant to BC, is completing a FOG Program Evaluation and Enhancement Study. The scope of work for this task includes:

- Identify FOG generators (e.g.: food service establishments, residents, industrial food processors, community kitchens, cooking schools, etc.) within the plant service area and from grease interceptor and grease trap available information
- Estimate the volume and type of FOG discharged to the sanitary sewer from each sector of the economy
- Identify the destination and quantity of FOG hauled and disposed of based on waste hauler data
- Coordinate with plant service area cities, agencies, and nearby cities outside the plant service area including Sunnyvale and Mountain View, to identify current and estimate future FOG waste volume

This evaluation is ongoing and the final report is expected to be completed in July, 2010. A preliminary estimate of FOG generation has been completed by EEC to estimate the potential digester capacity needed for the purposes of this TM. The current FOG generation within a 20-mile radius of the plant service area is estimated at 20,000,000 gallons per year and is expected to increase to 30,000,000 gallons per year within 10 years. The total potential FOG volume using the thirty-year projection is 37,000,000 gallons per year, which is approximately 101,000 gallons per day.

Table 7-2 provides the 2030 design criteria for FOG. A high value was assumed at the 30-year FOG volume projection level. However, as recommended in the EEC report, a design level of 80 percent of the volume projection is used. Although the EEC report projects a 30-year FOG volume, this report assumes that the design level is reached in the 2030 design year.

FOG has highly variable quality characteristics (Li et al, 2002; Schafer et al, 2008; and Suto et al, 2006) depending on source control and FOG hauler requirements and expertise. Therefore, Table 7-2 provides a range of solids concentrations from 5 to 15 percent TS. For development of the design criteria, a conservative TS assumption of 12 percent is used to ensure individual digester elements are sized sufficiently. The peak quantity of FOG that would be received at the plant will be limited by a hauling agreement based on the capacity limits of the plant. As discussed in Section 8.3, a maximum FOG loading to the digesters of 30 percent of total VS load is recommended to prevent digester operational problems. This would represent a load of 150,000 lb/VS/day based on average annual VS load from wastewater solids (Table 7-1). This load would be significantly higher than the available FOG market and represent a doubling of load on a given day. Therefore, an alternative assumption was made to represent a reasonable peak load based on six days per week of FOG hauling during a presumed holiday week and makeup of the lost haul day in two subsequent days. This results in an assumed peak of 50 percent above average FOG load for a two-day period.

Table 7-2. 2030 FOG Design Criteria				
Criterion	Low Value	High Value	Design Value - Average	Design Value – Peak Day[d]
FOG waste flow, gal/day	80,000[b]	101,000[c]	80,000[b]	120,000
TS concentration, percent [a]	5	15	12	12
FOG TS, lb/day	33,400	126,400	80,000	120,000
VS Content, percent VS [a]	90	97	95	95
FOG VS, lb/day	30,000	122,600	76,000	114,000
Mesophilic VSR, percent [a]	80	85	85	85
Thermophilic VSR, percent [a]	90	95	95	95
Digester gas production, cf/lb VSS destroyed [a]	18	25	23	23

[a] *Assumed range based on Schafer, et al, 2008.*

[b] *80 percent of 30-year FOG market per EEC report*

[c] *100 percent of 30-year FOG market per EEC report*

[d] *Based on 6 days per week of FOG hauling during presumed holiday week and makeup of lost haul day in two days, i.e. assumed 50 percent increase over average for two days.*

7.2.2 In-Plant Scum and Grease

Another source of grease is the plant scum and grease collected at the WPCP. Currently, the plant scum and grease is hauled offsite. The current plant scum and grease is approximately 153,000 gallons per year with a TS concentration ranging from 39 to 83 percent TS. The population growth is expected to increase by approximately 29 percent from today to 2030. Therefore, the current WPCP plant scum and grease design criteria are also increased by 29 percent to determine the plant scum and grease for the 2030 design criteria. Table 7-3 provides the projected WPCP plant scum and grease design criteria for 2030.

Table 7-3. Plant Scum and Grease – 2030 Design Criteria			
	Low Value	High Value	Design value
Plant Scum and Grease Flow, gal/day	400	500	500
Grease TS content, percent [a]	39	83	70
Plant Scum and Grease TS, lb/day	3,500	3,500	2,900
VS content, percent [b]	90	97	95
VS Loading, lb/day	1,200	3,400	2,800
Mesophilic VSR, percent [b]	80	90	85
Thermophilic VSR, percent [a]	90	95	95
Digester Gas Production, cf/lb VSS destroyed [b]	18	25	23

[a] *Provided by City*

[b] *Schafer, et al, 2008*

7.2.3 Source-Separated Food Wastes

The City is in the early stages of developing a food and food processing waste source control program; and therefore, the quantity and quality of the food and food processing waste that might be received at the WPCP is not know at this time. The purpose of this section is to categorize potential sources of source-separated food wastes and to characterize source separated food wastes.

Source-separated food wastes are defined as materials originating from residential and commercial sources such as residences, restaurants, and grocery stores. Food wastes must be pre-processed prior to anaerobic digestion. Pre-processing is often accomplished by a solid waste collection agency or company. Pre-processing requirements are discussed in Section 6.

The City has a goal of 75 percent diversion of waste from the landfill by 2013 and zero waste by 2022. To accomplish this, the City is evaluating renewable energy options from portions of municipal solid waste streams, including food and food processing wastes, using conversion technologies or alternative technologies. One of the best technologies available is anaerobic digestion. The City's existing source control program does not provide a means to separate food and food processing waste from other wastes. The City will be updating their policy on source separation in 2012 for commercial facilities and in 2015 for residential units to provide for source separation of waste, including food waste.

Since the City is in the early stages of developing a food waste separation program, the data available on the quantity and quality are limited. Because of the limited available data, the information provided in this section will be general in nature, but should provide sufficient information to identify potential impacts to the digesters. The resulting capacity and capabilities of the digesters will help establish design criteria and limits for food and food processing waste material and its pre-processing requirements. This information can be used by the Integrated Waste Management group in establishing requirements of future solids waste contracts.

Table 7-4 provides an estimate of recoverable food waste material from a needs assessment report for San Jose conducted by the City. The table shows that there is a significant potential for food waste to be available for digestion and additional gas production. Table 7-5 summarizes assumptions to be used for the average characteristics for source-separated food waste material.

Table 7-4. Source-Separated Food Waste Recoverable Material [a]

Waste	Annual Tons
Single family	70,572
Commercial	38,594
Multi-family	10,430
Total	120,000

[a] *Table 2B from the Overall City-Wide Waste Stream Review (email correspondence from Ravi Kachhapati, February 17, 2009)*

Table 7-5. Source-Separated Food Waste Characteristics and Potential Load Assumptions [a]

Waste Characteristic	Value
TS content, percent	22
TS content to digesters, percent	10
VS content, percent	85
VSR, percent	85
Food waste gallons per day at 10 percent TS	785,000
TS pounds per day	655,000
VS pounds per day	557,000

[a] *Zhang, et al, 2005*

7.2.4 Food Processing Wastes

Food processing industries often generate high-strength wastes that are potential biogas enhancement feedstock material. Table 7-6 shows the 5-day biochemical oxygen demand (BOD_5) values for some typical high-strength food processing wastes. BOD_5 is a common measurement of the organic strength of waste. For comparison, typical domestic wastewater concentration is approximately 250 to 300 milligrams per liter (mg/L) BOD_5, which is similar to San Jose's influent BOD_5 concentration.

Table 7-6. Typical High-Strength Food Processing Wastes [a]

Waste	BOD_5 (mg/L) Concentration
Milk	75,000
Milk fat	260,000
Blood (cow, chicken)	200,000
Soft drinks	143,000

[a] *Flippin, et al, 2005*

The City has very little industry generating food processing waste; and therefore, food processing waste would most likely come from outside the City's service area, if accepted at the WPCP. An estimate of regionally available food processing waste streams has not been completed and is not part of this project. This would require a market survey of potential food processing wastes in the area. There are two types of food processing waste streams: high moisture and low moisture sources. High moisture waste streams are defined as having greater than 55 percent moisture content, while low moisture waste streams have less than

55 percent moisture content. High moisture content waste streams are better suited for digestion and biogas enhancement than low moisture waste streams. Low moisture waste streams are more likely to have characteristics similar to solid wastes and require more extensive pre-processing prior to digestion. Typically high moisture waste industries include meat, wineries, tomato and fruit canneries, and fruit and vegetable distribution centers.

Table 7-7 summarizes assumptions to be used for the average characteristics for food processing waste material.

Table 7-7. Food Processing Waste Characteristics Assumptions

Waste	Value
TS content, percent	30
TS content to digesters, percent	10
VS content, percent	85
VSR, percent	85

Each potential waste stream and source will require evaluation to determine its suitability for digestion and use as a biogas enhancement feedstock before acceptance. Key parameters for consideration include:

- Volumes and delivery schedules
- TS content (recommend less than 10 percent concentration)
- VS content
- Degradability in the anaerobic digestion process
- Contaminants including 40 Code of Federal Regulations 503 metals
- pH
- Alkalinity
- Salt content
- Waste consistency (we recommend it be screened and/or ground for cleaning and easy pumping)

7.2.5 Approach to Feedstock Assumptions for Co-Digestion

The source separated food and food processing waste quantity and characteristics are not known at this time. Additional work will be required to identify food and food processing waste sources and characteristics of these wastes. The City is in the process of completing steps to accomplish this. In addition, a pilot study is planned by the City to characterize the food waste from residential and commercial sources. As the City's program develops, full-scale pilot studies at the WPCP for food waste digestion with dedicated digesters and blended with the existing feedstocks should be considered.

Since the source separated food and food processing waste quantity and characteristics are not known at this time, the approach in this TM will be to determine the digester capacity needed for primary sludge, TWAS, plant scum and grease, and a planning estimate for FOG. The remaining digester capacity, if any, will be available for future food and food processing waste digestion, either as separate food waste digesters or integrated digestion with sludge and other feedstocks. For sizing gas piping to individual digesters, this will be a conservative assumption as FOG has the greatest gas production value per unit volume fed of feedstocks available. For gas header sizing, room will be allocated for upsizing or adding additional mains as necessary if food waste co-digestion is implemented and the magnitude of the program is determined.

7.3 Alternative Feed Stock Flow and Load Design Basis

Table 7-8 summarizes the flows and loads associated with the alternative feed stocks. Table 7-9 summarizes the design basis using the design import materials. Table 7-10 summarizes the design basis using the maximum recommended import material. We have assumed that 80 percent of available area FOG would be received at the WPCP. This is a conservative estimate and is consistent with the EEC report that recommends that only 80 percent of the available FOG be assumed. If alternative feed stocks are included in the future, we recommend that the FOG should not make up more than 30 percent of the VS loading on an annual average basis. This is based on recent work performed at the EBMUD (Suto et. al., 2006). The current design basis has FOG loading representing 20 percent of the VS loading. The FOG and plant scum and grease loadings are assumed to be constant, however a peaking factor is assumed for FOG based on a presumed holiday week where FOG is hauled six days per week and the lost haul day is made up in two days.

Table 7-8. Flow and Load Design Basis for FOG and Plant Scum and Grease

Design Criteria	Design Value - Average	Design Value – Peak Day [a]
FOG		
Flow, gal/day	80,000	120,000
TS concentration, percent	12	12
TS Loading, lb/d	80,000	120,000
VS Loading, lb/d	76,000	114,000
Plant Scum and Grease		
Flow, gal/day	500	500
TS concentration, percent	83	83
TS Loading, lb/d	2,900	2,900
VS Loading, lb/d	2,800	2,800
Combined FOG and Plant Scum and Grease		
Flow, gal/day	81,000	121,000
TS Loading, lb/d	83,000	123,000
VS Loading, lb/d	79,000	117,000
Mesophilic VSR, percent	85	85
Thermophilic VSR, percent	95	95
Mesophilic FOG and Plant Scum and Grease Gas Produced, cfd	1,540,000	1,986,000
Thermophilic FOG and Plant Scum and Grease Gas Produced, cfd	1,720,000	2,555,000
Mesophilic Total Heat Content, MMBtu/day	1,080	1600
Thermophilic Total Heat Content, MMBtu/day	1,200	1790

[a] Based on six days per week of FOG hauling during presumed holiday week and makeup of lost haul day in two days, i.e. assumed 50 percent increase over average for two days.

Table 7-9. Design Basis for Primary and Secondary Sludges and Design Import Materials at 2030

Parameter	TS content, lb/d	VS Content, lb/d	Flow at 3.5 % TS, gpd	Flow at 5.5 % TS, gpd
Primary Sludge Loading				
Annual Average	232,700	197,800	-	-
Peak Month	295,100	250,900	-	-
Peak 2 Week	326,500	277,500	-	-
Peak Week	338,300	287,600	-	-
Peak Day[a]	357,700	304,000	-	-
TWAS Loading				
Annual Average	144,600	108,200	-	-
Peak Month	202,700	151,600	-	-
Peak 2 Week	210,400	157,400	-	-
Peak Week	219,400	164,100	-	-
Import Materials	83,000	78,800	-	-
Combined				
Annual Average	460,300	384,800	1,576,900	1,003,500
Peak Month	580,800	481,200	1,989,700	1,266,200
Peak 2 Week	619,900	513,700	2,123,700	1,351,400
Peak Week	640,600	530,400	2,194,600	1,396,600
Peak Day	660,100	546,900	2,261,400	1,439,100

[a] *Peak day loadings are calculated using peak day primary sludge production and peak week secondary sludge production. Peak week secondary sludge production is used because a peak day loading event would not impact secondary sludge production due to the long SRT (i.e. >6 days).*

Table 7-10. Design Basis for Primary and Secondary Sludges and Maximum Import Materials at 2030

Parameter	TS content, lb/d	VS Content, lb/d	Flow at 3.5 % TS, gpd	Flow at 5.5 % TS, gpd
Primary Sludge Loading				
Annual Average	232,700	197,800	-	-
Peak Month	295,100	250,900	-	-
Peak 2 Week	326,500	277,500	-	-
Peak Week	338,300	287,600	-	-
Peak Day[a]	357,700	304,000	-	-
TWAS Loading				
Annual Average	144,600	108,200	-	-
Peak Month	202,700	151,600	-	-
Peak 2 Week	210,400	157,400	-	-
Peak Week	219,400	164,100	-	-
Import Materials	137,900	131,100	-	-
Combined				
Annual Average	515,247	437,049	1,765,100	1,123,300
Peak Month	635,747	533,449	2,178,000	1,386,000
Peak 2 Week	674,847	565,949	2,311,900	1,471,200
Peak Week	695,547	582,649	2,382,800	1,516,300
Peak Day	515,247	437,049	2,449,600	1,558,900

[a] *Peak day loadings are calculated using peak day primary sludge production and peak week secondary sludge production. Peak week secondary sludge production is used because a peak day loading event would not impact secondary sludge production due to the long SRT (i.e. >6 days).*

8. DIGESTER LOADING AND OPERATIONAL DESIGN BASIS

This section provides the rationale that is used to develop the digester design criteria. The criteria are based on Brown and Caldwell recommendations, historical data (August 2008 through February 2010) from the WPCP and modeling results. A BioWin model was constructed to estimate digester performance at various operating temperatures and HRT conditions to estimate gas production and VSR. By applying the modeling results to the historical plant data, design criteria can be developed for conditions the existing digesters have rarely encountered. The results of this analysis are included as Attachment B.

8.1 Hydraulic Retention Time

The recommended minimum digester HRT for all digestion system alternatives is 15 days, based on peak 2-week sludge flows. Basing the design HRT on the peak 2-week flow provides enough buffer to meet the 15-day minimum HRT required to produce Class B biosolids. The staged thermophilic digestion alternative is based on an 8-day HRT at peak week flow for the first stage; and complete mix thermophilic digestion is based on a minimum HRT of 15 days at peak 2-week flows. For Cambi™ pretreatment of both primary and secondary sludge, since the product will meet Class A requirements, the 15-day HRT criterion is not relevant. For Cambi™, a 12-day HRT is recommended.

8.2 Active Digester Volume

Active digester volume refers to available volume for a well incorporated slug of feed to reside in close proximity to active microorganisms and for close to the average time of the other feed solids. Active volume can be decreased by poor mixing; grit, struvite, other debris and scum accumulation; and by lower digester operating level. The existing gas mixing system is undersized compared to typical recommended design standards (this issue will be discussed in TM 4.2) and the digesters have a history of heavy grit and debris accumulation. For these reasons, it is anticipated that the digesters are operating at an active volume well below their maximum potential. It should be noted that an assessment of fixed solids loss across the digesters was conducted as part of the VSR correction methodology discussed in Attachment A and an estimated 30 percent of the fixed solids (mass basis) is consistently being lost, presumably to grit deposition. At an average specific weight of 80 pounds per cubic foot, this represents an average deposition rate of approximately 1 foot per year.

On average, existing digesters are cleaned on a 4-year cycle (4 digesters cleaned each year) and plant staff have reported grit accumulation approximately 4 feet above the bottom of the walls after digester draining. An inspection of removed and dried grit indicates that a significant proportion is actually struvite crystals. Significant recognizable debris (rags, plastics, etc.) is also present. Plant staff measured the struvite content of the digester debris and based on these data, the digester debris is approximately 30 percent struvite. Whether from struvite or grit, settled inert materials reduce active volume. Although it is impossible to accurately estimate the rate of grit accumulation without staggered cleaning periods and rigorous sampling, one can reasonably assume that half of the total grit in the cone bottom plus that accumulated up to the 4 foot level above the wall is the average loss of active volume between cleanings. This represents a volume of approximately 217,000 gallons for digesters 1 through 3 (or 13 percent to total volume) and approximately 269,000 gallons for Digesters 4 through 16 (or 10 percent of total volume).

Beyond promoting grit deposition, poor mixing can also affect active volume directly by creating unmixed dead zones in the digester. A well-mixed digester can approach 100 percent availability of theoretical maximum volume. TM 4.2, Cover and Mixing System Selection, analyzes existing and recommended mixing energy and finds existing digester mixing well below recommended levels. Although the current mixing system may not be sufficient, without a tracer study, we do not believe that active volume can be significantly de-rated at this time for poor mixing. However, to recognize that the existing mixing system energy input is well below recommended levels, a small de-rating of active volume will be used in this analysis (Table 8-1). Tracer studies will be recommended to be conducted in the future to determine the long term schedule for mixing upgrades and adjust maximum loading rates for pre-upgrade digesters.

For analysis of the existing digesters prior to upgrades, we have assumed the bottom cone is not part of the active volume (approximately 195,000 gallons for digesters 1 through 3 and 260,000 gallons for digesters 4 through 16), there is one foot of grit in the cylindrical portion of the digester, and mixing efficiency is further de-rated by 10 percent. For analysis of performance after the digester mixing is upgraded, we have assumed the bottom cone is not part of the active volume and the mixing efficiency is de-rated by 5 percent.

An additional consideration that impacts active volume is digester liquid operating level. Floating covers cannot be operated at their maximum level, as some volume must be reserved for digester feed events and cover movement above normal to prevent overflows and cover damage. Plant staff supplied cover level data for March 16, 2010 for all digesters in operation (Digesters 9 through 16). Cover levels varied from 3.1 to 3.9 feet above the corbel seating level, with a maximum possible level indicated by the measurement range to a level of 6 feet. Therefore, plant staff currently operates the digesters with 2 to 3 feet of safety margin. This is approximately the level indicated in the Operations Manual as the "Normal Water Surface" elevation and operation at this mid level is prudent operation for floating covers. For analysis in this work, we will assume operation at the "Normal Water Surface" elevation, defining the sidewater depth of the digesters during operation. However, a small de-rating of 20,000 gallons is assumed due to displacement of sludge by the weight of the cover.

A summary of assumptions used in this TM regarding active digester volume under various conditions is shown in Table 8-1. The analysis presented in TM 4.2 showed that conversion of the digesters to submerged fixed covers has a lower net present value than fixed steel covers or floating covers. As a result, the total digester volume would increase to 2.89 MG.

Table 8-1. Active Digester Volume

Digester Condition	Digesters 1 through 3, MG	Digesters 4 through 16, MG
Actual Volume Including Cone Bottom [a]	1.64	2.67
No Mixing Upgrade/Floating Cover [b]	1.27	2.11
Mixing Upgrade/Floating Cover [c]	1.37	2.29
Mixing Upgrade/Submerged Fixed Cover	[d]	2.89

[a] Based on "Normal Water Surface" elevation reported in Operations Manual. Active volume includes cone bottom (11 feet deep for digesters 4 through 16 and 10 feet deep for digesters 1 through 3) and deducts 0.02 MG for volume displacement by cover slope.
[b] Actual volume less cone bottom, 1-foot grit above wall, and 10 percent de-rating for mixing efficiency
[c] Actual volume less cone bottom and 5 percent de-rating for mixing efficiency
[d] Digesters 1-3 would not be upgraded with submerged fixed covers

It should be noted that BioWin modeling of future digester performance was conducted assuming active digester volumes of 1.47 MG for digesters 1 through 3 and 2.43 MG for digesters 4 through 16 (see Attachment B). This recognizes a future condition assuming an approximate 2 foot higher operating level with fixed covers and other comparable active volume assumptions. Additionally, the analysis of impacts of grit deposition on VSR discussed in Attachment A estimated active volume based on the difference between modeled and calculated VSR. That analysis estimated active volume in existing digesters of 2.00 MG during the analyzed 2009 period (July through October) when 11 digesters were operating and 2.36 MG during late

2009 and early 2010 (December through May) when 8 digesters were being operated. Although the discussion of this approach in Attachment A recognizes the limitations of the calculation method, it is interesting to note that the results span the design basis assumptions shown in Table 8-1 and add validity to the assumptions moving forward. In addition, this methodology generates results consistent with the observed drop off of VSR performance above 25 day HRT shown in Figure 5-9 and discussed in Section 5.4 above.

8.3 Volatile Solids Loading

Historically, recommended maximum design digester loading criteria for a well mixed mesophilic digester ranged between 0.12 to 0.16 lb VS/cf/day. However, recently, design loadings used in the industry have increased. Food waste digesters have been reported to operate at loadings of 0.55 lb VS/cf/day. Cambi™ systems which load mesophilic digesters with hydrolyzed sludge after high heat and pressure are designed up to 0.55 lb VS/cf/day. These higher loadings suggest that the existing digesters can treat more solids loading, assuming that the mixing system provides for full use of tank volume and minimum HRT are met.

Under ideal conditions, mesophilic digesters are capable of loads well above even these values. However, in municipal wastewater digesters, varying peak loads, imperfect mixing, varying substrate characteristics, high ammonia concentrations, inhibitory effects from other compounds, and the potential for slug loads of other destabilizing or toxic compounds make conditions less than ideal and require prudent conservatism.

Based on past experience supported by full scale digester stress testing, Brown and Caldwell currently designs mesophilic digesters up to a maximum load of 0.20 lb VS/cf/day based on maximum 7-day loads to assumed active volume. The VS loading criteria are based on full-scale observations at the Pierce County, Washington's Chambers Creek. In 2000, the lead digester was destabilized from high peak loads and failed. Figure 8-1 presents data on loading conditions and resulting process upset during this failure. The digester had gas mixing, with reported gas leaks and plugged gas piping on several of the diffuser feed lines. These conditions represent failure loading in a poorly mixed digester.

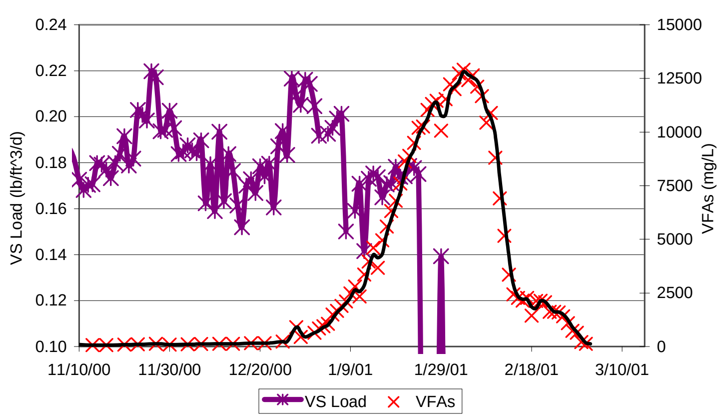


Figure 8-1. Digester failure data from Chambers Creek WWTP – 2000

In November of 2000, a peak week load of 0.2 lb VS/cf/day with a peak 2-day load of 0.22 lb VS/cf/day were tolerated with average loads subsequently dropping to an average of about 0.17 lb VS/cf/day. Several weeks later a peak 7-day load of approximately 0.21 lb VS/cf/day was experienced. Despite loads dropping back to the 0.17 lb/cf/day range, the digester became unstable with VFA concentrations rising to over 12,000 mg/L. Based on this data, a maximum 7-day load of 0.20 lb VS/cf/day is indicated for poorly mixed digesters. Brown and Caldwell recommends a prudent level of conservatism and moderation of this criterion to 0.18 lb VS/cf/day for a maximum 7-day load to active volume for poorly mixed digesters.

Subsequent to this event, Brown and Caldwell was retained to design mixing upgrades for the Chambers Creek digesters and mechanical draft tube mixers were added. In 2003, a digester stress test was conducted to determine maximum operating loads for the now well mixed digesters. Figure 8-2 presents data from that stress test.

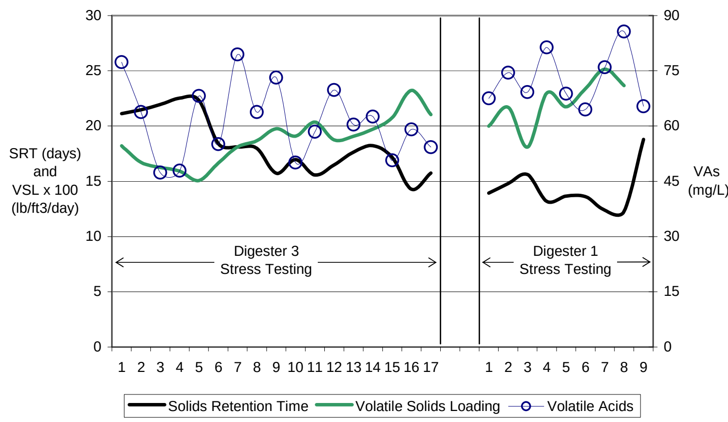


Figure 8-2. Digester stress testing data from Chambers Creek WWTP after mixing upgrade - 2003

Digester 3 was tested for a period of 10 days at an average load of 0.21 lb VS/cf/day with a peak of 0.26. A slight rise in VFA concentration from 45 to about 65 mg/L was exhibited, but the digester remained stable. Digester 1 was loaded for 9 days to an average load of 0.24 lb VS/cf/day with a peak daily load as high as 0.29. The VFA concentration rose to about 75 mg/L, but the digester again remained stable. Based on this stress testing data, a maximum 7-day load of 0.24 lb VS/cf/day is indicated for well mixed digesters. Brown and Caldwell recommends a prudent level of conservatism and moderation of this criterion to 0.20 lb VS/cf/day for a maximum 7-day load and 0.18 lb VS/cf/day for maximum monthly load to active volume for well mixed digesters.

The enhanced biological activity in the thermophilic digestion significantly increases the capacity of the digestion system in total. Thermophilic digesters have been loaded as high as 0.66 lb VS/cf/day, which is over four times greater than the maximum suggested solids loading rate of mesophilic digesters of 0.18 lb VS/cf/day. However, it is recommended that thermophilic systems be designed around a lower maximum month loading rate of 0.45 lb VS/cf/day, in order to account for variability in sludge characteristics. The Cambi™ process has a maximum VS loading of 0.25 lb/cf/d and 0.50 lb/cf/d for secondary only and primary and secondary, respectively.

Suto et. al. (2006) during pilot scale testing at EBMUD reported successful FOG loading rates of 35 percent by volume, but found digestion process failure at 50 percent by volume when unpredictable high strength FOG was added. Their average FOG concentration was five percent but varied widely. Assuming a coincident feed solids concentration of six percent, this represents a FOG load of approximately 33 percent of the total VS load on the digesters. Suto concluded that feeding higher amounts of FOG increased the risk of accepting a high load form a highly variable FOG supply that can destabilize the digester. Based on this research, Brown and Caldwell recommends a maximum FOG loading rate of 30 percent of total VS load. Suto also concluded that thermophilic digestion is superior to mesophilic digestion for FOG because of thermophilic digestions superior ability to degrade volatile fatty acids associated with the FOG. In addition, he reported a significantly smaller scum layer at the top of the digester with thermophilic versus mesophilic.

It is prudent to reduce maximum FOG loads on Cambi™ mesophilic digesters as their total load is up to three times a typical mesophilic digester. Although plant scum and grease loads of two to three percent are common with Cambi™ digesters, Cambi™ currently does not have full scale FOG programs contributing to their installations. FOG loads for Cambi™ digesters will be assumed to be limited to no more than 10 percent of the total VS load.

8.4 Temperature

Operating temperature of mesophilic is optimum at 98.6 degrees F (which is normal human body temperature). Optimum temperature of thermophilic and the most common operating temperature is 131 degrees F.

Modeling results (see Attachment B) predict a decline in VSR and digester gas when digesters are operated at lower temperatures. As discussed in Attachment B, stable operation at two temperatures (90 and 100 F) can result in a 2 percentage point difference in VSR and a comparable and compounding difference in specific gas production. Moving from one temperature to another quickly can limit the ability of microorganisms to stabilize and exacerbate the drop in performance. While the ideal temperature for mesophilic digestion is body temperature or 98.6 degrees F and more consistent and stable temperatures are preferable, other evidence indicates temperatures lower than 95 degrees F should be avoided. A temperature of lower than 95 degrees F is where some plants have seen temperatures begin to inhibit gas production and tax the heating capacity, and find it difficult to bring digesters back to optimum temperature until warmer wastewater temperatures occur. Whether this spiral tipping point is reached is subject to a number of factors including solids feed concentrations (and associated water heating demands), available heating capacity, and number of parallel digesters on line that can dampen out some disturbances in individual units. That said, operation below 95 degrees F is discouraged and mesophilic operation at 98 degrees F is recommended.

Mesophilic operation above 95 degree F is mandatory for plants wishing to meet the EPA Part 503 criteria for a Process to Significantly Reduce Pathogens (PSRP or Class B biosolids). However, it should be noted that San Jose is not required to meet the temperature criteria of 95 degrees F in the digesters, because the digesters are followed by lagoons and drying beds, where Class A pathogen criteria are met.

Another important temperature consideration is rapid temperature fluctuations. As noted above, moving from one temperature to another quickly can limit the ability of microorganisms to stabilize and exacerbate a drop in performance. Good operating practice avoids temperature changes greater than 2 degrees F per day to minimize stress on active microorganism and to help maintain stable conditions for optimum growth. With respect to temperature fluctuations, Boušková et al (2005) investigated the viability of two different methods for switching between thermophilic and mesophilic digestion, incremental temperature increases or immediate increase. The results of the study not only provided critical operating information, but also insight into critical temperatures associated with the operation of anaerobic digesters. The authors operated two digestion systems which were switch from 98.6 degrees F to 131 degrees F, one in incremental steps of no greater than 9 degrees F per step and the other in a single step. Figure 8-3 provides a summary of the incremental step approach. What is apparent from the data in Figure 8-3 is that there is a severe process disturbance at approximately 117 degrees F (47 degrees C). The authors attributed the disturbance as the inflection point where mesophilic organisms are reaching their maximum temperatures and thermophilic organisms are starting to move toward an optimum temperature range. The relatively small process disturbances in the incremental step data at temperatures above and below appear to support this assertion.

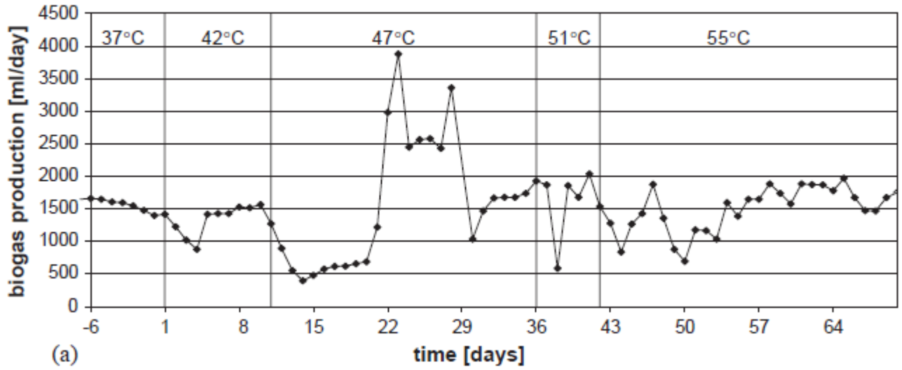


Figure 8-3. The impact of step-wise temperature increases on digester process parameters while converting from mesophilic to thermophilic temperatures (Boušková et al (2005))

Although this work was done at wider fluctuations than normally experienced, it is clear that temperature swings shift bacterial populations and require recovery time. Brown and Caldwell's design standard is to design digester heating systems to maintain temperature variations to within 2 degrees F over a one day time frame. This criterion is used for analysis of existing and future heating.

8.5 Volatile Solids Reduction

The average VSR from the historical data (July 2009 through October 2009) calculated when the impact of fixed solids deposition is considered was 54 percent (see Attachment A). This is associated with an average HRT of 24 days. For the future design, a HRT of 15 days is used. The BioWin model (Attachment B) showed that decreasing from a 24-day HRT to a 15-day HRT would reduce the VSR by 3 percentage points.

Salsali and Parker (2006) investigated the influence of temperature on 3-phased anaerobic digestion. In particular, the authors investigated how varying the first and second stage temperatures impacted system performance. The performance of the system was compared to a single stage mesophilic (95 degrees F) anaerobic digester. The first and second stage temperatures of the phased system were tested at 95, 108 and 120 degrees F (35, 42, and 49 degrees C, respectively), all producing stable operation at HRT of 15 days.

Figure 8-4 shows the VSR of each stage of the systems tested. The results show that the first phase temperature 95, 108 and 120 degrees F did not show a significant increase in the observed VSR, while total system VSR varied significantly. The paper reports that increasing temperature resulted in enhanced hydrolysis and acetogenesis, and only once the first stage temperature increased to 108 degrees F did the methanogenic population increase in metabolic rate to start to consume the VFAs produced, in the first reactor. What the data suggests is that methanogenesis and acetogenesis (including hydrolysis) start to come back into balance around 120 degrees F.

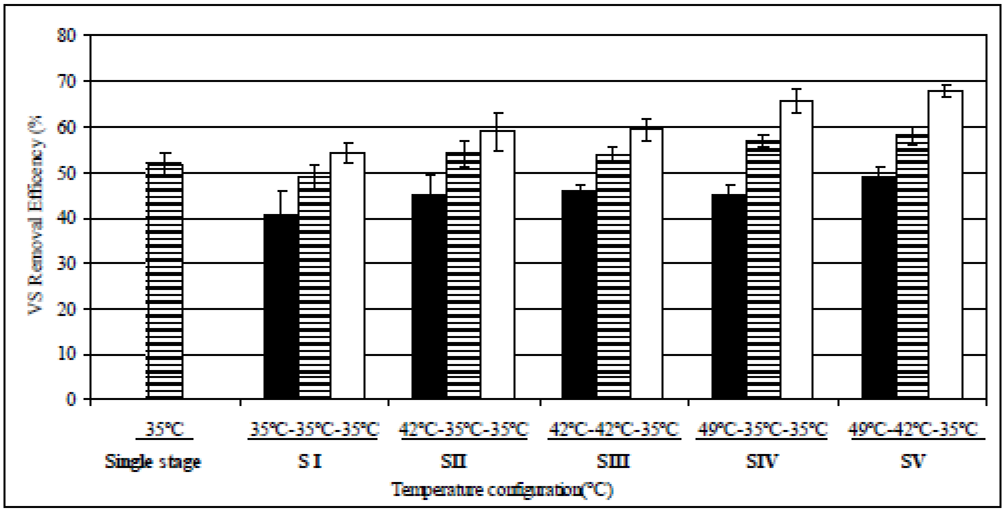


Figure 8-4. The impact of process temperature on VSR of different phased anaerobic digestion systems (Salsali and Parker [2006])

This data shows a small improvement in performance from series mesophilic digestion, but the increased load on the first stage digester, combined with a moderate mesophilic loading rate criterion mean that staged or series mesophilic digestion will likely require greater reactor volume than single stage complete mix operation. For this reason, the option of series mesophilic digestion is an unattractive option unless significant excess digestion capacity exists. For thermophilic digestion, performance was enhanced substantially (Figure 8-4): 68 percent VSR versus 52 percent for single stage mesophilic digestion, a 30 percent increase. For thermophilic digestion, series operation does make sense because the higher acceptable organic loading rate for thermophilic and similar HRT to mesophilic means HRT drives overall reactor volume and a staged system can be operated without extra digester capacity.

Kabouris et. al. (2009) loaded both mesophilic and thermophilic reactors with (1) a 40/60 percent blend of primary and secondary sludge and (2) a 21/31/48 percent blend of primary sludge, secondary sludge, and FOG, all at a 12-day SRT. The thermophilic runs showed a 21 and 13 percent increase in VSR, respectively. With mesophilic digestion, the biodegradable VSR jumped from 69 to 85 percent after adding FOG and with thermophilic, the biodegradable VSR jumped from 83 to 97 percent after adding FOG.

Many other plants have shown an increase in VSR when moving from mesophilic to thermophilic digestion at comparable HRT. For this study, an assumption is used of a 12 percent increase in VSR going from mesophilic to thermophilic digestion. An extra two points of VSR is assumed for system HRT with series digestion. There is no evidence of increased VSR with Cambi™ systems at the reduced HRT digestion recommended over mesophilic digestion.

For FOG loads, an estimated 85 percent VSR is assumed for mesophilic digesters and 95 percent for thermophilic digesters. The FOG addition will increase the VSR of municipal sludge due to the symbiotic effect. Therefore, the VSR of the municipal sludge has been increase by one percentage point increase for all VSR values.

8.6 Gas Production

Specific gas production rates were estimated using the BioWin model (Attachment B) and validated through a process developed to account for grit deposition and its impact on VSR (Attachment A). For the period from July 2009 through October 2009, the adjusted historical specific gas production (SGP) value of 15.4 cf/lb VS destroyed was validated against a modeled SGP of 15.24 cf/lb VS destroyed. For December 2009 through May 20101, adjusted historical SGP of 15.6 cf/lb VS destroyed was validated against a modeled prediction of 15.4 cf/lb VS destroyed.

For digestion of FOG and plant scum and grease, higher specific gas production is appropriate. Li et al (2002) investigated the theoretical biogas production from model substrates, pure lipids (fats), pure carbohydrate and pure protein. Li et al (2002) observed, based on stoichiometric calculations using generalized compound formulae, that lipids on a per mass basis produced almost twice the gas that carbohydrates produced and 33 percent more than protein (Table 8-2). Lipids are contained in cell walls of secondary sludge and include fats and oils predominantly found in primary sludge. Not only was the quantity of the gas different, the quality of gas was as well, with lipids and proteins generating more methane on a per unit volume basis. In addition, there has been evidence of a synergistic effect of adding FOG to sludge digesters increasing the theoretical gas production from the sludge component. What this would suggest is that the production of biogas from a specific sludge will be influenced not only by secondary treatment and the primary sludge, but also any other added constituents (ex. FOG or hauled waste).

Table 8-2. Theoretical Gas Production from Different Organic Waste Components (Li et. al. (2002))

Component	Reaction of Methane Fermentation	Gas Production cf/ lb VS destroyed	CH_4 percent in Biogas
Lipids (Fats)	$C_{15}H_{90}O_6 + 24.5\ H_2O \rightarrow 34.75\ CH_4 + 15.25\ CO_2$	22.9	69.5
Carbohydrates	$(C_6H_{10}O_5) + nH_2O \rightarrow 3n\ CH_4 + 3nCO_2$	13.3	50
Proteins	$C_{11}H_{24}O_5N_4 + 14.5\ H_2O \rightarrow 8.25\ CH_4 + 3.75\ CO_2 + 4\ NH_4^{+} + 4HCO_3$	14.8	68.8

It is important to note that the stoichiometric gas yields reported by Li et al (2002) are maximum values calculated for the generic compounds assumed in anaerobic digestion systems. As compounds, such as carbohydrates, are consumed by bacterial cells, they are used in numerous ways and converted to various byproducts. The equations presented by Li et al (2002) do not account for the conversion of substrate to new cell components as well as new cells; but rather the conversion of substrate to energy only. In the example of a simple carbohydrate like starch, some of the carbon in this compound is consumed for the growth and reproduction of the bacteria (which will consume some VS carbon and convert it to inert solid (IS) carbon, some of the carbon is used by the cells for maintenance activities (repair of cell parts), and some of the carbon is used for generation of energy and converted to byproducts like CO_2 and CH_4. Therefore, while much of the carbon that is consumed does go on to be converted to CH_4 and CO_2, some is utilized by the cells and wasted out as inert solids. For carbohydrate compounds that are harder to break down, like cellulose and lignin, more energy is required by the cell to break these down into useable forms. Therefore, more is used in the creation of compounds for cell growth and maintenance and less is available for the formation of byproducts like CH_4. Nonetheless, the theoretical values listed above are consistent with the calculated values for San Jose sludge (a blend of these components) at about 15.4 cf/lb VS destroyed.

There are several factors to consider when looking at the gas yield from secondary sludges under high liquid stream SRT aeration. First the fundamental yields will not change, but the amount of carbon diverted for uses other than energy generation and thus methane generation will change. The higher degree of stabilization of sludge achieved in the secondary system reduces the degradability of the substrate (food) that is introduced to the digesters in the raw sludge. With the reduction in degradability of the substrate, the bugs can change metabolic states and use more relative energy for cell maintenance to sustain themselves. There will be a reduction in the biogas yield because of this activity. Essentially the bugs will consume the substrate but rather than emitting biogas they fix themselves reducing the amount of gas that is released as the carbon is sequestered in the bugs. This is analogous to aerobic systems where difficult to degrade substrates require longer sludge ages, use more energy in degradation, and have lower sludge yields.

Gillette (2008) reported on bench scale batch testing of sludges and FOG resulted in similar results: Primary and secondary sludge averaged 19.3 and 17.0 cu ft/lb VS destroyed, respectively, while FOG ranged from 23.7 to 29.2 cu ft/lb VS destroyed. In addition, sludge gas averaged approximately 70 percent methane, whereas FOG gas averaged about 75 percent methane. For this study, FOG, scum, and grease load to the digester, a specific gas production of 23 cf/lb VS destroyed with 75 percent methane content is assumed.

In order to size digester gas system piping, peaking factors are necessary. Brown and Caldwell's design guideline is based on historical observations and recommends a manifold peaking factor of 1.5 (peak hour: peak day) for digesters that are not preceded by blend tanks and 1.25 for those that are. Recognizing that individual digesters can be loaded more heavily than average and that performance surges can quickly follow intermittent feeding of an individual digester, the guideline further recommends a lateral peaking factor of 3 (peak hour: peak day) for digesters that are not preceded by blend tanks and 2 for those that are. Current San Jose operation has TWAS flows well buffered through continuous DAFT operation, but primary sludge varies with load and timed pumping. Therefore, current operation represents a case in between the blend-tank and no-blend-tank criteria. Figure 8-5 presents hourly total gas flows from the San Jose plant manifold from March 31, 2010 through April, 27, 2010; and Table 8-3 presents the hourly peaking factors from that period. The data in Table 8-3 show that there are some extreme peaks with one exceeding the recommended 1.5 factor, however these are suspect as they are succeeded by a sudden drop in production and may be associated with a demand peak rather than a gas production peak. Given that the suspect nature of at least one of the plant peak hour gas flows and the existing TWAS flow buffering, moderated peaking factors are recommended and are shown in Table 8-4.

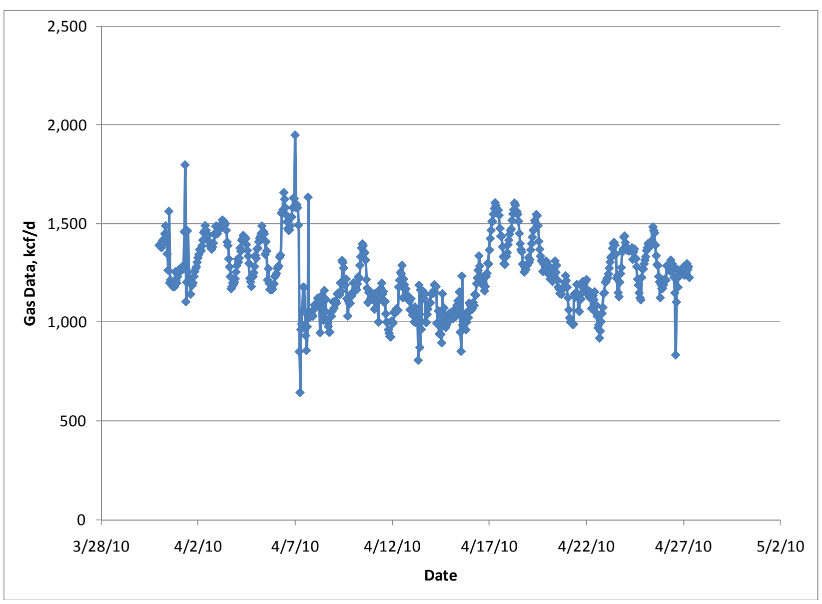


Figure 8-5. Hourly gas flow data (BG-1, BG-2 and flare gas)

Table 8-3. Summary of Hourly Peaking Factors [a]

Date	Average Gas Flow, kcf/d	Peak Hour Gas Flow, kcf/d	Peaking Factor
3/31/2010	1,315	1,561	1.19
4/1/2010	1,277	1,796	1.41
4/2/2010	1,413	1,489	1.05
4/3/2010	1,369	1,517	1.11
4/4/2010	1,327	1,439	1.08
4/5/2010	1,321	1,487	1.13
4/6/2010	1,473	1,656	1.12
4/7/2010	1,158	1,946	1.68
4/8/2010	1,057	1,160	1.10
4/9/2010	1,154	1,313	1.14
4/10/2010	1,229	1,396	1.14
4/11/2010	1,075	1,198	1.11
4/12/2010	1,128	1,288	1.14
4/13/2010	1,051	1,188	1.13
4/14/2010	1,053	1,190	1.13
4/15/2010	1,040	1,234	1.19
4/16/2010	1,188	1,336	1.12
4/17/2010	1,454	1,604	1.10
4/18/2010	1,430	1,603	1.12
4/19/2010	1,380	1,545	1.12
4/20/2010	1,219	1,310	1.07
4/21/2010	1,109	1,212	1.09
4/22/2010	1,089	1,216	1.12
4/23/2010	1,296	1,436	1.11
4/24/2010	1,300	1,403	1.08
4/25/2010	1,323	1,482	1.12
4/26/2010	1,226	1,314	1.07

[a] *Gas readings taken from Blend Gas and flare flow meters.*

Table 8-4 summarizes the recommended peaking factors that are used for the analysis. Gas manifolds and laterals are sized on peak instantaneous flow with redundant digesters out of service. The import materials are assumed to be a constant loading to the digesters, however a peak day-to-average factor of 1.50 is assumed. This allows for the condition that a delivery is missed one day over a presumed holiday weekend and is made up over the course of two subsequent days. This factor is applied to the entire digester load when import materials are received. The addition of a blend tank will reduce the impact of the peak hour gas flows and this is included in Table 8-4. For the lateral sizing, Brown and Caldwell design guideline recommends a peaking factor between 2 and 3, depending on timing of feed and loading rate. It is reasonable that the lateral peaking factor will be greater than the manifold factor, as during peak gas production, there will be variation in production from individual digesters. In addition, there are a number of conditions that can increase gas production for short periods from an individual digester that will not impact all digesters at the same time. Therefore, the lateral peaking factor provides a level of safety for the following possibilities:

- Variation in intermittent feeding time between individual digesters.
- Spike loading from import materials.
- Gas hold up and resultant gas output surge when mixing direction is switched (mechanical draft tube mixers) or when mixers are turned back on after being down for maintenance or power outage (gas or mechanical).

The peaking factor used for the gas laterals (1.75 times the peak day) is further discussed in TM 4.4, Gas Piping Connections/Modifications.

Table 8-4. Summary of Gas Production Peaking Factors for Mesophilic Digestion

Parameter	Annual Average Gas Production, kcf/d [a]	Peak Hour: Peak Day Peaking Factor	Peak Day: Annual Average Peaking Factor [a]	Peak Week: Annual Average Peaking Factor [a]
Peaking Factors determined from 2007 Gas Data	1,480	---	1.34	1.26
Peaking Factors determined from 2008 Gas Data	1,410	---	1.42	1.24
Peaking Factors determined from 2009 Gas Data	1,644	---	1.25	1.16
Peaking Factors determined from 2010 Gas Data	---	1.32[c]		
Peaking Factors determined from 2030 Loading Projections [b]	---	---	1.44	1.39
Recommended Peaking Factors for Gas Manifold (Primary and Secondary Sludges)	---	1.4 (no blend tank) 1.2 (with blend tank)	1.50	---
Recommended Peaking Factors for Gas Manifold (With Import Materials)	---	1.5[d]	1.5[e]	---
Recommended Peaking Factors for Laterals (Assume redundant digesters out of service)	---	1.75[f]	1.5	---

[a] From gas readings taken from blend gas and flare flow meters.

[b] Values determined from mesophilic digestion alternative.

[c] See Table 8-3. For April 2010, peak hour of 1946 kcf/d divided by maximum day for that month of 1473 kcf/d.

[d] Higher peaking factor to account for variability in FOG characteristics

[e] Allows for 1 day of delivery missed; made up over two days

[f] Discussed in TM 4.4

8.7 Redundancy

The number of redundant digesters is based on the number of digesters required at the peak condition (e.g. peak week, peak month, etc.). Table 8-5 summarizes the number of redundant digesters that are required as a function of operating digesters required. These redundancy criteria were developed during discussions with the City as part of the Master Plan work.

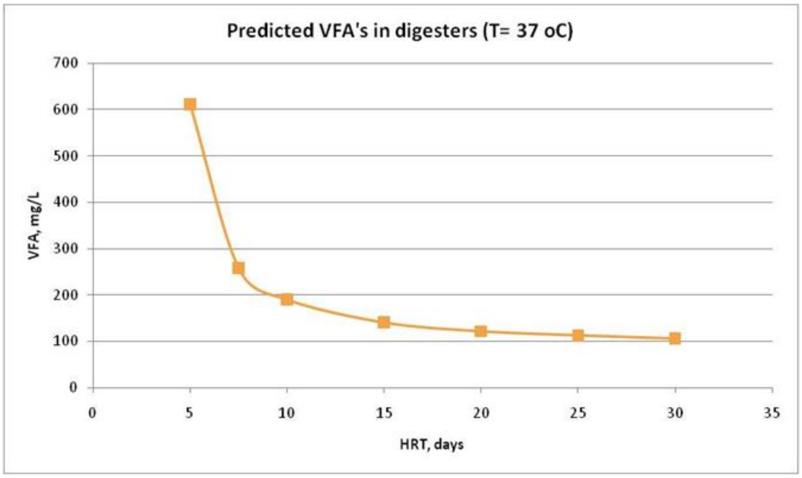
Table 8-5. Summary of Redundancy Requirements

Number of Digesters Necessary to Satisfy Design Criteria	Number of Redundant Digesters
0-5	1
6-10	2
11+	3

8.8 Lagoon Odor – Limits on Digester Operation

The number of operating digesters will be driven principally by criteria on minimum HRT and VS load. As a general rule, mesophilic digester HRT and VS loadings command similar digester volume when TS concentration in the feed solids is around 6 percent TS. For much thinner feed solids, HRT criterion will control. Principally, the VS loading criterion is established to protect digester stability. The HRT criterion provides stability, but also assures sufficient reaction time to achieve a well-stabilized biosolids. The 15-day criterion recommended above to achieve a Class B biosolids is driven by USEPA requirements for reduced pathogens and biosolids stability. At San Jose, current operations discharge digested biosolids into on-site lagoons where significant additional stabilization occurs prior to disposal. Therefore, the Class B limit from the digesters as a precursor to disposal may not at present be a primary driver for digester operation. However, biosolids stability will directly impact odors generated from those lagoons. Traditional designs of facultative sludge lagoons (FSLs) are configured with an aerobic water cap and are lightly loaded to minimize lagoon odors. They typically limit average VS loading to about 20 lb VS/1000 sf/day. The aerobic water cap includes a biological population that helps oxidize sludge degradation products and gasses. The San Jose lagoons are loaded well beyond these limits and are operated as anaerobic lagoons without a significant water cap. Therefore, odorous compounds will volatilize and gases will escape.

Currently, the system operates with minimal odor complaints. However, any increased odor potential may be problematic for the plant. Figure 8-6 shows BioWin model predictions of VFAs at differing HRTs for the San Jose digesters. In November 2009, the plant dropped from 11 to 8 operational digesters without noticeable increased odor from the plant. The average HRT in 2009 prior to November (11 digesters) was about 28 days, while the average after that period (8 digesters) through early 2010 was about 22 days. As can be seen from Figure 8-6, this drop in HRT would represent only a marginal increase in VFAs of less than 8 percent.



HRT, days	VFA
5	610.72
7.5	257.55
10	189.92
15	140.61
20	121.90
25	113.07
30	106.15

Figure 8-6. Model prediction of volatile fatty acid concentrations at various hydraulic residence times

While running 8 digesters, the running 14-day and 7-day average HRTs reached 19 and 16.4 days, respectively. With 8 operating digesters, the drop in HRT from 22 days to 16.4 days would result in an 8 percent increase in VFAs and, under this condition, resultant odor at the plant was still acceptable. A drop from 22 to 10 days would result in over a 50 percent increase in VFAs and would risk odor complaints.

VFA is no doubt part of the potential odor issue, but gas production is also part of it. At low-SRT digestion, more non-degraded material is pushed into the lagoons, so gas production at the lagoons is greater, which brings more gas bubbles to the surface with odorous gases (e.g. H_2S) part of the mix. Figure 8-7 shows BioWin model predictions for VSR versus HRT at various digester temperatures. The VSR reduction moving from 28 to 22 days is marginal, dropping from about 53 to 50 percent (at 95 degrees F) and representing only about a 4 to 5 percent increase in the gas production from the lagoon-stored sludge. The recommended maximum HRT is 15 days at peak two-week load. This would decrease VSR by about by about 13 percent and increase gas generation from lagoon sludge by 10 to 12 percent. This may be tolerable, but beyond that there is a rapid increase – at 10 days HRT, gas production from the lagoons would increase by about 25 percent from the 28-day condition.

With existing lagoon operation, the odor potential will increase in the future with increasing sludge loads. However, for the future, the Master Plan has recommended use of fewer lagoons, covering some lagoons with gas collection, and mechanical dewatering of some of the sludge in lieu of lagoon storage. In this case, the impact of odor from the lagoons will be reduced. Until lagoon operation is modified to reduce odor potential, we recommend that digester HRT not be decreased below the recommended 15 days based on a 14-day average without consideration and monitoring of lagoon odor potential.

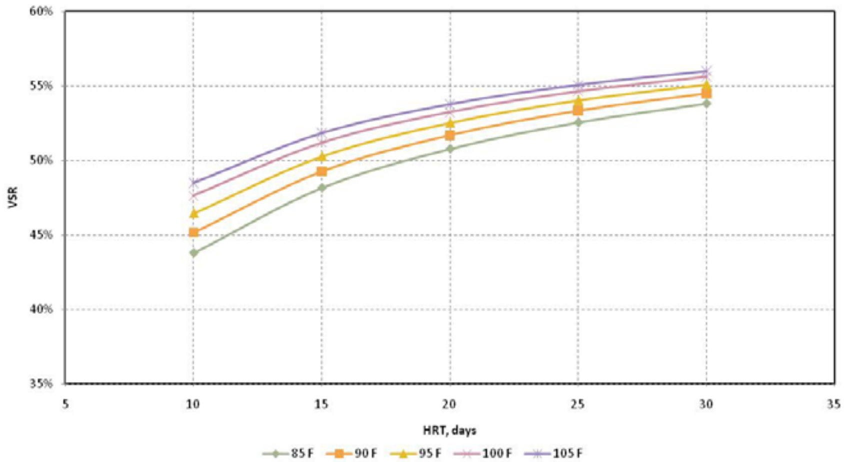


Figure 8-7. Model prediction of VSR over a range of HRT and temperature values

9. SUMMARY OF DESIGN CRITERIA

This section provides a description of the design criteria that are used for each digestion alternative. A summary of the design criteria is provided in Table 9-1. Table 9-2 presents estimated gas production from each alternative based on the flows and loads presented in previous sections and the design criteria from Table 9-1.

Table 9-1. Summary of Design Criteria

Design Criteria	Design Value	Comments
Minimum HRT, days		
Mesophilic	15 @ Peak 2-Week 14/1 (Series Only) @ Peak 2-Week	Section 8.1
Mesophilic – Odor Criterion	15 @ Peak 2-Week	Section 8.8
Cambi™	15 (Secondary Only) @ Peak 2-Week 12 (Primary and Secondary) @ Peak 2-Week	Section 8.1
Thermophilic, Complete Mix	15 @ Peak 2-Week	Section 8.1
Thermophilic, Series	Total System: 15 @ Peak 2-Week First Stage: 8 @ Peak Week	Section 8.1
Blend Tanks	0.5	Section 6.6.2
Temperature, degrees F (degrees C)		
Mesophilic	98.6 (37)	Section 8.4
Thermophilic	131 (55)	Section 8.4
VS loading, lb VS/cf/day		
Mesophilic (Existing Mixing System)	0.18 @ peak week	Section 8,3
Mesophilic (Well Mixed)	0.20 @ peak week 0.18 @ peak month	Section 8.3
Cambi™	0.25 @ peak week (Secondary Only) 0.50 @ peak week (Primary and Secondary)	Section 8.3
Thermophilic	0.35 @ peak week	Section 8.3
Maximum FOG load, percent of total VS load		
Mesophilic and Thermophilic	30	Section 8.3
Cambi™	10	Section 8.3
Sludge VSR, percent		
Mesophilic Complete Mix	54 (average) 51 (maximum loading and minimum HRT)	Section 8.5, Attachment A

Table 9-1. Summary of Design Criteria		
Design Criteria	Design Value	Comments
Mesophilic with Preprocessing[a]	60 (average) 57 (maximum loading and minimum HRT)	Section 6.5
Cambi™	54 (average) 51 (maximum loading and minimum HRT)	Section 8.5
Thermophilic Complete Mix	60 (average) 57 (maximum loading and minimum HRT)	Section 8.5
Thermophilic Series (First Stage/Second Stage)	62 (50/12) (average) 59 (47/12) (max load and min HRT)	Section 8.5
All Alternatives with FOG added	+1	Section 8.5
FOG VSR, percent		
Mesophilic FOG and Plant Scum and Grease	85	Section 8.5
Thermophilic FOG and Plant Scum and Grease	95	Section 8.5
Feed Solids Content, percent TS		
Mesophilic	3.5 and 5.5	Section 6.6.1
Cambi™	6.5 (Secondary Only) 9.5 (Primary and Secondary)	A feed thickness of 9.5 percent TS for primary and secondary sludge is selected to reduce the ammonia content in the digester to prevent toxic impacts to digestion process.
Thermophilic	5.5	Section 6.6.1
FOG and Plant Scum and Grease	12 (FOG) 83 (Scum and Grease)	Section 6.6.1
Gas Production, cf/lb VS destroyed		
Combined PS and TWAS without FOG addition, cf/lb VS destroyed	15.4	Section 8.6
FOG, cf/lb VS destroyed	23	Section 8.6
Food processing waste, cf/lb VS destroyed	14 to 23	Section 8.6. Note: Not used in gas projections – only FOG assumed
Gas Flow Peaking Factor - Peak Day: Average Annual	1.50	Section 8.6
Gas Manifold Peaking Factors – Peak Hour: Peak Day for Primary and Secondary Sludge [b]	1.4 (no blend tank) 1.2 (with blend tank)	Section 8.6
Gas Manifold Peaking Factor – Peak Hour: Peak Day with Import Materials [b]	1.5	Section 8.6
Gas Lateral Peaking Factors – Peak Hour: Peak Day [b]	1.75	Section 8.6

[a] *Includes Acid/Gas Phase digestion with new acid reactor prior to existing digesters*
[b] *Assumes redundant units off line*

10. BASIS OF NET PRESENT VALUE ANALYSES

The net present value evaluation includes the capital expenditures and annual operating costs associated with each alternative. All costs are in 2010 dollars. The alternatives were evaluated on a 30-year period from 2010 to 2040. Operations and maintenance (O&M) costs were amortized using a 2-percent discount rate (5-percent interest rate, 3-percent inflation rate). Percentage markups were applied to the capital expenditures to develop project costs. These factors are from the project memorandum titled "Basis of Cost Evaluation" developed for the WPCP Master Plan in 2009. Table 10-1 summarizes the markups used for the cost estimates. Table 10-2 presents the assumptions used for the net present value calculation. The operating costs were increased each year by 1.6 percent. This percentage is reflective of the estimated annual increase in primary sludge and WAS loading to the WPCP digestion system.

Table 10-1. Basis for Estimating Project Costs

Markups on Raw Construction Cost	
Demolition Costs	10%
Yard piping, sheeting, shoring, piles, coatings and other miscellaneous costs	15%
Electrical and Instrumentation	20%
Markup on Construction Cost Subtotal	
Estimating Contingency	15%
Markup on Base Construction Cost	
Construction Contingency	25%
Markup on Total Construction Cost	
Engineering, Legal, and Administration	30%

Table 10-2. Basis for Net Present Value Calculation

Period	30 years
Interest Rate	5%
Inflation Rate	3%
Discount Rate	2%
Annual Escalation of Operating Costs	1.6%

11. NUMBER OF DIGESTERS REQUIRED – EXISTING AND FUTURE CONDITIONS

This section provides an overview of the digester capacity at the existing operating conditions and the number of digesters necessary for each alternative.

11.1 Digester Requirements at Existing Operation

The number of digesters necessary to satisfy the design criteria (Table 9-1) was determined at existing digester conditions, including mesophilic digestion without mixing upgrades. Table 11-1 summarizes the number of digesters that would be necessary at the 2030 design sludge flow and load without FOG, scum, and grease. The redundancy requirement is added to the number of digesters. The number of digesters is expressed in terms of 110-ft diameter digesters. Table 11-1 shows that at the existing sludge thickness (3.5 percent TS), the HRT criterion determines the number large digesters to be 16 (including redundancy). At the existing conditions, there are just enough digesters to satisfy the operating design requirements. However, even though there are currently 16 digesters at the WPCP, three of them are smaller and cannot meet the volume required for full redundancy.

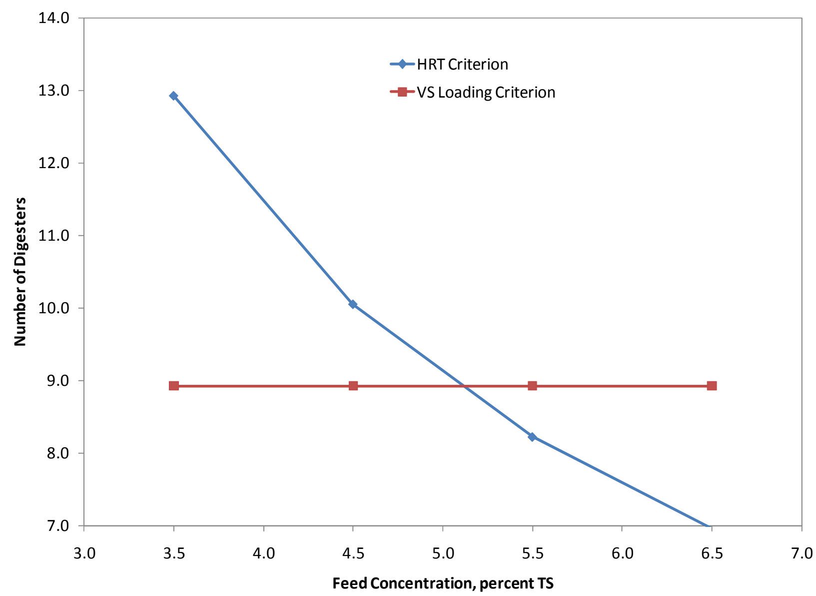
Table 11-1 also presents the number of digesters if the feed sludge thickness were increased. At a feed sludge concentration of 5.5 percent TS, the VS loading criterion and HRT criterion specify the same number of digesters. This is shown graphically in Figure 11-1. If feed sludge concentration were increased through thickening upgrades, we would recommend that mixing improvements be undertaken.

Table 11-1. Summary of Digester Requirements in year 2030 at Existing Operating Conditions [a]

Feed Sludge, percent TS	Max 2-Week Load, 1000 lb VS/day	Max 1-Week Load, 1000 lb VS/day	Max 2-Week Flow, mgd	Max 1-Week Flow, mgd	Min. HRT at Peak 2-Week Flow, days	Max. Org. Load at Peak Week Load, lb VS/cf/d	No. of Digesters (HRT Criterion)	No. of Digesters (VS Loading Criterion)	Total No. of Digesters	Total No. of Digesters w/ Redundancy [b]
3.5	429	452	1.84	1.91	15	0.18	13.1	8.9	13	16
4.5	429	452	1.43	1.49	15	0.18	10.2	8.9	10	12
5.5	429	452	1.17	1.22	15	0.18	8.3	8.9	9	11
6.5	429	452	0.99	1.03	15	0.18	7.1	8.9	9	11

[a] *Mesophilic digestion with floating covers, No mixing improvements, No FOG input. Number of digesters based on 2.11 MG active volume of 110-foot diameter digesters (Active volume from Table 8-1)*

[b] *Redundancy criterion from Table 8-4*



Note: Number of digesters shown does not include redundancy requirement

Figure 11-1. Number of digesters necessary at existing conditions in design year 2030

Table 11-2 summarizes required digesters at current flows and loads (2009) and current digester conditions using historical data. As a baseline for digester stability, 5 digesters could be operated, but this would risk odor in the lagoons. Until lagoon operation is modified to reduce odor potential, we recommend that digester HRT not be decreased below the recommended 15 days based on a 14-day average without consideration and monitoring of lagoon odor potential.

Table 11-2. Summary of Digester Requirements in year 2009 at Existing Conditions using January through October data [a]

Feed Sludge, percent TS	Current Max 2-Week Load, 1000 lb VS/day	Current Max 1-Week Load, 1000 lb VS/day	Current Max 2-Week Flow, mgd	Current Max 1-Week Flow, mgd	Min. HRT at Peak 2-Week Flow, days	Max. Org. Load at Peak Week Load, lb VS/cf/d	No. of Digesters (HRT Criterion)	No. of Digesters (VS Loading Criterion)	Total No. of Digesters	Total No. of Digesters w/ Redundancy [b]
3.5	279	293	1.24	1.28	15	0.18	8.8	5.0	9	11
4.5	279	293	0.96	1.00	15	0.18	6.8	5.0	7	9
5.5	279	293	0.79	0.82	15	0.18	5.6	5.0	6	8
6.5	279	293	0.67	0.69	15	0.18	4.7	5.0	6	8

[a] *Mesophilic digestion with floating covers, no mixing improvements, no FOG input. Number of digesters based on 2.11 MG active volume of 110-foot diameter digesters (Active volume from Table 8-1). Primary sludge loading determined from primary clarifier TSS removal. Secondary sludge loading determined from primary effluent BOD loading and BioWin predicted sludge yield. Peaking factors from Master Plan were used to estimate peak week and peak 2 week loadings.*

[b] *Redundancy criterion from Table 8-4*

The capacity of the existing digesters based on the 2030 loading projections from the Master Plan is presented in Table 11-3. For each condition, it was assumed that all 13 of the 110-foot diameter digesters with an active volume of 2.11-MG each would be in operation and that the three, 100-foot diameter digesters would satisfy the redundancy requirement. The results in Table 11-3 indicate that the digesters will run out of capacity in 15 years (2025) at the current sludge thickening concentration (3.5 percent TS). If sludge thickening were increased to 4.5 percent TS or higher, the digester capacity would exceed the planning period (20 years). However, as stated earlier, feeding a thicker sludge would require mixing improvements.

Table 11-3. Capacity of Existing Digesters (Assume 3, 100-Foot Diameter Digesters Fulfill Redundancy Requirement)

Feed Sludge, percent TS	Peak 2-Week Hydraulic Loading Capacity at HRT Criterion, mgd	Peak Week VS Loading at HRT Criterion, lb VS/d	Peak Week VS Loading Capacity at VS Loading Criterion, lb VS/d	Number of Years of Capacity Remaining (HRT Criterion)	Number of Years of Capacity Remaining (VS Loading Criterion)	Number of Years Remaining
3.5	1.83	432,000	659,000	21	>30	21
4.5	1.83	555,000	659,000	>30	>30	>30
5.5	1.83	678,000	659,000	>30	>30	>30
6.5	1.83	801,000	659,000	>30	>30	>30

11.2 FOG Addition under Existing Digester Conditions

Current annual average VS loading is approximately 200,000 lb/day. This TM recommends a maximum of 30 percent of average total VS load to the digesters be from FOG for well mixed digesters. This equates to approximately 86,000 lb/day of FOG VS current and 131,000 lb/day in 2030.

At an average loading rate of 0.135 lb VS/cu ft/day and an active volume of 2.11 MG, one digester (digesters 4 through 16) can accept 38,000 lb VS/day, including approximately 11,400 lb VS/day of FOG. At 5 to 15 percent TS content, this could represent 4 MG/yr to 11 MG/yr or 9,600 to 29,000 gpd (at 15 percent and 5 percent TS, respectively). The average total digester load of 38,000 lb/day VS at 81 percent VS/TS and 3.5 percent TS is about 160,000 gpd.

At an average 20-day HRT and a 2.11 MG active volume, one digester could be fed 153,000 gpd of liquid and 204,000 gpd at max 2-week HRT of 15 days. Maintaining FOG feed based on average proportion of VS load will be limited by hydraulic load – 153,000 gpd fed per digester with 8,600 gpd to 25,800 gpd of FOG feed. After the thickening upgrade, VS load will control.

A review of this background information highlights several critical issues for consideration. Depending on the TS concentration of the received FOG load (5 percent to 15 percent), the current market is sufficient to fully satisfy the FOG capacity of 2 to 6 larger digesters (Digesters 4 through 16) if well mixed. By 2030, the FOG market would be capable of fully charging from 4 to 11 well mixed digesters. Excessive FOG load to a poorly mixed digester has the potential for causing several operational problems. The potential exists for heavily loaded, poorly mixed dead zones to become incorporated quickly, causing a surge of gas production. This can cause sudden volume expansion and potential foaming and overwhelm gas piping, causing gas release from the pressure release valves. In addition, FOG can consolidate at the surface, causing a grease mat that can further detract from active volume. Consequently, we recommend de-rating the maximum FOG VS load for poorly mixed digesters to one third of that recommended for well mixed digesters, or 10 percent of the total digester VS load. This will help mute the foaming and gas surges and delay the formation of a grease mat at the surface. Based on this criterion, prior to mixing upgrades, we recommend limiting the FOG feed rate to any of the larger digesters to approximately 3,000 to 9,000 gpd.

11.3 Digester Requirements for Alternatives

The following section summarizes digester requirements for each alternative with and without import materials. For all future alternatives, at least two digesters would be reserved for pilot studies. These two digesters would be part of the total number of digesters required to meet design criteria and redundancy criterion. For each of these alternatives, there are specific design considerations for future upgrades. The digester upgrades include the following:

- Covers – submerged fixed covers assumed (fixed cover conditions will be evaluated in TM 4.2 - Cover and Mixing System Selection)
- Mixing – mixing upgrades are assumed for all future alternatives
- Heating – heating upgrades are assumed for all future alternatives
- Gas piping – gas piping upgrades are assumed for all future alternatives

11.3.1 No Import Materials

Table 11-4 summarizes the number of digesters needed for each alternative with no import materials. It is assumed that the digesters would be upgraded with submerged fixed covers which is the recommendation provided in TM 4.2. This would increase the digester volume to 2.89 MG. The values in parentheses represent the number of digesters if floating covers were retained.

Table 11-4. Summary of Digester Requirements in Design Year 2030 (No Import Materials)[a]

Alternative	Sub-Alternatives	Feed Sludge, percent TS	Feed Sludge, percent VS	Max 2-week Flow, mgd	Max 1-week Flow, mgd	Min. HRT, d (1st Stage)	Min. HRT, d (2nd Stage)	Max. Week Org. Load, lb VS/cf/d	No. of 1st Stage Digesters (HRT Criterion)	No. of 2nd Stage Digesters (HRT Criterion)	No. of 1st Stage Digesters (VS Load Criterion)	Total	Total w/ Redundancy
Mesophilic	Complete Mix	3.5	2.8	1.84	1.91	15	---	0.20	9.5 (12.1)	---	5.8 (7.4)	10 (12)	12 (15)
Mesophilic	Complete Mix	5.5	4.5	1.17	1.22	15	---	0.20	6.1 (7.7)	---	5.8 (7.4)	6 (8)	8 (10)
Cambi™	WAS Only	6.5[b]	5.3	0.99	1.03	15	---	0.25	5.1 (6.5)	---	4.7 (5.9)	5 (7)	6 (9)
Cambi™	Primary and WAS	9.5	7.7	0.68	0.70	12	---	0.50	2.8 (3.6)	---	2.3 (3.0)	3 (4)	4 (5)
Thermophilic	Complete Mix	5.5	4.5	1.17	1.22	15	---	0.35	6.1 (7.7)	---	3.3 (4.2)	6 (8)	8 (10)
Thermophilic	Series	5.5	4.5	1.17	1.22	8	7	0.35	3.2 (4.3)	2.8 (3.5)	3.3 (4.2)	6 (8)	8 (10)
Preprocessing w/ Mesophilic	Many	5.5	4.5	1.17	1.22	15	---	0.20	6.1 (7.6)	---	5.8 (7.4)	6 (8)	8 (10)

[a] Number of digesters based on 2.89-MG active volume of 110-foot diameter digesters equipped with submerged fixed covers; values in parentheses represent number of digesters if floating covers were retained (2.29-MG active volume)

[b] Combined concentration of Cambi™ WAS and primary sludge thickened in primary sedimentation basins

11.3.2 With Import Materials

The digester requirements if import materials are summarized in Tables 11-5 and 11-6. Table 11-5 presents the design condition (20 percent of import materials accounting for annual VS loading). Table 11-6 presents the maximum condition (30 percent of import materials accounting for annual VS loading). For both conditions, it is assumed that the digesters would be upgraded with submerged fixed covers which is the recommendation provided in TM 4.2. This would increase the digester volume to 2.89 MG. The values in parentheses represent the number of digesters if floating covers were retained.

Table 11-5. Summary of Digester Requirements in Design Year 2030 (Including Design Import Materials)[a,b]

Alternative	Sub-Alternatives	Feed Sludge, percent TS	Feed Sludge, percent VS	Max 2-week Flow, mgd	Max 1-week Flow, mgd	Min. HRT, d (1st Stage)	Min. HRT, d (2nd Stage)	Max. Org. Load, lb VS/cf/d	No. of 1st Stage Digesters (HRT Criterion)	No. of 2nd Stage Digesters (HRT Criterion)	No. of 1st Stage Digesters (VS Load Criterion)	Total	Total w/ Redundancy
Mesophilic	Complete Mix	3.5	2.9	2.12	2.19	15	---	0.20	11.0 (13.9)	---	6.9 (8.7)	11 (14)	14 (17)
Mesophilic	Complete Mix	5.5	4.6	1.35	1.40	15	---	0.20	7.0 (8.9)	---	6.9 (8.7)	7 (9)	9 (11)
Cambi™	WAS Only	6.5 [c]	5.4	1.14	1.18	15	---	0.25	5.9 (7.5)	---	5.5 (7.0)	6 (8)	8 (10)
Cambi™, [d]	Primary and WAS	9.5	7.8	0.72	0.75	12	---	0.50	3.0 (3.8)	---	2.5 (3.2)	3 (4)	4 (5)
Thermophilic	Complete Mix	5.5	4.6	1.35	1.40	15	---	0.35	7.0 (8.9)	---	3.9 (5.0)	7 (9)	9 (11)
Thermophilic	Series	5.5	4.6	1.35	1.40	8	7	0.35	3.7 (4.9)	3.3 (4.1)	3.9 (5.0)	7 (9)	9 (11)
Preprocessing w/ Mesophilic	Many	5.5	4.6	1.35	1.40	15	---	0.20	7.0 (8.9)	---	6.9 (8.7)	7 (9)	9 (11)

[a] Number of digesters based on 2.89-MG active volume of 110-foot diameter digesters equipped with submerged fixed covers; values in parentheses represent number of digesters if floating covers were retained (2.29-MG active volume)

[b] All first stage digesters are loaded with design flow and load of FOG, scum, and grease up to a maximum of 30 percent of VS load except Cambi™ to a maximum of 10 percent of VS load

[c] Combined concentration of Cambi™ WAS and primary sludge thickened in primary clarifiers

[d] Import materials represents 10 percent of average VS loading for Cambi™ (primary and WAS), only

Table 11-6. Summary of Digester Requirements in Design Year 2030 (Including Maximum Import Materials)[a, b]

Alternative	Sub-Alternatives	Feed Sludge, percent TS	Feed Sludge, percent VS	Max 2-week Flow, mgd	Max 1-week Flow, mgd	Min. HRT, d (1st Stage)	Min. HRT, d (2nd Stage)	Max. Org. Load, lb VS/cf/d	No. of 1st Stage Digesters (HRT Criterion)	No. of 2nd Stage Digesters (HRT Criterion)	No. of 1st Stage Digesters (VS Load Criterion)	Total	Total w/ Redundancy
Mesophilic	Complete Mix	3.5	2.9	2.31	2.38	15	---	0.20	12.0 (15.2)	---	7.5 (9.5)	12 (15)	15 (18)
Mesophilic	Complete Mix	5.5	4.6	1.47	1.52	15	---	0.20	7.6 (9.6)	---	7.5 (9.5)	8 (10)	10 (12)
Cambi™	WAS Only	6.5[c]	5.5	1.24	1.28	15	---	0.25	6.5 (8.2)	---	6.0 (7.6)	7 (8)	9 (10)
Cambi™[d]	Primary and WAS	9.5	7.8	0.72	0.75	12	---	0.50	3.0 (3.8)	---	2.5 (3.2)	3 (4)	4 (5)
Thermophilic	Complete Mix	5.5	4.6	1.47	1.52	15	---	0.35	7.6 (9.6)	---	4.3 (5.5)	8 (10)	10 (12)
Thermophilic	Series	5.5	4.6	1.47	1.52	8	7	0.35	4.1 (5.3)	3.6 (4.5)	4.3 (5.5)	8 (10)	10 (12)
Preprocessing w/ Mesophilic	Many	5.5	4.6	1.47	1.52	15	---	0.20	7.6 (9.6)	---	7.5 (9.5)	8 (10)	10 (12)

[a] *Number of digesters based on 2.89-MG active volume of 110-foot diameter digesters equipped with submerged fixed covers; values in parentheses represent number of digesters if floating covers were retained (2.29-MG active volume)*

[b] *All first stage digesters are loaded with design flow and load of FOG, scum, and grease up to a maximum of 30 percent of VS load except Cambi™ to a maximum of 10 percent of VS load.*

[c] *Combined concentration of Cambi™ WAS and primary sludge thickened in primary clarifiers*

[d] *Import materials represents 10 percent of average VS loading for Cambi™ (primary and WAS), only*

12. GAS PRODUCTION PROJECTIONS

This section summarizes the projected gas flow for the digesters with and without import materials.

12.1 Gas Production without Import Materials

The projected gas flows for the condition where import materials are not accepted are summarized in Table 12-1.

Table 12-1. Summary of Gas Production for each Alternative in Design Year 2030 (No Import Materials).

Alternative	Sub-Alternatives	Annual Average Gas Production, kcf/day	Peak Week Gas Production, kcf/d	Peak Day Gas Production, kcf/day	Peak Instantaneous Gas Production, kcf/day	Number of Digesters in Operation[a]	Peak Gas Flow per digester, kcf/day [a,b]
Mesophilic	Complete Mix @ 3.5 percent TS	2,546	3,564	3,818	6,682	10 (12)	696 (557)
Mesophilic	Complete Mix @ 5.5 percent TS	2,546	3,564	3,818	6,682	6 (8)	1,114 (835)
Cambi™	WAS Only	2,546	3,564	3,818	6,682	5 (7)	1,336 (955)
Cambi™	Primary and WAS	2,546	3,564	3,818	6,682	3 (4)	2,227 (1,671)
Thermophilic	Complete Mix	2,834	3,968	4,251	7,439	6 (8)	1,240 (930)
Thermophilic	Series (Total)	2,928	4,100	4,393	7,687	6 (8)	---
	First Stage	2,343	3,280	3,514	6,150	3 (4)	2050 (1,538)
	Second Stage	586	820	879	1,537	3 (4)	512 (384)
Preprocessing w/ Mesophilic	Many	2,834	3,968	4,251	7,439	6 (8)	1,240 (930)

[a] *Number of digesters and peak flow per digester based on 2.89-MG active volume of 110-foot diameter digesters equipped with submerged fixed covers; values in parentheses represent values if floating covers were retained (2.29-MG active volume)*

[b] Based on peak hour:peak day factor for laterals of 1.75 from Table 8-4

12.2 Gas Production with Import Materials

The projected gas flows for the condition where import materials are accepted are summarized in Table 12-2 and Table 12-3. Table 12-2 represents the design condition (20 percent of import materials accounting for annual VS loading). Table 12-3 represents the maximum condition (30 percent of import materials accounting for annual VS loading).

Table 12-2. Summary of Gas Production for Each Alternative in Design Year 2030 (With Design Import Materials)

Alternative	Sub-Alternatives	Annual Average Gas Production, kcf/day	Peak Week Gas Production, kcf/d	Peak Day Gas Production, kcf/day	Peak Instantaneous Gas Production, kcf/day	Number of Digesters in Operation [a]	Peak Gas Flow per digester, kcf/day [a,b]
Mesophilic	Complete Mix @ 3.5 percent TS	4,133	5,170	6,200	10,850	11 (14)	986 (775)
Mesophilic	Complete Mix @ 5.5 percent TS	4,133	5,170	6,200	10,850	7 (9)	1,550 (1,206)
Cambi™	WAS Only	4,133	5,170	6,200	10,850	6 (8)	1,808 (1,356)
Cambi™	Primary and WAS	3,257	4,294	4,885	8,549	3 (4)	2,850 (2,137)
Thermophilic	Complete Mix	4,603	5,756	6,905	12,083	7 (9)	1,726 (1,343)
Thermophilic	Series (Total)	4,697	5,888	7,046	12,331	7 (9)	---
	First Stage	3,758	4,710	5,637	9,865	4 (5)	2,466 (1,973)
	Second Stage	939	1,178	1,409	2,466	3 (4)	822 (617)
Preprocessing w/ Mesophilic	Many	4,422	5,574	6,633	11,607	7 (9)	1,658 (1,290)

[a] *Number of digesters and peak flow per digester based on 2.89-MG active volume of 110-foot diameter digesters equipped with submerged fixed covers; values in parentheses represent values if floating covers were retained (2.29-MG active volume)*

[b] Based on peak hour:peak day factor for laterals of 1.75 from Table 8-4

Table 12-3. Summary of Gas Production for each Alternative in Design Year 2030 (With Maximum Import Materials).

Alternative	Sub-Alternatives	Annual Average Gas Production, kcf/day	Peak Week Gas Production, kcf/d	Peak Day Gas Production, kcf/day	Peak Instantaneous Gas Production, kcf/day	Number of Digesters in Operation[a]	Peak Gas Flow per digester, kcf/day [a,b]
Mesophilic	Complete Mix @ 3.5 percent TS	5,155	6,192	7,732	13,531	12 (15)	1,128 (902)
Mesophilic	Complete Mix @ 5.5 percent TS	5,155	6,192	7,732	13,531	8 (10)	1,691 (1,353)
Cambi™	WAS Only	5,155	6,192	7,732	13,531	7 (8)	1,933 (1,691)
Cambi™	Primary and WAS	3,257	4,294	4,885	8,549	3 (4)	2,850 (2,137)
Thermophilic	Complete Mix	5,745	6,897	8,617	15,080	8 (10)	1,885 (1,508)
Thermophilic	Series (Total)	5,839	7,029	8,759	15,327	8 (10)	---
	First Stage	4,671	5,623	7,007	12,262	4 (5)	3,065 (2,452)
	Second Stage	1,168	1,406	1,752	3,065	4 (5)	766 (613)
Preprocessing w/ Mesophilic	Many	5,443	6,596	8,165	14,289	8 (10)	1,786 (1,430)

[a] *Number of digesters and peak flow per digester based on 2.89-MG active volume of 110-foot diameter digesters equipped with submerged fixed covers; values in parentheses represent values if floating covers were retained (2.29-MG active volume)*

[b] Based on peak hour:peak day factor for laterals of 1.75 from Table 8-4

12.3 Discussion of Gas System Requirements

Based on the gas production rates shown in Table 12-3, the gas system header size will be driven by the series thermophilic alternative with the full FOG and plant scum and grease load. Gas lateral size on specific digesters will be driven either by the first stage thermophilic digesters or by the Cambi™ digesters, whichever has the highest ratio of gas production to digester number. This is discussed in TM 4.4 – Gas Piping Connections/Modifications.

13. CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the conclusions from the analysis of historical data, development of the design basis and design criteria, and projected number of digesters for the future. As a result of this analysis, recommendations are presented for future activity.

13.1 Conclusions

This TM defines the design criteria that will be used for the Digester Modifications and Gas System Improvements projects. The design criteria identified in this TM were derived from historical plant data, Brown and Caldwell design experience, and the results of published studies. These design criteria in conjunction with 2030 flow and load projections based on the Master Plan, the number of digesters and projected gas flows for several digester alternatives were presented. In addition, the digester requirements assuming import materials are accepted is presented. The key findings from this effort include the following:

- The current digester mixing system has resulted in a significant loss of active volume. Upgrading the mixing system would restore active volume and allow for higher VS loading rates.
- The current data collection is inadequate to determine digester loading. It is recommended that primary and secondary sludge sampling and flow measurements are improved.
- The Van Kleeck method to calculated VSR underestimates digester performance due to grit deposition. The mass balance method provides a better estimate of performance.
- The current VSR and gas production values are within range of typical municipal anaerobic digester processes.
- The current digester temperature varies depending on the time of year and between individual units. It is recommended that better temperature control is implemented to provide a more stable condition for the digesters.
- At current peak sludge flow and load, nine digesters are required to meet the 15-day HRT criterion plus two redundant digesters. Currently, eight digesters are in operation and have performed well. There is evidence that active volume in a given digester may be greater with eight digesters operating than with 11 due to potentially better mixing from hydraulic load and higher VS load generating more gas, which contributes to mixing.
- At current loads, operation with five digesters would be possible based on organic loading criterion. This would reduce the HRT below the 15-day Part 503 Class B criterion from the digesters, but additional stabilization in the lagoons would potentially qualify the lagoon-harvested sludge as Class B. Testing would be required to confirm this and discussions with regulatory authorities would be required to confirm acceptability of this classification with this strategy. Reduced HRT (below 15 days) would also risk odor formation in the sludge lagoons. This would require testing to determine the impact of odor on from the lagoon at reduced HRT.
- At the 2030 flows and loads, without import materials, at existing conditions, 13 digesters would be required to meet the 15-day HRT criterion with three redundant units. If the sludge thickness were increased to 5.5 percent TS with a thickening upgrade, nine digesters would be required, with two redundant units. Increasing sludge thickness would require mixing improvements.
- Assuming mixing improvements are made, the import material loading can be as much as 30 percent of the annual average VS loading. However, the Cambi™ process (primary and secondary sludge) should be limited to 10 percent to mitigate the potential for ammonia toxicity.
- At 2030 flows and loads, without import materials and with mixing improvements, mesophilic digester at a feed sludge thickness of 3.5 percent TS would require the most digesters (15 total, including

redundancy). Cambi™ (primary and secondary sludge) would require the least digesters (five total, including redundancy). At the maximum recommended import material loading, the most digesters required would be 18 total for mesophilic digestion at a feed sludge thickness of 3.5 percent TS.

- Annual average gas production for the 2030 flow and loads is projected to range from 2,546 scfm to 2,928 scfm, depending on the alternative. If the maximum import material loading were accepted, gas productions could double.
- The highest peak instantaneous gas production per digester is associated with Cambi™ (primary and secondary sludge) because of the relatively few digesters necessary for operation. The next highest peak instantaneous value is associated with the first stage of a staged thermophilic process.

13.2 Recommendations

As a result of the analysis of historical data and analysis for digester requirements for the future, the recommendations include:

- It is likely that the WPCP will receive import materials in the future. It is recommended that the design basis that implements the design import materials is used for this project.
- It is possible to operate a digester with 30 percent of the VS loading originating from import materials. It is recommended that the two pilot digesters are designed for this condition.
- The Cambi™ process (primary and secondary sludge) would require the fewest number of digesters, but would require ancillary facilities for pretreatment. In addition, the gas peaking factors for this alternative are the highest of all of the alternatives. Since there are no space constraints at the WPCP, designing for the Cambi™ process is not recommended.
- The digesters that are rehabilitated will most likely be operated as mesophilic digesters. However, the gas systems should be designed to allow for series thermophilic operation.
- The digesters that are rehabilitated should have sufficient heating for mesophilic conditions. However, the option to upgrade to thermophilic digestion in the future should be considered.
- The Master Plan recommends adding a new sludge fine screening facility. This project team concurs and supports this recommendation to further develop a fine screening facility project.
- It is recommended that the City determine the on-going ability to dampen diurnal peaks of solids loads within the liquid stream. If this is possible, the City should continue to optimize this practice. If this is not possible, thickened sludge blend tanks should be considered for sludge load equalization and blending.

14. REFERENCES

Black & Veatch, March 2006. *San Jose/Santa Clara Water Pollution Control Plant Scum Digestion Pilot*.

Black and Veatch, August 1997. *Facilities Condition Assessment Study*.

Boušková, A, M. Dohányos, J.E. Schmidt, I Angelidaki, (2005)"Strategies for Changing Temperature From Mesophilic to Thermophilic Conditions in Anaerobic CSTR Reactors Treating Sewage Sludge", Water Research,39, 1481-1488.

Brown and Caldwell, 2007. *SRWTP Biogas Enhancement Project, Phase 2 Technical Feasibility*.

Carollo, Brown and Caldwell, SOM, 2009. *San Jose/Santa Clara Water Pollution Control Plant Master Plan, Task No. 3, Project Memorandum No. 4 – Master Plan Design/Standby Criteria,* Final Draft, July 2009.

Carollo, Brown and Caldwell, SOM, 2010. *San Jose/Santa Clara Water Pollution Control Plant Master Plan, Task No. 5, Project Memorandum No. 2 – Biosolids Treatment Alternatives,* Draft, May, 2010.

Carollo, Brown and Caldwell, SOM, 2008. *San Jose/Santa Clara Water Pollution Control Plant Master Plan, Task No. 3, Project Memorandum No. 6 – Historical and Projected Service Area/Population, Final Draft, August, 2008.*

Carollo, Brown and Caldwell, SOM, 2010. *San Jose/Santa Clara Water Pollution Control Plant Master Plan, Task No. 5, Project Memorandum No. 1, Liquids Treatment Alternatives,* Final Draft, June 2010.

CH2M Hill, May 2008. San Jose-Santa Clara Water Pollution Control Plant Process Piping Assessment

CH2M Hill, May 2007. *Infrastructure Condition Assessment*.

EEC, 2009. FOG Projections within the Plant Service Area and surrounding Area (email correspondence, February 23, 2009).

Environmental Protection Agency, 1979. *EPA Process Design Manual for Sludge Treatment and Disposal*.

Flippin, H., Busch, D., Karas, B., and Bowen, P. 2007. *Beneficial Use of Dairy, Fountain, and Fruit Beverages in POTWS,* presented at the WEFTEC 2007 conference.

Gillette, Robert, 2008. *Increasing your Gas Production and Reducing your FOG Problems.* Presented at the California Water Environment Association 80th Annual Conference, April, 2008.

Gray, D., Suto, P., and Peck, C., March, 2008. *Anaerobic Digestion of Food Waste, East Bay Municipal utility District, USEPA No. EPA-R9-WST-06-004.*

HDR, October 2008. *City of San Jose Integrated Waste Management Zero Waste Plan, Conversion Technologies and Facilities (Draft Report)*.

Kabouris, J.C., Tezel, U., Pavlostathis, S.G., Engelmann, M., Dulaney, J.A., Todd, A.C., and Gillette, R.A., May, 2009, *Mesophilic and Thermophilic Anaerobic Digestion of Municipal[al Sludge and Fat, Oil, and Grease, Water Environ Res. 81(5):476-485.*

Li. Y. Y., Sasaki, H., Yamashita, K., and Kamigochi, I., 2002. *High-Rate Methane Fermentation of Lipid-Rich Food Wastes by High Solids Co-Digestion Process*, Water Science and Technology, Vol. 45, No. 12, pp143-150.

Reyes, J., Noble, M., Matz, R., and Blach, P., 2003, 2004, 2005, and 2007. *Digestion Coating Inspection Reports*.

Salsali, H.R., W.J. Parker "An Evaluation of 3 Stage Anaerobic Digestion of Municipal Wastewater Treatment Plant Sludge" Proceedings of the Residuals and Biosolids Conference 2006, (2006) Nashville TN.

City of San Jose, 2009. Existing On-line Operations Manual.

City of San Jose, 2009. Table 2B from the *Overall City-Wide Waste Stream Review* (email correspondence from Ravi Kachhapati, February 17, 2009)

Sanders, W.T.M., M. Geerink, G. Zeeman, and G. Lettinga, *Anaerobic Hydrolysis Kinetics of Particulate Substrates.* Water Science and Technology, 2000. 41(3): p. 17-24.

Schafer, P., Trueblood, D. Fonda, K., and Lekvin, C., 2007. *Grease Processing for Renewable Energy, Profit, Sustainability, and Environmental Enhancement*, presented at the WEFTEC 2007 conference.

Suto, P., Gray, D., Larsen, E., and Hake, J., 2006. *Innovative Anaerobic Digestion Investigation of Fats, Oils, and Grease*, presented at the WEF Residuals and Biosolids Conference.

Water Environment Federation, 1992. *WEF Design of Municipal Wastewater Treatment Plants, Manual of Practice No. 8*.

Vavilin, V.A., S.V. Rytov, and L.Y. Lokshina, *A Description of Hydrolysis Kinetics in Anaerobic Degradation of Particulate Organic Matter.* Bioresource Technology, 1996. 56: p. 229-237.

YEI Engineers, October 2004. *San Jose/Santa Clara WPCP Electrical System Improvement Study*.

Zhang, R., and El-Mashad, H., 2005. Research Report on *Characterization of Dairy Manure and Food Waste for Anaerobic Digestion,* prepared for Sacramento Municipal Utility District.

ATTACHMENT A: RELATIONSHIP BETWEEN HRT AND VSR IN MESOPHILIC DIGESTION

Technical Memorandum 3.3A

Brown AND Caldwell
201 N. Civic Drive - Suite 115
Walnut Creek, CA, 94596
Tel: 888.299.0000
Fax: 925.937.9026

Prepared for: San Jose/Santa Clara Water Pollution Control Plant

Project Title: FOG Evaluation, Digester Rehabilitation and Gas Line Replacement

Project No: 136242-004

Technical Memorandum No. 3.3 – Attachment A

Subject: Evaluation of Existing Digester Volatile Solids Reduction Performance

Date: June 30, 2010

To: Ravi Kachhapati, Project Manager

From: Steve Krugel, Project Manager

Prepared by: Christopher Muller, PhD

Reviewed by: Steve Krugel

Rion Merlo, PhD, PE

Table of Contents

1. FACTORS IMPACTING DIGEST PERFORMANCE

The following list provides a brief summary of the various factors that may influence the observed performance in digesters. As will be apparent, some are within the control of the operator or design engineer while other are not. Understanding all of these factors can help in making design and operating decisions.

- *Primary Sludge to Secondary Sludge Ratio:* Secondary sludge is typically poorly degradable relative to primary sludge. Increasing the proportion of secondary sludge will reduce the observed volatile solids reduction (VSR). This is the fundamental message of the Parkin and Owen curves shown in this report as well as in Grady et al. (1999).

- *Secondary Process Solids Retention Time (SRT):* Increasing the secondary process SRT will decrease the overall degradability of the secondary sludge being loaded to the digesters. At longer SRTs, decay becomes more significant and thus material is aerobically degraded prior to the digester. This partial aerobic stabilization of organics prior to anaerobic digestion can result in a lower digester VSR.

- *Industrial Input:* Some industrial inputs, such as pulp and paper processing water, contain material that show up in the volatile solids (VS) test but are not degradable under the conditions typically found in a municipal sludge digester. These relatively inert materials artificially increase the raw sludge VS content resulting in a reduction in the calculated value.

- *Mixing:* Poor mixing can impact the digestion process and process parameters. It can also lead to stratification and poor contact between the microorganisms and substrate, and short circuiting. As an example, process steps such as hydrolysis require external forces to bring the substrate into contact with the enzymes, which catalyze the reaction, as neither the enzymes nor the flocculated cells they are associated with are particularly motile. Most extracellular enzymes, many of which are hydrolytic enzymes, are located in the extracellular polymeric substances (EPS) of the sludge floc (Mišík and Riesz, 1999) or close to the cell (Cadoret et al., 2002). Hydrolysis, the conversion of high molecular weight compounds to low molecular weight compounds, is considered to be one of the major rate limiting steps of digestion (Vavilin et al., 1997). Poor mixing can reduce the contact between theses enzymes and substrate due to stratification or short circuiting. Ensuring sufficient mixing is critical. However, over mixing can be detrimental to the process as well. Stroot et al. (2001) reported that excessively high mixing rates in a digester (co-digesting organic solid waste and sludge) resulted in process failure relative to a digester with less intense mixing. The process failure was hypothesized to be due to the spatial separation of the syntrophic organisms associated with bioconversion of sludge to biogas.

- *Unstable Heating:* The elevated operating temperatures of mesophilic digesters are what allow the microorganisms to remain in the tank at "relatively" low hydraulic retention times (HRTs) and operate at higher metabolic rates than at ambient temperatures. Fluctuations in temperature can result in process destabilization, potentially through stress on the microorganisms. Typically, designers should target maintaining temperatures within ±1 degree C of optimum.

- *Inconsistent Loading:* Anaerobic digestion (mesophilic or thermophilic) depends on balance and consistency to operate optimally. Rapid and frequent fluctuations in sludge loading to anaerobic digesters can lead to process destabilization and potentially failure. Typically, acid forming/fermentative organisms have faster growth rates than their methanogenic counterparts. Thus, when a spike loading occurs, acid formation out paces consumption. If sufficient alkalinity is present, the digester may not be negatively impacted by the spike load, but if repeated spikes in succession occur, the alkalinity will be consumed, pH will drop and the process will fail.

- *Toxicity/Inhibition:* The presence of toxins or inhibitory compounds can artificially decrease the performance of digesters. It is particularly difficult to detect such toxicity or inhibition when it is chronic or partial. Given the myriad of industrial chemicals discharged to sewers, it is possible to have inhibition and attribute it to another mitigating factor. Speece (2008) discusses a variety of topics including; ammonia, hydrogen sulfide, metals, and organic chemical toxicity.

- *Sludge Composition:* New data is entering the literature that suggests that the chemical composition of the sludge can impact the overall digestibility of the solids (Park et al., 2006). Researchers have suggested that metals such as iron and aluminum impact the overall anaerobic degradability of sludge (Muller and Novak, 2007). The differences in digestibility are based on the differences in redox chemistry between the metals (iron and aluminum) and their subsequent interactions with the organic material in the sludge (Novak et al., 2003). As this body of literature develops, it may be possible to further explain some of variation in digester performance to a greater extent.

After initial review of San Jose operating data, several of these performance factors were suspected to potentially having influence on digester performance: digestion system HRT, secondary system SRT, mixing, grit deposition, and primary/secondary sludge ratio. The following sections discuss these factors in more detail. Other issues such as heating, loading , and mixing are discussed in other technical memoranda.

2. RELATIONSHIP BETWEEN HRT AND VSR IN MESOPHILIC DIGESTION-A HISTORICAL PERSPECTIVE

Increasing HRT in an anaerobic digester has been long reported to increase the observed VSR in anaerobic digesters. The rate of return, in terms of additional VSR, diminishes with increasing HRT, as has been reported by Parkin and Owen (1986) and the USEPA (WEF, 1998). However, the extent of VSR is not only dependent upon the HRT but also a variety of other parameters. One parameter that is commonly thought to be influential in predicting anaerobic digester performance is the primary sludge to secondary sludge ratio in the raw solids loaded to the digester. Parkin and Owen (1986), as shown in Grady et al. (1999), developed a predictive relationship between the HRT of a mesophilic digester and the reduction of chemical oxygen demand (COD) through the digester. Figure 2-1, is a reproduction of the graph presented in Grady et al. (1999) produced by selecting points off the graph and re-plotting. In the absence of the raw data, this effort is intended to produce a reliable facsimile of the graph for the purposes of assessing its current relevance.

It should be noted that Figure 2-1 reports the values on the Y-axis as VSR rather than COD reduction, as originally reported by Parkin and Owen. This change in units allows for comparison of the trend reported by Parkin and Owen to operating mesophilic digesters in North America, which customarily report the extent of biological conversion of organic matter to biogas in terms of VSR. This change in units is supported by the statements made in Grady et al. (1999), which state that the values are essentially equivalent. It should be noted that the assertion that VSR and COD removal are equivalent is only valid in mesophilic digesters, when there are not significant quantities of volatile degradable substrates in the digester liquor, such as volatile fatty acids (VFAs). These compounds are lost during the VS test but retained in the COD test thus creating a divergence in the calculated removal. Stable mesophilic anaerobic digestion operates at VFA concentrations in the range of 50 to 300 mg/L as acetate. In this range, the discrepancies in measurements between the VS and COD tests are minimal, as determined by conducting a sensitivity analysis (data not shown).

The average two year (2006-2007) HRT and VSR , as calculated by the Van Kleeck and mass balance methods, of the San Jose mesophilic digesters was plotted along with the Parkin and Owen data in Figure 2-1. Inspection of the data suggests that the digesters, assuming an approximate 50/50 ratio of primary sludge to secondary sludge, are performing close to, if not slightly better than, would be expected. However, this may not necessarily be the case.

Periodically fundamental relationships such as the one presented in Figure 2-1 should be revisited to ensure its current validity, especially as the technologies used to execute the process, such as anaerobic digestion, advance and the fundamental understanding of the controlling factors increase. The data presented by Parkin and Owen, while based on fundamentally sound principals, represents the state of knowledge and engineering acuity of 23 years ago and should be revisited. A simple and relatively low cost approach to verifying the current usefulness of the Parkin and Owen data and other such trends would be to survey the performance of a variety of mesophilic digesters currently in operation or recently reported in the literature. By comparing the respective HRT and VSR of other digesters, operating and literature based, to the Parkin and Owen data one should be able to determine if the relationship, in all aspects, still holds true. The type of digesters to be included in the survey should be a mix of full-scale, pilot, and bench-scale efforts as they each provide distinct advantages and disadvantages. Full-scale systems report on the actual performance of modern engineered systems, but tend to have more variable operation as they are influenced by the changes in the primary and secondary treatment processes. Pilot and bench-scale efforts, while mechanically simplistic, typically show a very high degree of process control and optimization as they are relatively disconnected from the other processes at a wastewater plant. If all types of conventional mesophilic digestion systems, bench through full-scale, fall on or around the predicted values of a trend, one would conclude the trend fundamentally describes mesophilic digestion very well.

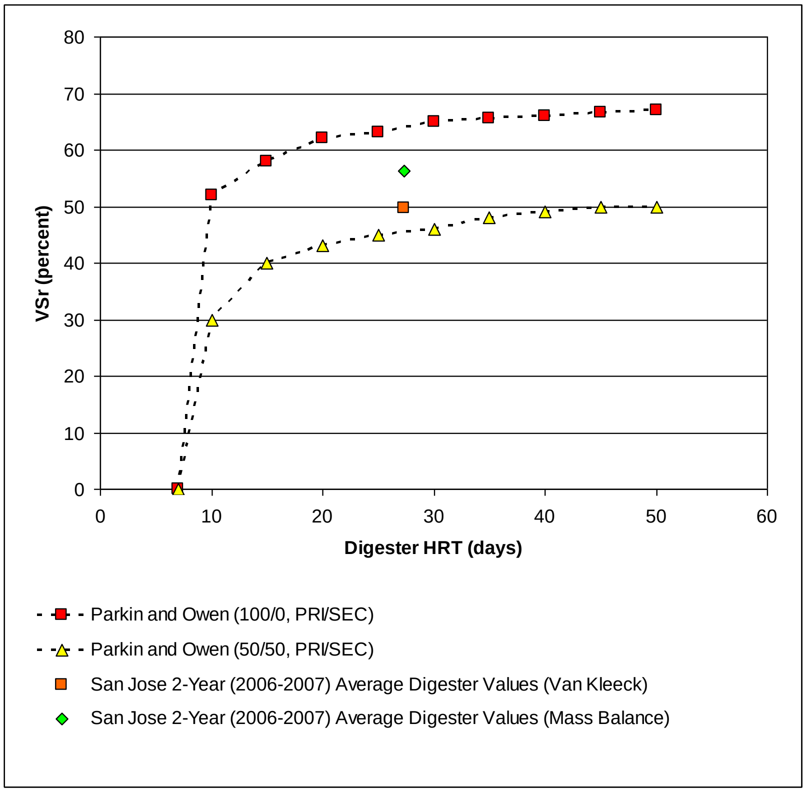


Figure 2-1: Comparison of San Jose 2-year average digester HRT and VSR to a reproduction of Parkin and Owen (1986) relationship between raw sludge composition, digester HRT and digester VSR: Source (Grady et al., 1999), assuming VSR is equivalent to CODr

Data collected (HRT and VSR) by Brown and Caldwell from a variety of stable, single-stage, mesophilic anaerobic digesters digesting varying blends of both primary sludge and secondary sludge were compared to the predicted performance curves reported by Parkin and Owen to test its validity. It should be noted that the data presented from this survey effort does not discriminate between the method of VSR calculation, Van Kleeck, or mass balance. Each methodology for calculation has its inherent benefits and draw backs and often that data is not available from the literature. If it is assumed that these systems are complete mix (i.e. no stratification or deposition of solids) as is commonly done, the method of calculation is less relevant.

The results of this analysis are presented in Figure 2-2 along with San Jose's average 2-year (2006-2007) mesophilic anaerobic digester HRT and VSR (Van Kleeck and mass balance), as reference points. It should be noted that the data included in this analysis represents only digesters in the survey set; which receive both primary sludge and secondary sludge in varying proportions as a feedstock. Using only mesophilic digesters that digest a blend of primary sludge and secondary sludge was intentional as the two curves developed by Parkin and Owen should represent defined boundary conditions, between which all facilities should fall, if the underlying data still is valid today.

The data in Figure 2-2 clearly shows that a majority of the survey based data points, used in this assessment, lie along or above the 100/0 primary sludge to secondary sludge curve (i.e. primary sludge digestion only). This finding would indicate that the Parkin and Owen curves under predict the rate and extent of the VSR in current mesophilic digesters. Had the reported values by Parkin and Owen been reflective of current digester operations one would expect the data to be clustered below the 100/0 primary sludge to secondary sludge line and above and around the 50/50 primary sludge to secondary sludge curve. While the principals of microbial and enzyme kinetics, which drive all biological reactions, are not being questioned in this analysis, the definition used by the authors of optimized digestion to produce such curves is questioned.

The improved performance of the surveyed mesophilic digesters in Figure 2-2, relative to the predicted values, suggests that newer installations are performing better than anticipated compared to older process models. The data presented by Parkin and Owen is approximately 23 years old, and given the advances of the last decade alone in process equipment, operating protocols, and fundamental understanding of anaerobic microbiology and biochemistry, there is little doubt that the degree of process optimization is greater now than ever.

While it may be convenient to attribute enhanced mesophilic digester performance to improved design and process engineering, it is unlikely that these improvements alone tell the whole story of why one mesophilic digester performs better than another. While the survey data clearly show the limited value of the Parkin and Owen trends today as a litmus test for performance, the scatter in the survey based data suggest not all digesters are equally optimized. However, care must be taken when defining digester optimization, because factors beyond the control of the operator or engineer can influence the performance, of even the most mechanically efficient mesophilic digestion process.

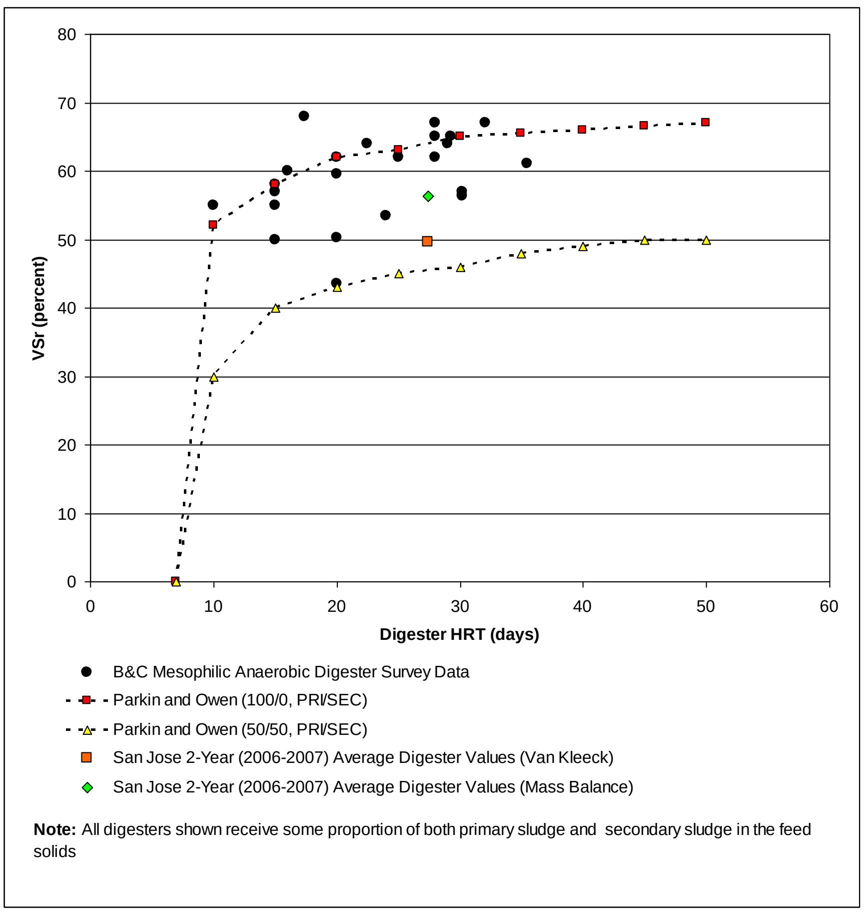


Figure 2-2: Comparison of predicted digester VSR Relative to other facilities: Predicted performance based on Parkin and Owen (1986) data presented in Grady et al. (1999) assuming that COD reduction is equivalent to VSR. BC survey data includes only mesophilic anaerobic digesters loaded with a mixture of primary sludge and secondary sludge.

3. INFLUENCE OF LIQUID STREAM TREATMENT CONDITIONS ON OBSERVED PERFORMANCE OF ANAEROBIC DIGESTERS

The digestion process is impacted by the process conditions set by the operators or engineers, such as thermophilic or mesophilic temperatures in staged and/or phased digestion. The performance and conditions within in the primary and secondary treatment systems impact the process as well. This section discusses some basic influences of primary and secondary system impacts on digestion.

3.1 Primary-to-Secondary Ratio

In the previous section, the work of Parkin and Owen (1986) was discussed and found to not be representative of modern digester performance. Brown and Caldwell performed a limited survey of mesophilic digesters operating at different primary and secondary ratios. The data was evaluated to calculate an average annual primary to secondary ratio on a total solids basis and an average annual VSR, calculated using the mass balance method. The results of the analysis are summarized in Table 3-1 and plotted in Figure 3-1.

Table 3-1: Summary of Plant Survey Results on Impact of Primary to Secondary Ration on Mesophilic Digester VSR.

Facility	PRI:SEC[a]	VSR [b], percent
Iona Island WWTP, Vancouver, BC	100/0	70
Columbia Blvd-All Sludge, Portland, OR	65/35	72
Laguna WWTP, Santa Rosa, CA	65/35	62
57th Street Plant, Boulder, CO	65/35	56
San Jose WWTP, San Jose, CA (Jul-Oct 2009)	60/40	60
Chambers Creek Regional WWTP, Pierce County WA	55/45	62
Escondito WWTP, Escondito, CA	55/45	56
LUD-Lakota Plant, Federal Way, WA	55/45	54
San Jose WWTP, San Jose, CA (2005-2007)	50/50	58
MWMC, Eugene, Or	45/55	56
Columbia Blvd-WAS Only, Portland, OR	0/100	66

[a] *Based on total solids ratio*

[b] *Calculated using mass balance method*

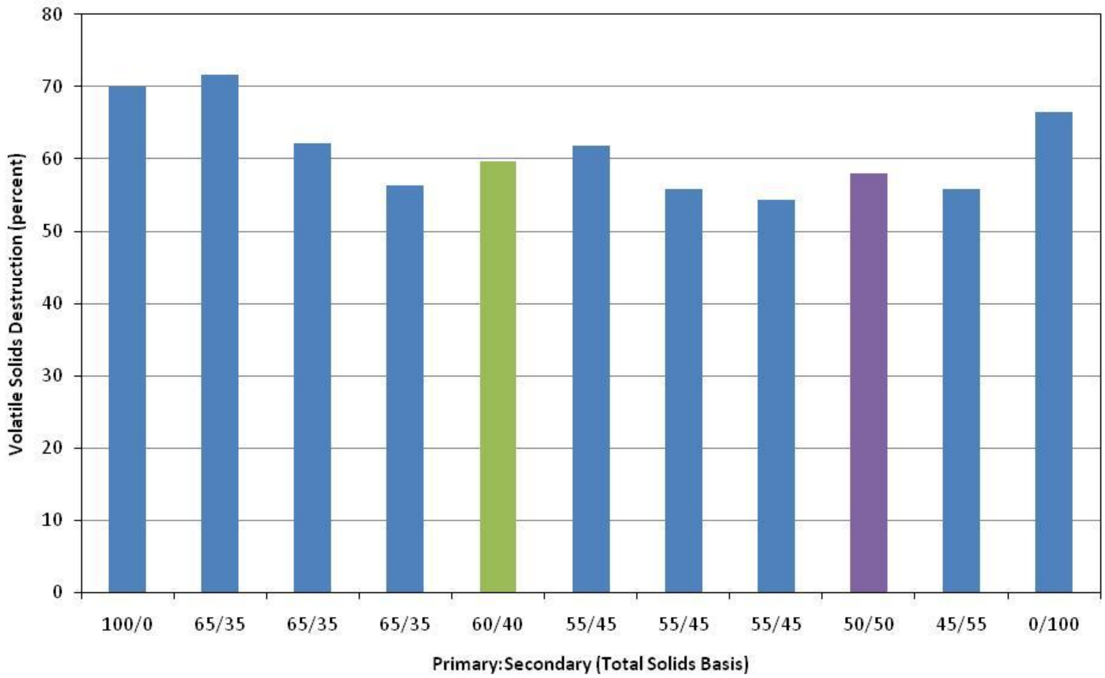


Figure 3-1: Change in mesophilic digester VSR as a function of the primary-to-secondary sludge ratio (Note: purple column San Jose (2005-2007), green column San Jose (July 19, 2009 – October 31, 2009))

In general, the data indicate that increasing the amount of secondary sludge to the digestion process has a tendency to reduce the observed VSR. This type of result is not unexpected as it has been long held that secondary sludge is more difficult to biologically degrade than primary sludge, as it has some degree of stabilization during aeration prior to digestion. As the data show, the trend of decreasing VSR with decreasing primary sludge content does not always hold true. As will be discussed later, other factors can influence the biological process as well as the observed process parameters, especially mixing efficiency.

3.2 Influence of Secondary System SRT on WAS VSR and Specific Gas Production (SGP)

The production of primary sludge is a function of the influent characteristics and the efficiency of the primary clarifiers. Secondary sludge production is driven primarily by the process demand imposed on the plant to meet specific effluent quality criteria. The primary mechanism for process control in the secondary system is SRT. Changes in SRT impact the characteristics of the secondary sludge. These changes in characteristics typically manifest themselves in the digesters as variation in VSR and biogas production.

Figure 3-2 presents the change in calculated or observed VSR of secondary sludge during mesophilic anaerobic digestion. The calculated values are based on assuming that primary sludge VSR is fairly uniform at 70 percent, based on an evaluation of a primary only plant with mesophilic digestion. In the case where a plant practiced secondary digestion sludge only, direct measured VSR was used. The data show that as the SRT increases, the observed VSR decreases asymptotically. The data appears to indicate that marginal changes in secondary system SRT can have a considerable impact on sludge degradability at secondary system SRTs less than approximately 12 days.

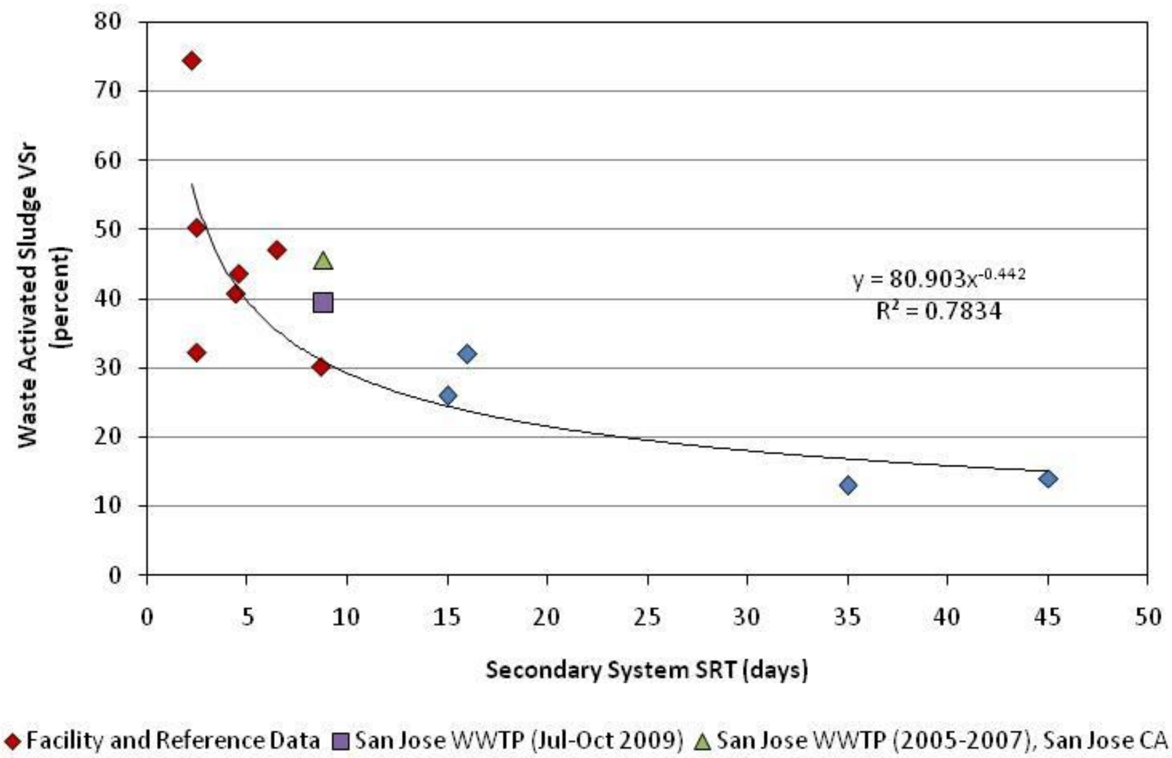


Figure 3-2: Influence of secondary system SRT on secondary sludge VSR (Note: Blue diamond points are from Bolzonella et al., 2005)

For comparison, data from San Jose was plotted along with the reference data. The San Jose data appear to have a better than average secondary sludge VSR for its operating SRT. This may be due to the biochemical characteristics of the sludge or could potentially be an artifact of the method used to calculate VSR; which will be discussed in Section 4

A reduction in the VSR, due to increasing secondary system SRT, should result in a reduction in the specific gas production (SGP) from the secondary sludge as well. Most plants do not digest secondary sludge alone. Therefore, to estimate the SGP of the secondary sludge, it was assumed that primary sludge has a uniform VSR at 70 percent and a biogas yield of 17 cubic feet-biogas/lb-VS destroyed (cf/lb VS destroyed), based on data from a primary sludge only plant using mesophilic digestion. The results of this analysis, including data from San Jose, are shown in Figure 3-3.

As with VSR (Figure 3-3), SGP decreases with increasing secondary system SRT. Plotting the calculated SGP for the two San Jose data sets, 2005to2007 and July 19, 2009 through October 31, 2008, it is apparent that SGP is variable for the plant. The older data set demonstrated a lower than expected SGP while the newer data demonstrated a SGP close to predicted. The discrepancy between the two data sets could be linked to process changes or upgrades that occurred between 2007 and 2008.

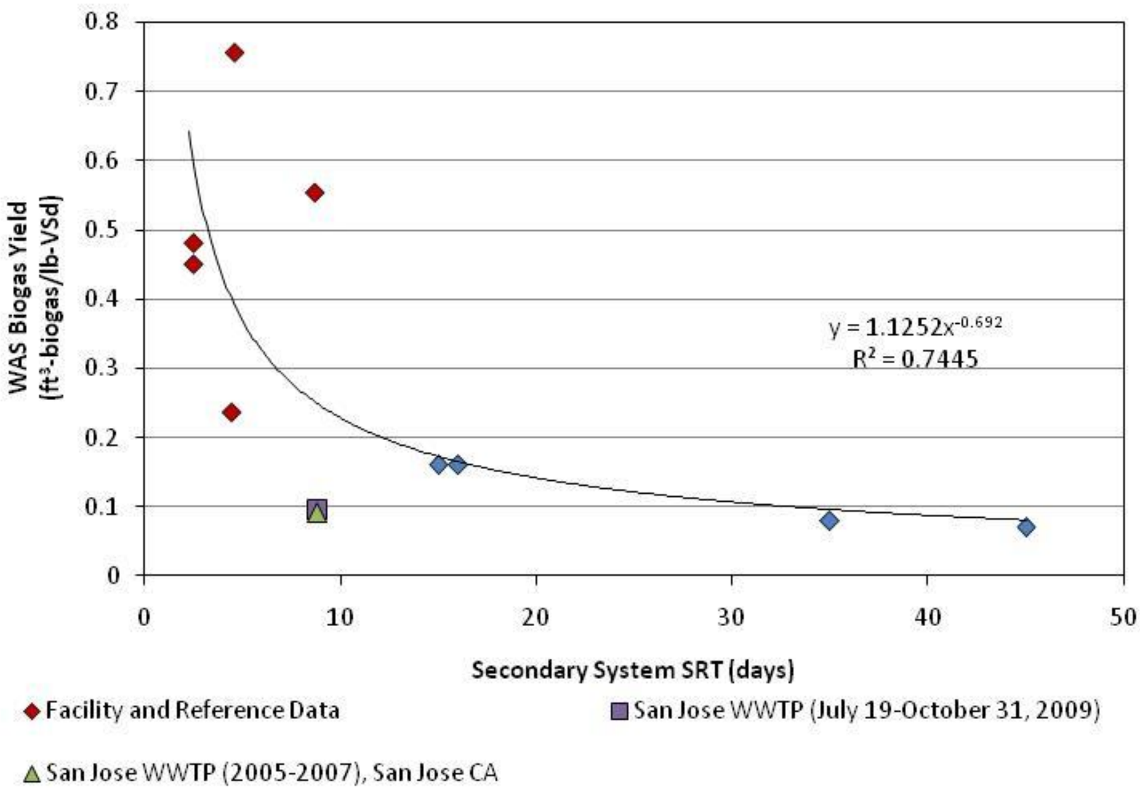


Figure 3-3: Influence of secondary system SRT on the SGP rate from mesophilic anaerobic digesters. (Note: blue diamond indicate data from Bolzonella et al., 2005)

4. INFLUENCE OF SOLIDS DEPOSITION ON VSR

In prior sections, it was noted that the VSR for some facilities was above average for the conditions reported. There are a number of potential possibilities to explain the validity or lack of validity of the data. One such argument is the influence of solids deposition in the digester on the calculated VSR. Inadequate mixing can lead to the deposition of solids in an anaerobic digester. Fundamentally, higher density solids require greater energy to remain in suspension, while lower density materials require less. Therefore, if mixing efficiency is marginal, it is possible that some materials will settle out, moving a digester away from the typical complete mix assumption used in most analyses.

Inadequate mixing may not only impact plant operations (i.e. digester cleaning frequency, loss of active volume, etc.) but also the observed process parameters such as VSR. Deterioration in mixing can result in short circuiting of a digester, reducing the actual HRT the solids experience in a digester, resulting in reduced VSR. Exacerbating this is the impact of the deposition of solids in the digester due to inadequate mixing.

VSR can be calculated by two methods, the mass balance method and the Van Kleeck method. Each method is susceptible to systemic error when a digester moves away from the complete mix assumption. The mass balance approach can be calculated using either concentrations of solids in the raw sludge and digesters or, if flow is known, the actual total mass conveyed. The Van Kleeck equation uses the VS content or volatile fraction, the ratio of volatile solids to total solids in the system, to calculate VSR. If inert materials (i.e. fixed solids) are deposited in an anaerobic digester, the Van Kleeck equation will under estimate the VSR. This is because the digested sludge volatile fraction (VS/TS) is artificially increased by the loss of fixed solids. The under estimation becomes more pronounced with increasing loss of fixed solids as shown in Figure 4-1.

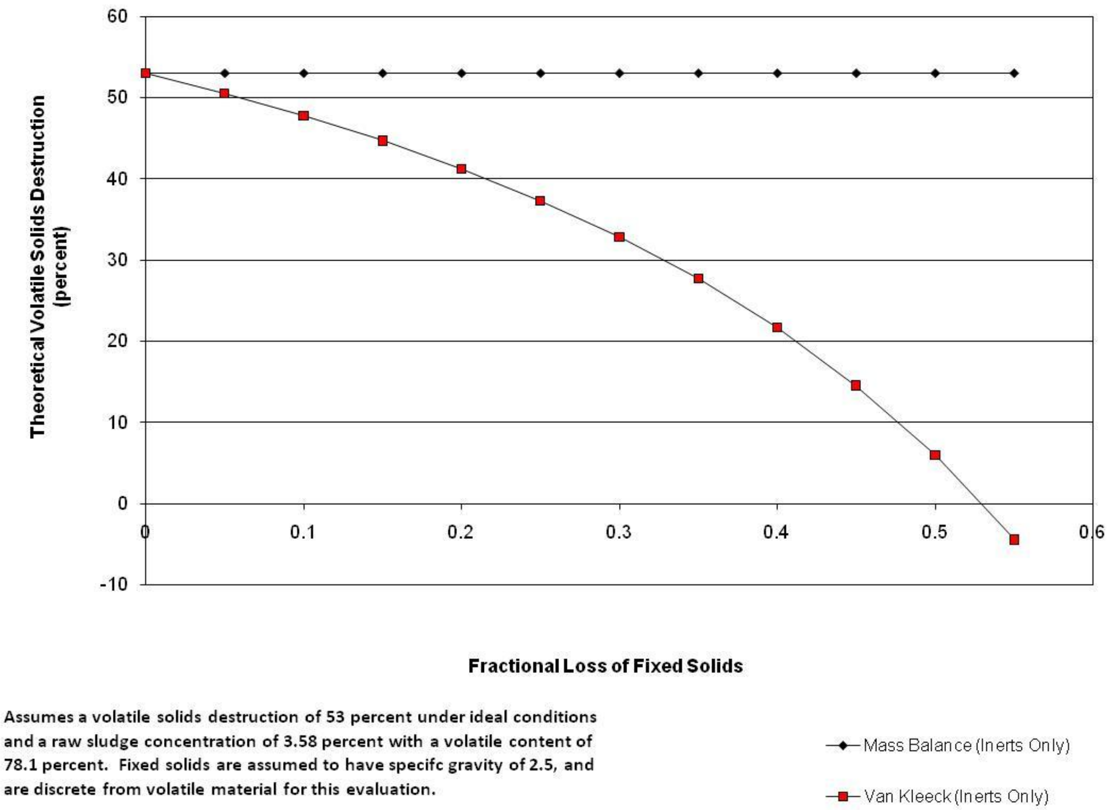


Figure 4-1: Impact of active volume reduction due to fixed solids deposition on theoretical VSR

The data presented in Figure 4-1 indicate that, if there is any deposition of fixed solids in an anaerobic digester, the method of VSR calculation will influence the result. If the Van Kleeck calculation is used, the actual VSR could be much higher than calculated. The mass balance approach is not affected by fixed solids deposition, as those materials are not incorporated into the calculation. However, it is unrealistic to think that only fixed solids would deposit in a digester, exclusive of volatile matter. As an example, following a recent digester cleaning, the grit and struvite mixture removed from the digesters at San Jose had a volatile content of 22 percent, even after the washing that takes place during cleaning. An evaluation of the data used to generate Figure 4-2 was conducted assuming that the fixed solids would be associated with some fraction of volatile material. Figure 4-2 shows that the Van Kleeck method continues to under estimate VSR anytime there is a loss of fixed solids. The mass balance approach over estimates VSR when both fixed and volatile solids are deposited in the digester, though the extent does not appear to be as severe as observed with the Van Kleeck method.

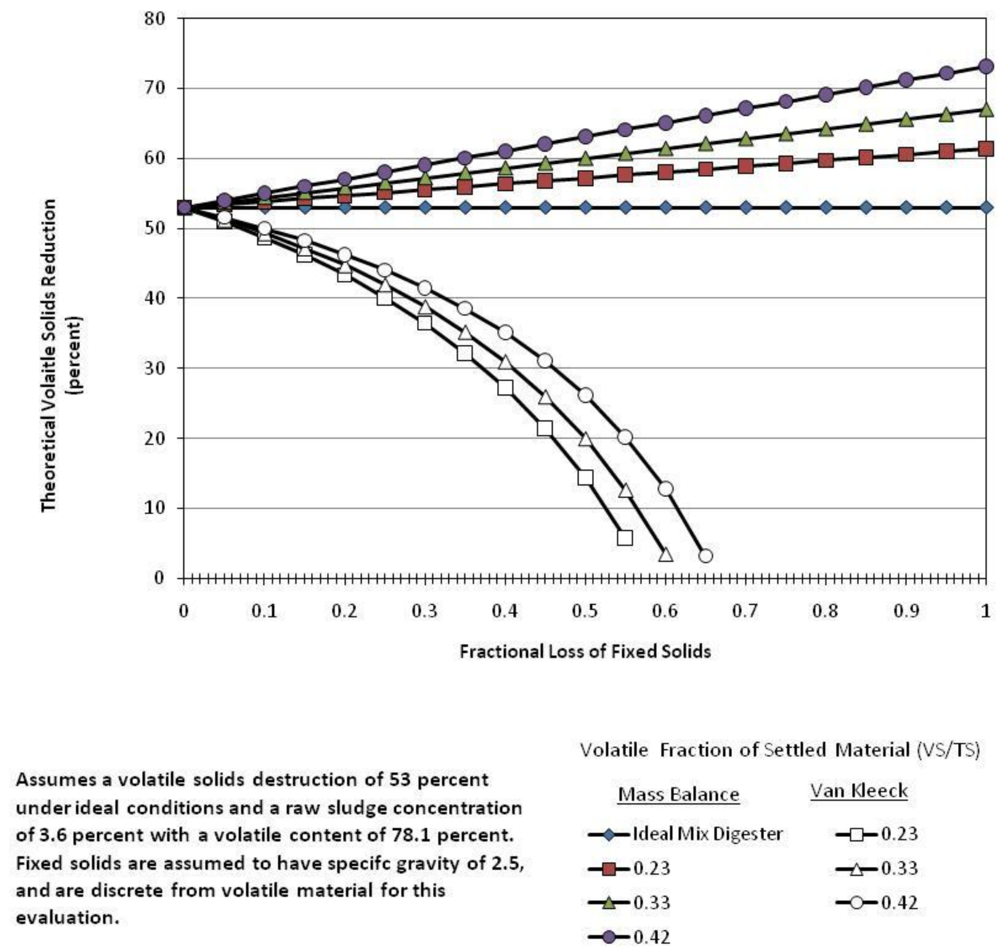


Figure 4-2: Influence of deposition of fixed solids with volatile organics on the calculation of volatile solids reduction in complete mix digesters

The data presented in Figures 4-1 and 4-2 indicates that when solids deposition occurs in a digester, it can result in a skewing of process data, either positively or negatively. These conditions and erroneous calculated VSR values can influence not only process monitoring, but solids disposal as well, as most plants use the 38 percent VSR rule to meet vector attraction reduction requirements.

Typically, solids deposition in digesters is associated with poor or inadequate mixing. Significant divergence in calculated VSR using the mass balance versus Van Kleeck methods could be indicative of this condition.

To investigate the potential that the San Jose digesters are experiencing inadequate mixing; which can lead to inaccurate measurement of VSR, reduction in actual VSR, loss of active volume, reduced biogas production, and short circuiting, several parameters must be assessed or assumed.

- *Ideal VSR*: this is the measure of VSR that would occur if the digester operating conditions were ideal. Given that full-scale determination is infeasible, the next best method would be to use a process simulator, such as BioWin.

- *Volatile Fraction of Deposited Materials*: The volatile fraction of the materials lost from the active volume can be either highly volatile or highly inert depending on the location of the material. Scum materials have tendency to be highly volatile while the volatile fraction of grit is typically lower, given that quantification of these materials discretely is not possible at this time, a mixed number will be used for this analysis. All assumed values will use the best available data.

- *Observed VSR*: the observed VSR for the digesters will be calculated using both the Van Kleeck and the mass balance approach to provide the needed reference points on the curves.

- *Fixed Solids Deposition Rate*: The loss of fixed solids through the digestion system will be estimated using plant data by calculating a mass balance around the digesters. The average annual deposition rate will be used as the basis of evaluation.

4.1 Influence of Solids Deposition on VSR and Active Volume with Eleven Digester Operation

To further investigate the potential of solids deposition to impact VSR, data from a period in 2009 (July 19, 2009 through October 31, 2009) when 11 digesters were in operation was conducted. The same period was selected for BioWin modeling of the digester performance as discussed in Attachment B to TM 3.3. Results of that modeling are used in this evaluation and are discussed below. The average time since digester cleaning prior to the beginning of this data period was approximately 15 months. Based on data from July 19, 2009 through October 31, 2009, the average VSR for San Jose was approximately 59.8 percent when calculated by the mass balance approach and 44.8 percent when calculated by the Van Kleeck equation. The significant spread in the VSR values, based on the trends in Figure 4-2 would suggest that there is considerable loss of fixed and volatile solids in the digesters.

Evaluation of the fixed solids losses in the digesters was conducted over the same period as the VSR, with the results summarized in Figure 4-3. The loss of fixed solids over that period of time averaged 30.3 percent of the fixed influent solids deposited in the digesters on a daily basis. It should be noted that while a majority of the loss of fixed solids is grit, volatile materials can also be entrained with the grit and settle out.

The evaluation of the volatile content of the material deposited in the digesters is more difficult in that it can be in several forms and locations which are not typically sampled. Recently, San Jose conducted an analysis of the grit removed from a recently cleaned digester to assess the volatile fraction, fixed solids content, and the fraction of the material that is comprised of struvite (see struvite control TM 4.6). The results of that analysis indicated that 31 percent of total solids was struvite, 47 percent of the material was other fixed solids, and 22 percent was other VS. If the struvite fraction is removed from the percentage calculation, as it is not present as solids in the influent, and it is assumed that the volatile content of struvite as organics is negligible, the volatile content of the deposited solids would be approximately 32 percent, rather than the 22 percent when struvite is included. For comparison, the anticipated volatile content of the digested sludge is expected to be over 65 percent.

Using the above values, the apparent real VSR can be estimated by plotting requisite data on a family of curves for Van Kleeck and mass balance VSR at differing fixed solids deposition rates and sludge volatile fractions.

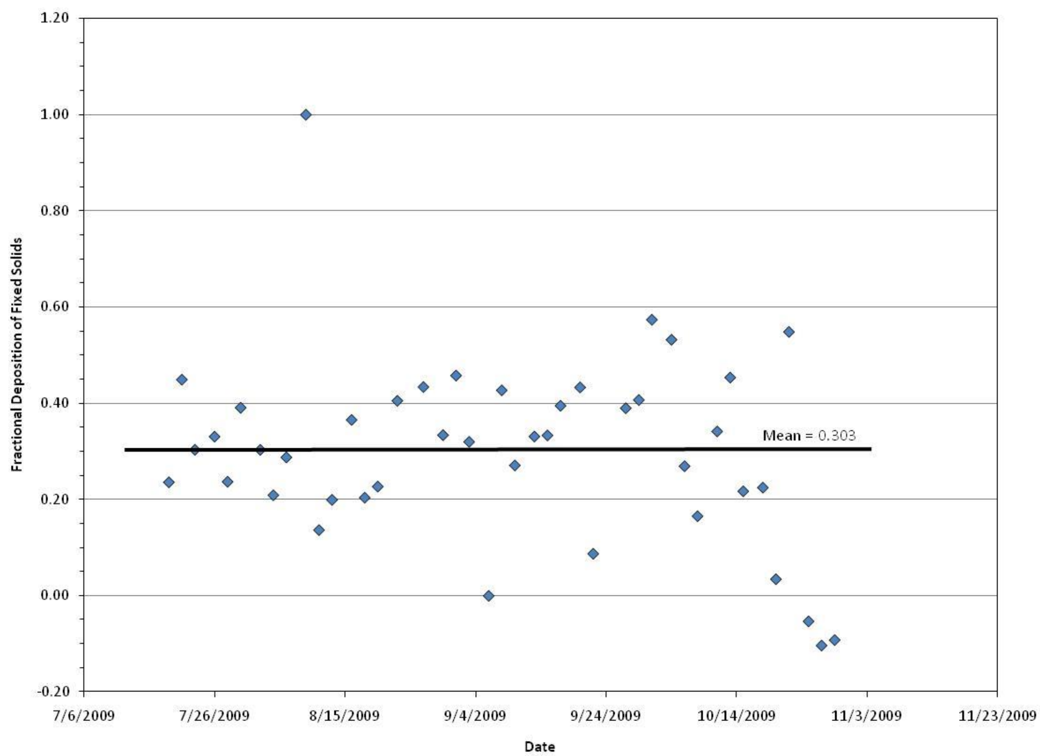


Figure 4-3: Daily fractional deposition of fixed solids through San Jose's anaerobic digestion system (July 19, 2009-October 31, 2009)

By repeatedly evaluating the observed Van Kleeck and mass balance VSR values against a theoretical "true VSR", as shown in Figure 4-4, estimates of several process parameters and sludge characteristics could be made, which are summarized in Table 4-1. Based on the data presented in Table 4-1, the two observed VSR points, a 30.3 percent deposition rate of fixed solids, the actual VSR of the San Jose digesters is estimated to be approximately 54 percent, slightly less than the 55.7 percent estimated by the BioWin model. This assessment was reached assuming the actual biogas yield is close to that predicted by the BioWin model run (15.54 ft3-biogas/lb-VSd), the volatile content of the digested sludge in the active volume nearly matched the observed (67.3 percent), and assuming the slightly increased volatile content of the predicted deposited material of 47.3 percent (verses 32 percent observed in Figure 4-3) is due to the loss of organics during washing of the grit during the digester cleaning process.

The implications of measuring true VSR are two fold: they affect the observed performance trends presented in Figure 3-2 and Figure 3-3 and also suggest that the active volume of the digesters is reduced relative to the assumed conditions for the BioWin modeling conducted in Attachment B. Using the trends presented in Attachment B relating to the influence of HRT on VSR and biogas yield, an operating HRT can be estimated based on the "true VSR".

Using the curves presented in Attachment B and an assessed "true VSR" of 54 percent, the actual digester detention time is estimated to be approximately 24 days rather than the 29.1 days calculated by the Biowin model and reported in Attachment B. This represents a reduction in active volume by about 17.5 percent relative to the assumption used by BioWin (2.00 MG active volume for a large digester versus model assumption of 2.43 MG). This represents a loss of over 4 million gallons of process volume. This suggests that loss of active volume is likely occurring and could be due to grit deposition and/or dead zones due to poor mixing. Dye tracer studies could verify this reduction as well as a program of sampling and analyzing of deposited materials.

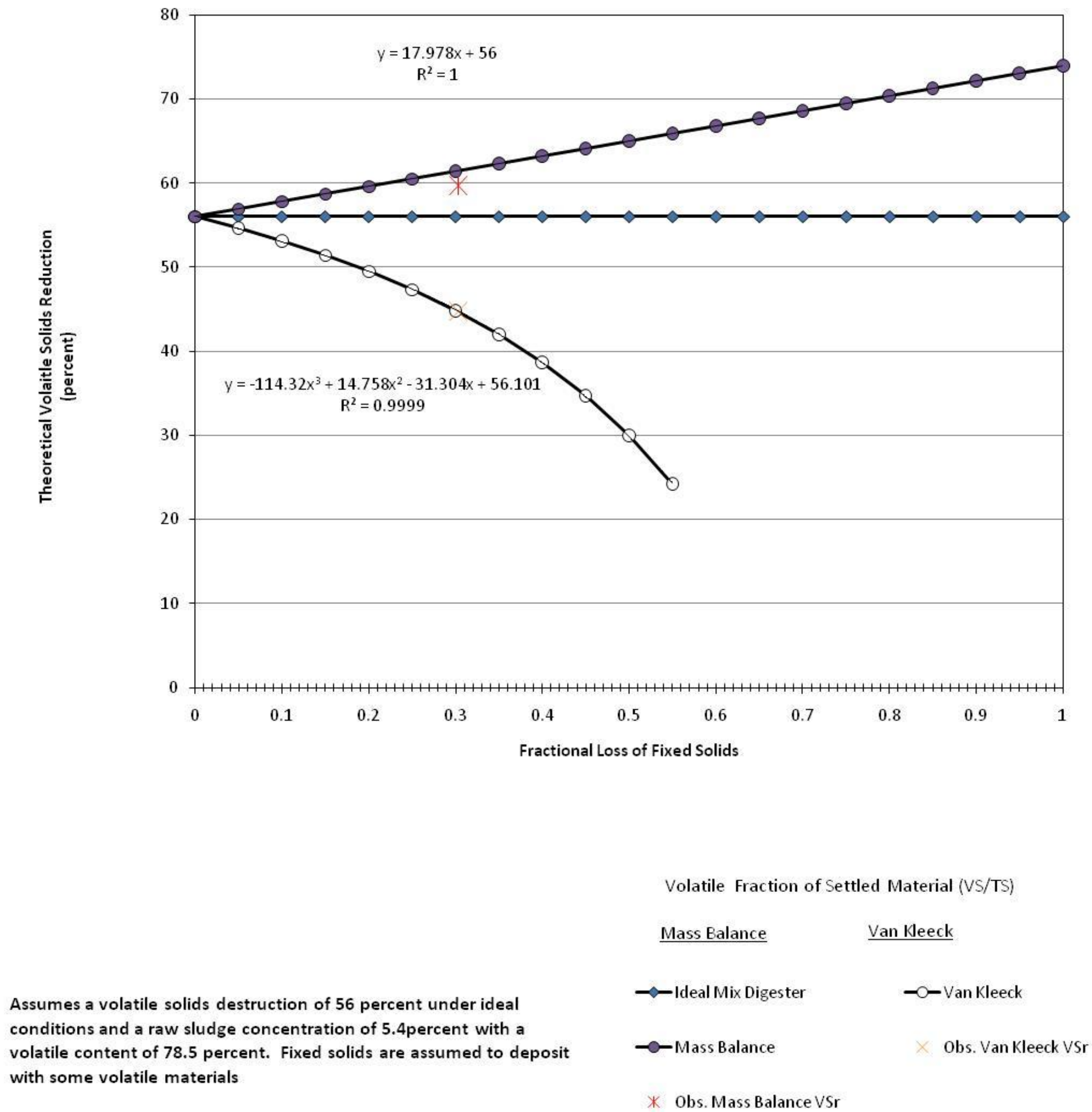


Figure 4-4: Comparison of observed digester VSR values and fixed solids deposition relative to the predicted VSR through Biowin simulation

Table 4-1: Changes in Digester Parameters Based on Assumed "True VSR"						
Predicted VSR, percent	Observed VSR Mass Balance, percent	Observed VSR Van Kleeck, percent	Calculated Volatile Content of Settled Sludge, lb-VS/lb-TS	Calculated Volatile Content of Sludge in Active Volume, lb-VS/lb-TS	Specific Biogas Production, ft3-biogas/lb-VS-loaded	Biogas Yield cf/lb/d
43	59.7	44.8	0.691	0.668	8.3	19.3
44[a]	59.7	44.8	0.679	0.668	8.3	18.9
45	59.7	44.8	0.666	0.668	8.3	18.4
46	59.7	44.8	0.651	0.668	8.3	18.0
47	59.7	44.8	0.636	0.668	8.3	17.7
48	59.7	44.8	0.619	0.668	8.3	17.3
49	59.7	44.8	0.601	0.668	8.3	16.9
50	59.7	44.8	0.581	0.668	8.3	16.6
51	59.7	44.8	0.558	0.668	8.3	16.3
52	59.7	44.8	0.533	0.668	8.3	16.0
53	59.7	44.8	0.505	0.668	8.3	15.7
54	59.7	44.8	0.473	0.668	8.3	15.4
55	59.7	44.8	0.437	0.668	8.3	15.1
56	59.7	44.8	0.396	0.668	8.3	14.8
57[b]	59.7	44.8	0.349	0.668	8.3	14.6
58	59.7	44.8	0.293	0.668	8.3	14.3
59	59.7	44.8	0.226	0.668	8.3	14.1
60	59.7	44.8	0.146	0.668	8.3	13.8
61	59.7	44.8	0.048	0.668	8.3	13.6

[a] Point where VS content of settled solids equals digested sludge
[b] Point where VS of settled solids approximates washed grit cleaned from digester

Based on these findings, data from July 19, 2009 through October 31, 2009 presented in Figure 3-2 and Figure 3-3 relating to the WAS VSR and the biogas yield and secondary system SRT was further evaluated. The results of this analysis are presented in Figure 4-5 and Figure 4-6 for VSR and biogas yield, respectively. What we have concluded from the data is that the adjustment of the VSR to 54 percent resulted in a better alignment with the reference data trends. This suggests that accounting for non-ideal mixing conditions within the digester is critical to evaluating the process based on plant data as well as through modeling.

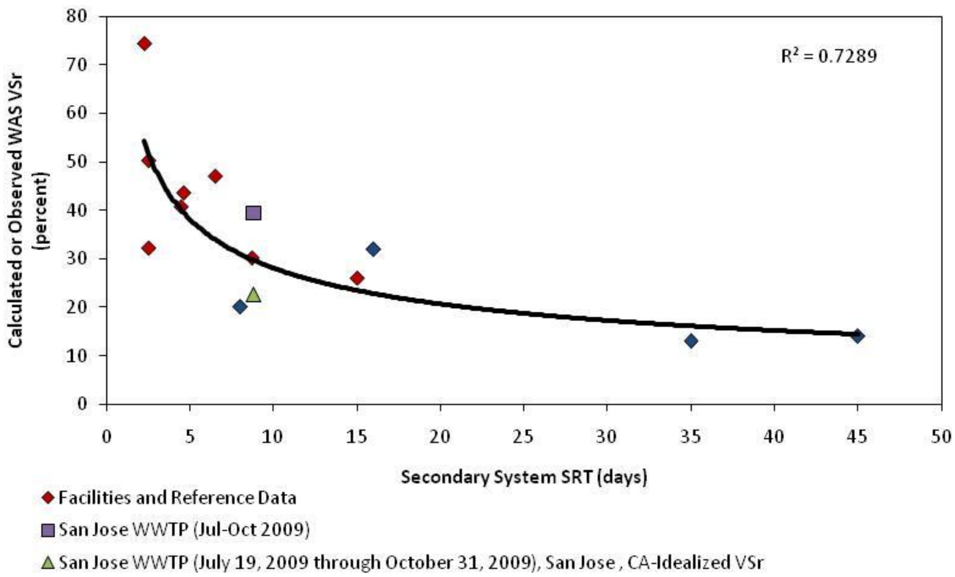


Figure 4-5: Predicted WAS VSR based on observed data and correction of data for reduction in active volume due to inadequate mixing as function of secondary system SRT

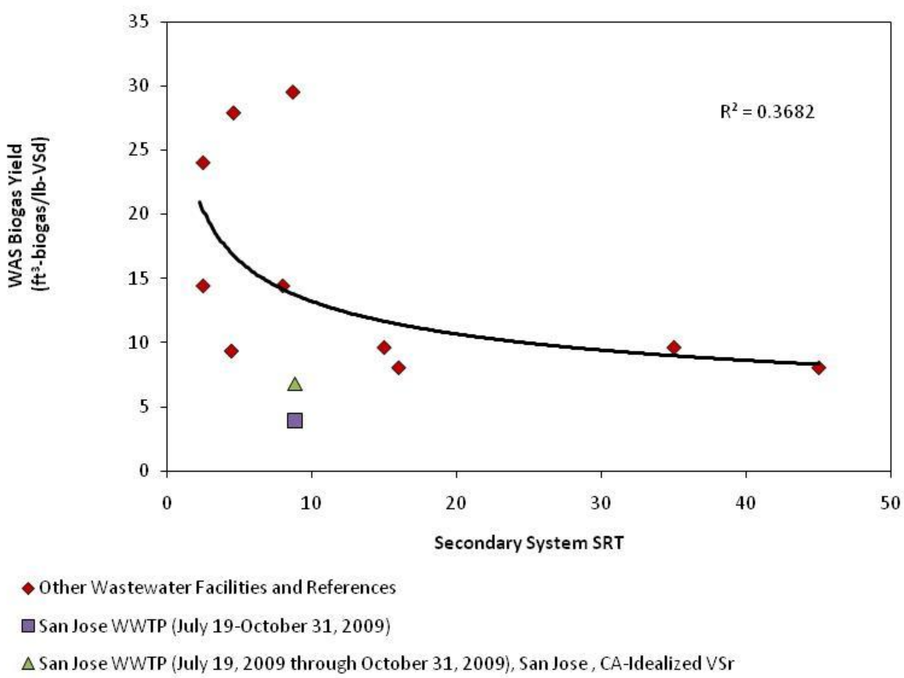


Figure 4-6: Change in WAS biogas yield as a function of secondary system SRT with an accounting for reduced digester active volume at San Jose

4.2 Influence of Solids Deposition on VSR and Active Volume with Eight Digester Operation

In December 2009, San Jose started to operate the system with eight digesters in service rather than 11. This new operating condition was evaluated using the methods described in the previous section of this report. The average time since digester cleaning prior to the beginning of this data period was approximately 17 months. The BioWin modeling was conducted on this data set as well and predicted an average VSR of 54.3 percent at an HRT of 20.6 days (see Attachment B). Using plant recorded data, the calculated VSR by mass balance and Van Kleeck methods were 56.7 and 35.8 percent, respectively. The calculated biogas yield ranged from 14 to 25 cf/lb/VSd, depending on the method of VSR used to calculate the yield. Table 5-1 presents the summary data for the analysis of the digesters under the eight digesters in-service scenario.

Table 5-1: Estimated “True VSR “with 8 Digesters in Service at San Jose WWTP

Predicted VSR, percent	Observed VSR Mass Balance, percent	Observed VSR Van Kleeck, percent	Calculated Volatile Content of Settled Sludge, lb-VS/lb-TS	Calculated Volatile Content of Sludge in Active Volume, lb-VS/lb-TS	Specific Biogas Production, ft3-biogas/lb-VS-loaded	Biogas Yield cf/lb/d
45	56.7	35.8	0.547	0.682	8.52	18.94
46	56.7	35.8	0.524	0.682	8.52	18.52
47	56.7	35.8	0.499	0.681	8.52	18.13
48	56.7	35.8	0.471	0.681	8.52	17.75
49	56.7	35.8	0.440	0.680	8.52	17.39
50	56.7	35.8	0.405	0.680	8.52	17.04
51	56.7	35.8	0.366	0.680	8.52	16.71
52	56.7	35.8	0.321	0.679	8.52	16.39
53	56.7	35.8	0.268	0.679	8.52	16.08
54	56.7	35.8	0.208	0.679	8.52	15.78
55	56.7	35.8	0.136	0.678	8.52	15.49
56	56.7	35.8	0.049	0.678	8.52	15.22
57	56.7	35.8	-0.056	0.678	8.52	14.95

Assuming the actual biogas yield is similar to that predicted by the BioWin model (Table 2-8 of Attachment B), the estimated “true VSR” of the 8 digester system from Table 5-1 above could range from 54 to 56 percent, less than the 56.7 percent calculated from the plant data using the mass balance method and greater than the 39 percent calculated by the Van Kleeck method. This correlates with the model-predicted VSR of 54.3 percent. For this comparison to be valid, the volatile content of the settled sludge (grit) must be below the values observed and reported in the previous section for the 11 digester service condition. This assumption may hold as the 8 operating digesters could be expected to have slightly better mixing efficiency due to the higher hydraulic load applied. Mixing efficiency would be expected to degrade with time as more grit is deposited, covering mixing spargers. Lighter, more volatile material would be deposited or held in inactive, unmixed volume after long in-service periods as mixing efficiency declines, though some peak, steady state value would likely be achieved. A more rigorous sampling program of the grit, mixing, active volume, and fixed and volatile fractions within the digester would be needed to verify this.

The fractional deposition of inerts was calculated from plant data for the 8 digester operating period (similar to Figure 4-3 above for 11 digester operation) and it increased from 30.3 to 32 percent with the switch in service conditions, though this is likely not statistically significant difference. This would indicate that the rate of fixed solids loss has not appreciably changed between service conditions.

An estimate of reduction in active volume was made for the 8 digester service condition. It was assumed that the actual biogas yield is in relatively close agreement with that predicted by the model (15.7 ft3-biogas/lb-VSd), ranging from 15.5 to 15.8 ft3-biogas/lb-VSd. Assuming a condition of slightly lower gas yield would result in grit volatile content below levels that are reasonable (see Table 5-1 above). Therefore, while no grit sampling data was available for the 8 digester case, it was necessary to assume that the grit being deposited was lower in volatile content than the grit sampled from the 11 digester service condition. Using data from Figures 3.3 and 3.4 of Attachment B and assuming an average "true VSr" of 54.5 percent, the HRT of the digesters should be approximately 20 days, slightly less than the 20.6 days used by the model simulation. The data suggests that the operating active volume of the 8 digester service condition is close to that assumed for modeling (2.36 MG per digester, 18.87 MG total predicted versus 2.43 MG per digester, 19.44 MG total assumed for modeling). However, the considerable divergence in the VSR values for the digesters (56.7 percent by mass balance and 35.8 percent by Van Kleeck) suggests that this condition may not be permanent (grit is accumulating rapidly) and that further deterioration of active volume will occur over time.

5. CONCLUSIONS

From the forgoing analyses, it can be concluded that:

- The VSR and specific gas production of the San Jose digestion system is within the range of expected based on analysis of other plant data and literature values.
- If inert materials (i.e. fixed solids) are deposited in an anaerobic digester, the Van Kleeck equation will severely under estimate the VSR. The mass balance approach over estimates VSR when both fixed and volatile solids are deposited in the digester, though the extent does not appear to be as severe as observed with the Van Kleeck method.
- The considerable divergence in the VSR values for the San Jose digesters suggests that grit is accumulating rapidly and that severe deterioration of active volume will occur over time.
- Loss of fixed solids through the San Jose digesters averaged 30 percent of the fixed influent solids.
- Loss of active volume has occurred and could be due to grit deposition and/or dead zones due to poor mixing. Dye tracer studies could verify this reduction as well as a program of sampling and analyzing deposited materials and digester contents at various locations.

6. LIMITATIONS OF USE

The materials presented in Sections 3, 4 and 5 represent an emerging approach to digester performance analysis. While the fundamental elements are founded in basic engineering principals, the application has been limited to the San Jose WWTP to date, thus corroborating empirical evidence is limited. As such, the data presented here, as with any novel and innovative approach, should be used with a high degree of conservatism and be assumed to be subject to change. A more rigorous sampling program of the grit, mixing, active volume, and fixed and volatile fractions within the digester would be needed to verify actual conditions.

7. REFERENCES:

Bolzonella, D., P. Pavan, P. Battistoni and F. Cecchi (2005) Mesophilic Anaerobic Digestion of Waste Activated Sludge: Influence of Solid Retention Time in the Wastewater Treatment Process". Process Biochemistry, (40): p. 1453-1460.

Cadoret, A., A. Conrad, and J.-C. Block (2002) Availability of Low and High Molecular Weight Substrates to Extracellular Enzymes in Whole and Dispersed Activated Sludges. Enzyme and Microbial Technology. **31**: p. 179-186.

Grady Jr., C.P.L., G.T. Daigger, and H.C. Lim (1999), Biological Wastewater Treatment Second Edition, Revised and Expanded. 2 ed. New York: Marcel Dekker Inc

Mišík, V. and P. Riesz (1999) EPR Characterization of Free Radical Intermediates Formed During Ultrasound Exposure of Cell Culture Media. Free Radical Biology and Medicine **26**(7/8): p. 936-943.

Muller, C.D., J.T. Novak (2007) The Impact of Floc Metals on Conventional and Enhanced Mesophilic Anaerobic Digestion Technologies, WEFTEC 2007, San Diego, CA; October, 2007

Novak, J. T., M. E. Sadler and S. N. Murthy (2003). "Mechanisms of Floc Destruction during Anaerobic and Aerobic Digestion and the Effect on Conditioning and Dewatering of Biosolids." Water Res. **37**: 3136-3144.

Park, C., M. M. Abu-Orf and J. T. Novak (2006) "The Digestibility of Waste Activated Sludges." Water Environ. Res. **78**(1): 59-68.

Parkin, G.F. and W.F. Owen (1986) "Fundamentals of Anaerobic Digestion of Wastewater Sludges". Journal of Environmental Engineering Division, ASCE (112): p. 867-920.

Speece, R. (2008). Anaerobic Biotechnology and Odor/Corrosion Control for Municipalities and Industries, Archea Press, Nashville, TN.

Stroot, P. G., K. D. McMahon, R. I. Mackie and L. Raskin (2001). "Anaerobic Codigestion of Municipal Solid Waste and Biosolids Under Various Mixing Conditions-I. Digester Performance." Water Res. **34**(7): 1804-1816.

Vavilin, V.A., S.V. Rytov, and L.Y. Lokshina (1997) A Balance Between Hydrolysis and Methanogenesis during the Anaerobic Digestion of Organic Matter. Microbiology **66**(6): p. 712-717.

ATTACHMENT B: EVALUATION OF DIGESTER BIOWIN MODELING

Brown AND Caldwell

201 North Civic Drive
Walnut Creek, CA 94596
Tel: 925.937.9010
Fax: 925.937.9026

Technical Memorandum 3.3B

Prepared for: San Jose/Santa Clara Water Pollution Control Plant

Project Title: FOG Evaluation, Digester Rehabilitation and Gas Line Replacement

Project No: 136242-003

Technical Memorandum 3.3 – Attachment B

Subject: Evaluation of Digester Performance Using BioWin Modeling

Date: June 30, 2010

To: Ravi Kachhapati, Project Manager

From: Steve Krugel, Project Manager

Prepared by: Derya Dursun, Ph.D.

Reviewed by: John Bratby, Ph.D.

Rion Merlo, Ph.D., P.E

Steve Krugel

1. INTRODUCTION

As a part of the Digester Rehabilitation Project, a BioWin model was constructed to represent the digesters at the San Jose/Santa Clara Water Pollution Control Plant (WPCP). The model was calibrated using historical data and was subsequently validated using two separate sets of historical data. Using the calibrated and validated model, the impact to digester performance was determined at varying digester temperatures and hydraulic retention times (HRT). These predictions were used to develop digester design criteria as discussed in technical memorandum (TM) 3.3. Calibrating a BioWin model using historical data does not have the same level of accuracy of a model calibrated using the results of an extensive wastewater characterization and bench-scale study. However, the model can be used to determine relative changes in process performance as a function of operating conditions.

2. BIOWIN MODELING

2.1 Model Calibration

The main data set for the digester modeling was based on the liquid stream BioWin simulator output for the WPCP that was generated for the Master Plan. The information in the data set, which includes the characteristics of primary sludge (PS) and thickened waste activated sludge (TWAS), was used for calibrating the model. There were issues of mass balance closure in the liquid stream BioWin simulations. Therefore, various alternative scenarios were created to achieve the best fit to plant data. Table 2-1 summarizes the modeling assumptions for sludge flows and concentrations. The BioWin model uses these two parameters as inputs to calculate the sludge loadings. For each scenario, primary sludge loads were user-calculated outside the model based on primary clarifier TSS removal for use in adjusting either primary sludge flow or concentration for model input. TWAS loads were based either on previous BioWin modeling of the liquid stream (Scenarios 1 and 3) or from plant reported flows and loads (Scenarios 2 and 4).

Biowin simulations were performed using steady state input derived from the output generated by the liquid stream Biowin steady state output using August 2007 data. Figure 2-1 shows the configuration used for the BioWin digester model calibration. An anaerobic mesophilic digester with 24.8 million gallon (MG) capacity was assumed for the steady state modeling, which represents 11 digesters in operation (2 @ 1.47 MG and 9 @ 2.43 MG). It should be noted that the actual volume of the small and large digesters are 1.64 MG and 2.67 MG, respectively, but were derated for modeling purposes to account for lower than maximum floating cover level and modest grit deposition and mixing inefficiency.

The combinations of different input values provided in Table 2-1 were assessed to establish the most appropriate BioWin inputs that simulate the existing plant conditions best. Table 2-2 summarizes the results for the four scenarios analyzed and Table 2-3 compares the removal rates of various parameters for the four different cases. For all these analyses, temperature was kept at 98 degrees F and default parameters in BioWin were used. For all cases, BioWin predicted slightly lower volatile solids reduction (VSR)[1] compared to the values achieved at the WPCP. However, predicted gas production rates were significantly higher in all cases than reported plant data.

As a check to the validity of the BioWin digester model, Table 2-3 also shows that simulator results for

[1] VSR in digesters can be calculated by two different methods: mass balance and van Kleeck. Since the BioWin simulator uses the mass balance method when calculating VSR, the VSR results presented herein are all in terms of mass balance.

Chemical Oxygen Demand reduction (CODr) and VSR through the digesters correspond quite closely. This is consistent with results reported in the literature, suggesting that BioWin accurately simulates performance of the digesters, provided that input parameters to the simulation digesters are accurate.

State variables are those variable inputs to the model that define sludge characteristics. For Scenarios 1 through 4, the state variables are different and these variables are adopted from the liquid stream BioWin simulator for each scenario. The selected state variables define sludge concentration and characteristics and are held constant throughout a given model run. One goal of the calibration is to select the state variables that best match actual performance and those that will be used for any further predictive modeling.

For Scenarios 1 through 4 the state variables are different and were adjusted to best match expected performance. The calibration effort indicated that the state variables from Scenarios 1 and 2 resulted with significantly higher PS volatile solid (VS) loads, which did not reflect the plant reported values (i.e. the product of primary sludge flow and primary sludge concentration). However, predicted higher VS loads fit well with the calculated VS loads based on the TSS removal efficiency of primary clarifiers, which is assumed to be a more accurate measure of actual PS loading. State variables for Scenarios 3 and 4 predicted similar sludge characteristics to plant reported values for PS and TWAS. Based on the information received from the plant personnel and evaluation of the historical data, conditions defined for Scenario 1 were found to be more accurate measure of actual plant performance. Therefore, the state variables determined from Scenario 1 were used to define the concentration of the primary and secondary sludges for subsequent modeling.

Table 2-1. Description of Input Conditions Used for Model Calibration

	Primary Sludge		TWAS	
Scenario	**Flow**	**Concentration**	**Flow**	**Concentration**
1	Plant reported	Adjusted to match primary sludge load calculated outside the model from plant data based on primary clarifier TSS removal	Adjusted to match TWAS load determined from liquid stream BioWin simulation based on plant reported MLSS and BOD	Plant reported
2	Plant reported	Adjusted to match primary sludge load calculated outside the model from plant data based on primary clarifier TSS removal	Plant reported	Adjusted to match plant reported TWAS concentration
3	Adjusted to match primary sludge load calculated outside the model from plant data based on primary clarifier TSS removal	Plant reported	Adjusted to match TWAS load determined from liquid stream BioWin simulation based on plant reported MLSS and BOD	Plant reported
4	Adjusted to match primary sludge load calculated outside the model from plant data based on primary clarifier TSS removal	Plant reported	Plant reported	Adjusted to match plant reported TWAS concentration

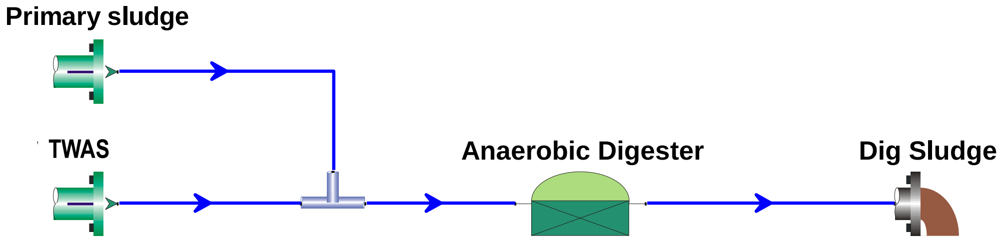


Figure 2-1. Configuration used for BioWin digestion model calibration

Table 2-2. Preliminary Analyses of Various Input Values								
Influent Conditions /Parameter	HRT, days	Flow, mgd	Gas Flow Rate, scfm	Methane Content, %	CO_2 Content, %	Hydrogen Content, %	Ammonia Content, %	VSR, %
Scenario 1	35.3	0.70	1,315	62.6	36.8	0.07	0.42	57.3
Scenario 2	30.5	0.81	1,387	62.9	36.4	0.04	0.51	55.9
Scenario 3	27.0	0.92	1,243	63.2	36.3	0.07	0.30	54.6
Scenario 4	24.1	1.03	1,314	63.5	36.0	0.07	0.36	53.4
Plant Reported Data	**30.3**	**0.83**	**902**					**58.0**

Table 2-3. Model Predicted Removal in Digesters												
Parameter	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	In	Out	% Rem	In	Out	% Rem	In	Out	% Rem	In	Out	% Rem
Total COD, lb/d	334,862	143,582	57.12	365,283	162,498	55.51	335,354	152,570	54.50	365,775	171,580	53.09
Total cBOD, lb/d	129,535	21,484	83.41	142,601	26,403	81.48	129,840	26,754	79.39	142,906	31,861	77.70
TKN, lb/d	11,986	11,704	2.38	14,091	13,731	2.55	12,047	11,861	1.54	14,153	13,910	1.70
TP, lb/d	8,391	8,391	0.00	8,648	8,648	0.00	8,400	8,400	0.00	8,657	8,657	0.00
VSS, lb/d	213,978	91,455	57.26	234,928	103,660	55.88	213,978	97,147	54.60	234,928	109,489	53.40
TSS, lb/d	270,485	143,130	47.08	291,777	155,650	46.65	270,485	146,989	45.66	291,776	160,073	45.14

2.1.1 BioWin Sensitivity Analyses

A sensitivity analysis was performed to determine the impact of modeling parameters on predictions. The kinetic constants for methanogens and acetogens were altered by no more than 10 percent from the default values described in the BioWin process simulator. Hydrolysis rate and hydrolysis half saturation constants were also manipulated. The effects of temperature and HRT in the digesters were assessed.

The results of the sensitivity analysis indicated the significance of acetolastic maximum rate coefficient, acetolastic half saturation coefficient and acetoclastic decay rate for methanogens. These three parameters alter the volatile fatty acids (VFAs) in the digesters. The kinetic parameters for acetogens did not change the VFAs notably. None of the kinetic parameters for acetogens or methanogens had any notable effect on VSR or gas production rates; however hydrolysis rate and hydrolysis half saturation constants significantly changed the VSR and gas production rates. Besides these parameters, temperature and HRT were affected gas production and VSR considerably. The effect of these parameters will be assessed in detail in the following sections.

2.1.1.1 Effect of Alkalinity Addition

The model predictions indicated lower pH and alkalinity values (pH = 6.5, alkalinity =1650 mg $CaCO_3$/l) in the digester compared to plant historical data (avg pH =7.3, alkalinity = 2,900 mg $CaCO_3$). As digesters are extremely sensitive to pH, the accuracy of the results was questioned. To eliminate the possible consequences of low pH, alkalinity was added artificially in the form of lime (3 Molar) in the model. Required amount of lime to reach the target pH and alkalinity values were determined by model runs. Table 2-4 summarizes the results.

Based on Table 2-4, 0.023 mgd of 3 molar (M) lime was added into the system to match plant reported digester pH for August 2007. Note that it was not possible to match both pH and alkalinity by lime addition. The sensitivity analyses were then repeated with the addition of 0.023 mgd 3M lime, as described above. The sensitivity analyses did not show significant differences with or without lime addition in terms of gas production and VSR. Therefore, the accuracy of previous analyses was accepted.

Table 2-4. Alkalinity Addition to Control pH (target pH = 7.3 & target alkalinity = 2,873 mg $CaCO_3$/L)

Lime Properties			Digester Conditions		
Flow, mgd	Ca	CO_2	pH	Alkalinity, mmol/L	Alkalinity, mg $CaCO_3$,/L
0.0007	120,000	6	6.54	38.95	1,948
0.001	120,000	6	6.60	41.17	2,059
0.004	120,000	6	6.71	47.97	2,399
0.008	120,000	6	6.82	54.73	2,737
0.012	120,000	6	6.93	64.69	3,235
0.02	120,000	6	7.22	108.23	5,412
0.023	120,000	6	7.33	129.95	6,948
0.025	120,000	6	7.40	144.50	7,225

2.1.1.2 Effect of Influent Wastewater Characteristics

All modeling efforts were based on the initial sludge characteristics derived from liquid stream BioWin simulations conducted previously. To investigate the influence of influent wastewater characteristics on sludge quality and the performance of the digesters, sensitivity analyses were carried out by systematically varying influent wastewater characteristics. For this purpose, a simplified version of the overall plant configuration was created, as shown in Figure 2-2.

From the sensitivity analysis, the factors that affect gas production, VSR and the VS content of primary and secondary sludge were identified. Gas production rate was found to be influenced most strongly by influent COD, Fxsp (non colloidal slowly biodegradable fraction of the COD), and the solid removal efficiency of the primary settling tank. VSR was found to be influenced most strongly by Fxsp and Fup (unbiodegradable particulate fraction of COD).

By changing these three factors (influent COD, Fxsp and Fup), the target VSR rate was achieved. Nevertheless, the gas production rate was still found to be 22 percent higher than the plant historical value. To match both gas production and VSR to plant data, both primary and secondary sludge VS loadings would need to be around 20 percent less than the reported historical plant data (while maintaining the same ratio of secondary sludge VSS/primary sludge VSS as reported in plant data).

It is important to note that it would be generally unacceptable to simply change selected influent wastewater characteristics since it is important to maintain a balance between all the wastewater parameters. However, the objective herein was to develop a general picture of which parameters influence digesters significantly. A full wastewater characterization would determine the wastewater fractions, such as Fxsp and Fup, and would be expected to provide a more accurate prediction of gas production.

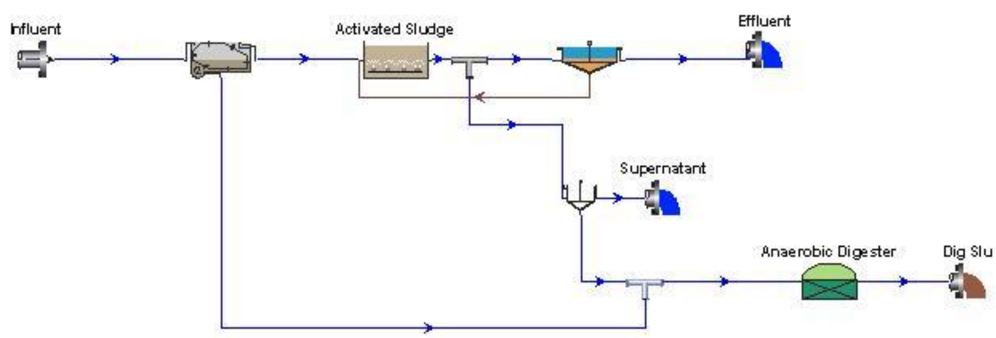


Figure 2-2. Simplified process schematic

2.2 Model Validation

After calibrating the model, simulations were performed under dynamic conditions with different input conditions to validate the model. Validation was performed using three sets of historical data: August 2007, several months of the 2009 when 11 digesters were in operation, and recent data from December, 2009 through May, 2010 when 8 digesters were in operation. Table 2-5 summarizes the sludge flows and concentrations that were input to the model to predict sludge loadings. Minor adjustments were made to the state variables for primary sludge and TWAS where necessary for the validation.

Table 2-5. Description of Input Conditions used for Model Validation

	Primary Sludge		TWAS	
Run	Flow	Concentration	Flow	Concentration
A	Adjusted to match load calculated outside the model from plant data for primary sludge flow and primary sludge concentration	Model predicted from state variables (Scenario 1)	Adjusted to match load calculated from DAFT flow (DSEPS flow minus primary sludge flow) and DAFT sludge concentration	Model predicted from state variables (Scenario 1)
B	Plant reported	Model predicted from state variables (Scenario 1)	Plant reported (DSEPS flow minus primary sludge flow)	Model predicted from state variables (Scenario 1) with minor adjustment to match secondary sludge production predicted from primary effluent BOD load and BioWin predicted sludge yield
C	Plant reported	Model predicted from state variables (Scenario 1)	Plant reported (DSEPS flow minus primary sludge flow)	Model predicted from state variables (Scenario 1) with minor adjustment to match plant reported DAFT sludge concentration

2.2.1 August 2007

Historical daily PS flows for August 2007 were input as a 30-day influent itinerary for the dynamic simulations. As a result of discussions with plant personnel it was decided that there is a higher level of confidence in the PS flow information reported by the plant, whereas TWAS flow data is not reliable. Therefore, based on information from the plant that digested sludge flow and primary sludge flow are more reliable, TWAS flow was computed as the difference between these two flows.

Table 2-6 summarizes the results for each run. In addition, plant reported values calculated in three different ways are presented for comparison. When plant reported VS loads were exactly matched with the digester model (Run A) by adjusting the PS and TWAS flows, model predicted VSR was slightly less than the plant reported value. When plant reported PS and TWAS flows were input in Run B, it was possible to predict the influent primary sludge and TWAS loads within 10 percent of the plant reported data calculated loads. These numbers are slightly different because the model is calculating loads using fixed state variables selected as part of the calibration step discussed above. Predicted VSR values were lower than the reported values. Table 2-6 shows variable results in terms of VSR.

In terms of gas production, it was not possible to match plant data within 10 percent of the reported plant value. All BioWin runs predict specific gas production numbers of close to 15 cf/lb VS destroyed, whereas plant data reports very low values for August 2007 (Table 2-6). Although modeled VSR and gas production values did not exactly match up, it was possible to achieve a somewhat close VSR and similar pattern for gas production rate. Figure 2-3 compares the model predicted gas production rate with plant reported values for Run B.

Table 2-6. Results of Model Validation with August 2007 Data

Parameter	Plant Reported Data for August 2007			Model Validation for August 2007		
	A[1]	B[2]	C[3]	Run A	Run B	Run C
Primary Sludge VSS, lbs/d	97,146	165,841	165,841	97,146	151,309	151,309
TWAS VSS, lbs/d	103,063	64,201	103,063	103,064	70,439	91,189
Total Digester Feed VSS, lbs/d	200,209	230,042	268,904	200,211	221,748	242,500
Digested Sludge VSS, lbs/d	81,398	81,398	81,398	89,499	96,249	97,196
VSR, %	59.23	64.62	69.72	55.31	56.56	59.91
Gas Production, ft^3/min	902	902	902	1,129	1,353	1,538
Gas Production, ft^3/lbs VSS dest	11.24	8.49	6.93	14.68	15.52	15.24
HRT, days	25.3	25.3	25.3	28.1	29.5	29.5

[1] Calculated assuming primary sludge loading can be determined from primary sludge flow and concentration and TWAS loading can be determined from DAFT flow (DSEPS flow minus primary sludge flow) and DAFT sludge concentration

[2] Calculated assuming primary sludge loading can be determined from primary clarifier TSS removal and TWAS loading can be determined from primary effluent BOD loading and BioWin predicted sludge yield

[3] Calculated assuming primary sludge loading can be determined from primary clarifier TSS removal and TWAS loading can be determined from DAFT flow (DSEPS flow minus primary sludge flow) and DAFT sludge concentration

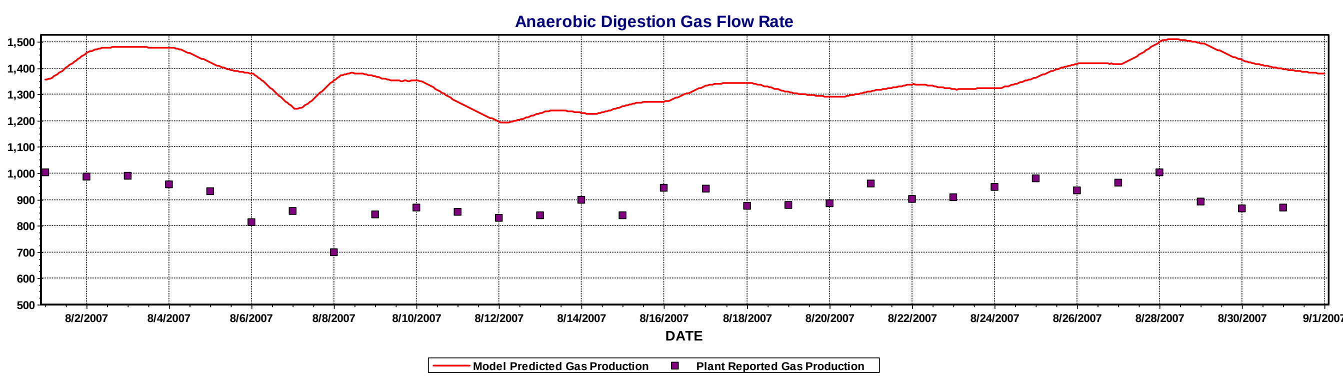


Figure 2-3. Comparison of model predicted and plant reported gas production with August 2007 plant data (results from Run B)

2.2.2 Year 2009 – 11 Digesters in Service

Historical daily PS and TWAS flows from July 19, 2009 through November 1, 2009 were input for the dynamic simulations. This is the period when input values were available for Run A, B and C and the plant had stable operation with 11 digesters on-line. After this period, the plant had taken some digesters off line.

The modeling results for Runs A, B, and C are presented in Table 2-7. Plant reported values calculated in three different ways are presented for comparison. In addition, calculated VSR, specific gas production, and

HRT were adjusted based on a methodology that accounts for grit deposition and active volume of the digester (see Attachment A). Similar to the results observed for the validation of August 2007, modeled VSR was significantly less than the plant reported data for all runs. In parallel to this modeling work, a new calculation method for adjusting VSR to account for anomalies due to grit deposition in the digester was undertaken (see Attachment A to TM 3.3). When this adjustment is made, the adjusted values match modeled values for model Run B very closely.

Figure 2-4 compares the plant reported VSR with modeled values for Run B. Plant reported VSR is typically higher than the modeled VSR. However, when the plant reported data was adjusted for grit deposition, plant reported and modeled VSR values matched well (see Table 2-7 and Attachment A). On the other hand, it was possible to achieve close match with the plant reported gas production rate and modeled values. Figure 2-5 shows the model predicted gas production rate and compares it with plant reported values for Run B. Although slightly higher gas production was predicted by BioWin, gas production rate followed the same pattern with the plant reported data.

Table 2-7. Results of Model Validation with 2009, 11 Digester Data

Parameter	Plant Reported Data (7/19/2009 through 11/1/2009)				Model Validation		
	A[1]	B[2]	C[3]	Plant Historical Data Adjusted for Grit Deposition (see Attachment A)	Run A	Run B	Run C
Primary Sludge VSS, lbs/d	90,945	129,559	129,559	129,559	90,944	149,861	149,861
TWAS VSS, lbs/d	122,044	66,247	122,044	66,247	122,045	75,852	98,223
Total Digester Feed VS, lbs/d	212,988	195,810	251,602	195,810	212,989	225,713	248,085
Digested Sludge VS, lbs/d	76,520	76,520	76,520	-	99,916	100,040	101,321
VSR, %	62.56	59.68	67.56	54.0	53.13	55.77	59.24
Gas Production, ft^3/min	1,156	1,156	1,156	1,156	1,137	1,356	1,553
Gas Production, ft^3/lbs VSS dest	12.20	13.95	9.51	15.4	14.48	15.54	15.24
HRT, days	23.4	23.4	23.4	24 (@20.46 MG active volume)	26.8(@24.81 MG active volume)	29.1(@24.81 MG active volume)	29.1(@24.81 MG active volume)

[1] Calculated assuming primary sludge loading can be determined from primary sludge flow and concentration and TWAS loading can be determined from DAFT flow (DSEPS flow minus primary sludge flow) and DAFT sludge concentration

[2] Calculated assuming primary sludge loading can be determined from primary clarifier TSS removal and TWAS loading can be determined from primary effluent BOD loading and BioWin predicted sludge yield

[3] Calculated assuming primary sludge loading can be determined from primary clarifier TSS removal and TWAS loading can be determined from DAFT flow (DSEPS flow minus primary sludge flow) and DAFT sludge concentration

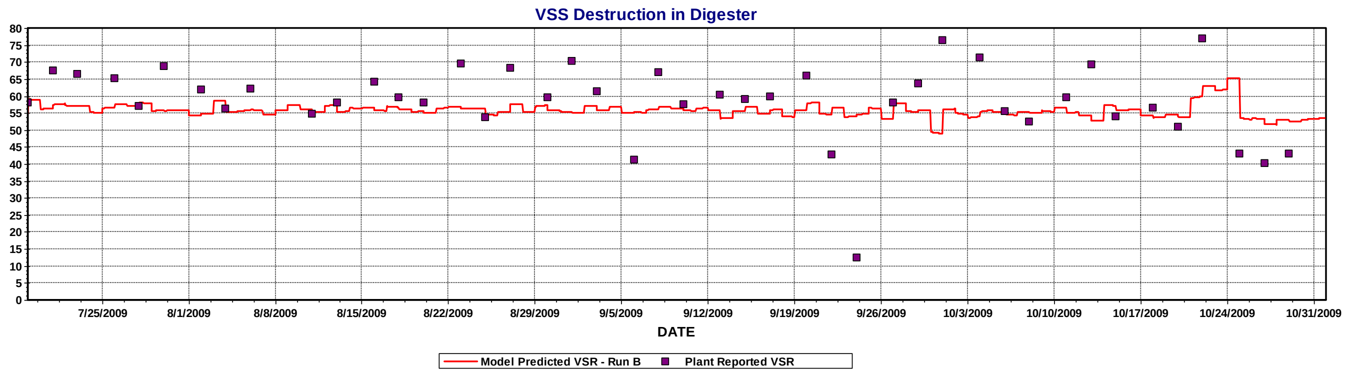


Figure 2-4. Comparison of model predicted and plant reported VSR with 200, 11 digester data (results from Run B)

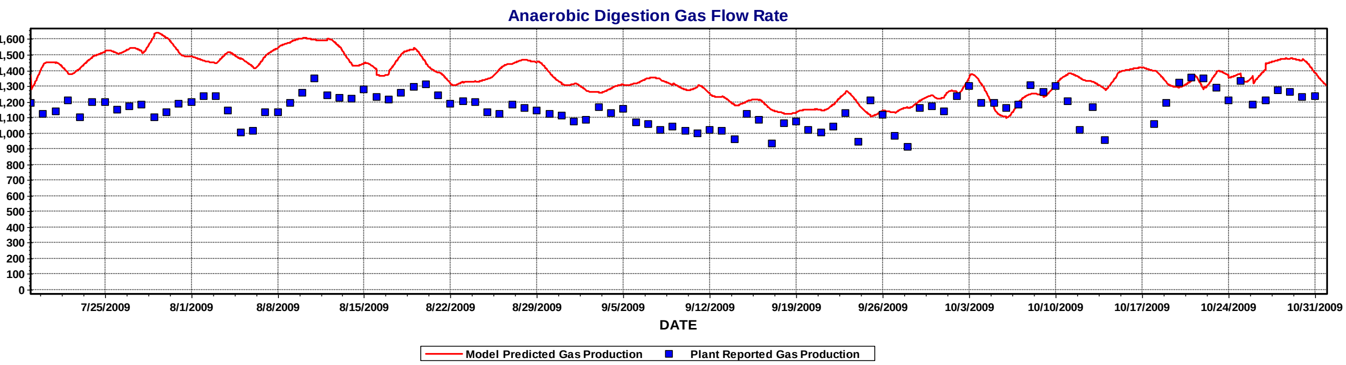


Figure 2-5. Comparison of model predicted and plant reported gas production with 2009, 11 digester plant historical data (results from Run B)

2.2.3 Year 2009 and 2010 - 8 Digesters in Service

At the beginning of December 2009, San Jose WPCF had taken some digesters off line and initiated to operate the plant with 8 digesters. Historical data from December 1, 2009 through May 14, 2010 was utilized to validate the model under new conditions. Since the conditions defined in Run B are consistent with the methodology used to project the loadings for master planning, it was decided to use only the conditions defined in Run B for validation purpose.

Table 2-8 presents the modeling results and compares the plant reported values with model predictions. As depicted in Figure 2-6, plant reported VSR was slightly higher than the model predicted value which is in accordance with the findings of previous validation efforts. After adjustments were made in plant reported data to account for grit deposition, model predicted VSR matched the adjusted plant reported VSR very closely (see Attachment A). It was also possible to achieve a very close match for gas production with plant reported and model predicted values (Figure 2-7).

	Table 2-8. Results of Model Validation - 8 Digesters On-Line		
Parameter	Plant Reported Data (12/1/2009 through 05/14/2010)	Plant Historical Data (12/1/2009 through 05/14/2010) Adjusted for Grit Deposition (see Attachment A)	Model Validation
Primary Sludge VSS, lbs/d	128,872	128,872	138,078
TWAS VSS, lbs/d	85,390	85,390	87,982
Total Digester Feed VS, lbs/d	214,262	214,262	226,060
Digested Sludge VS, lbs/d	90,700	-	103,375
VSR, %	56.70	54.5	54.33
Gas Production, ft^3/min	1,276	1,276	1,308
Gas Production, ft^3/lb VSS destroyed	14.87	15.73	15.4
HRT, days	20.1	20 (@ 18.87 MG active volume)	20.6 (@19.44 MG active volume)

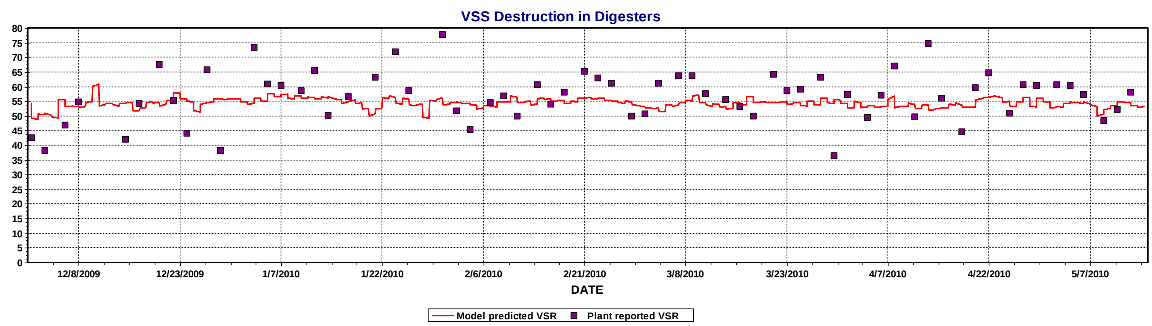


Figure 2-6. Comparison of model predicted and plant reported VSR when 8 digesters were on-line

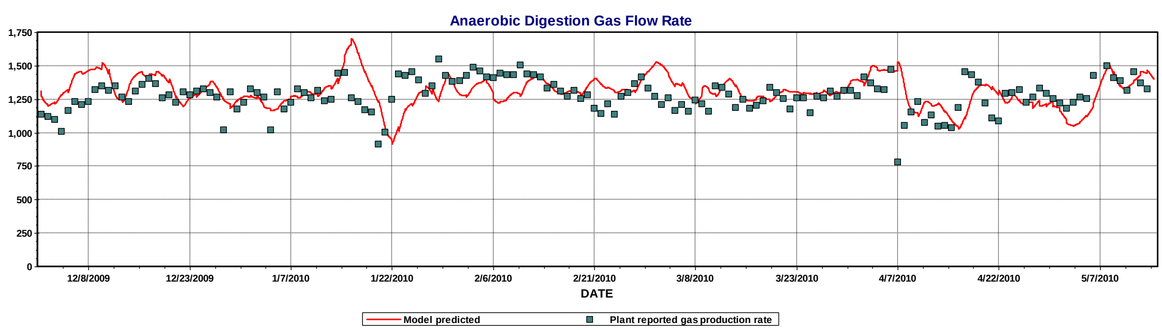


Figure 2-7. Comparison of model predicted and plant reported gas production when 8 digesters were on-line

2.2.4 Summary of Findings

A process model was developed to simulate the digesters in San Jose WPCF. The information (which includes the characteristics of PS and TWAS) was retrieved from the liquid stream process simulation. Historical data sets were utilized to calibrate the data. Since the accuracy of some plant reported data sets were questionable, four different scenarios were generated based on different flow and load characteristics of PS and TWAS. Calibration efforts indicated that Scenario 1 would be the best fit to simulate the actual plant performance at the WPCF. Therefore, all subsequent analyses were carried out by using the conditions defined in Scenario 1 with minor adjustment to the primary and secondary sludge where necessary.

Three separate sets of historical data (August 2007,the data from 7/19/2009 through 11/1/2009, and the data from 12/1/2009 through 05/14/2010) were used to validate the model. Three conditions (Run A, B, and C) were identified to be assessed in validation. Although some discrepancies were observed between plant reported and modeled values, it was possible to validate the model with all data sets. Since the conditions defined in Run B are consistent with the methodology used to project the loadings for master plan, Run B was selected for process performance evaluations.

The historical data sets from 2009 and 2010 present significantly higher specific gas production rate compared to the data from August 2007. This could be because the 2009 and 2010 data represent a condition where all the digesters had been cleaned recently, resulting in a modeled HRT that was closer to actual conditions. This might also be a reason why modeled gas production rates for 2009 and 2010 fit better than August 2007. In addition, specific gas production rates for the 2009 and 2010 data were adjusted using a new calculation method for adjusting VSR to account for anomalies due to grit deposition in the digester was undertaken (see Attachment A to TM 3.3). Similar specific gas production rates between model predicted and calculated values were assumed in this methodology to adjust VSR and active digester volume. This methodology resulted in very close concurrence in VSR values.

3. IMPACT OF DIGESTER OPERATION ON PROCESS PERFORMANCE

The calibrated and validated model was used to determine the impact of process changes to digester performance. This was found to be useful in predicting performance values to use in establishing the design basis when different HRTs and temperatures were being assumed for different alternatives and loading conditions. The conditions defined in Run B were used to evaluate the performance of digesters. Digester HRT and operating temperature were varied to determine the expected difference in gas production and VSR.

3.1.1 Effect of HRT and Temperature for 2030 Design Basis Loads

Previous sensitivity analyses carried out at steady state conditions indicated the significance of HRT and temperature on VSR and gas production. Dynamic simulations were run to assess these effects in detail. For this purpose, 2030 design basis loads were utilized. Primary sludge and TWAS sludge flows were adjusted to match the VS content. Table 3-1 provides the loadings used for the modeling. Figures 3-1 and 3-2 presented below summarize the results from modeling efforts.

In the analyses, HRT was varied from 10 days to 30 days and the temperature was changed from 85 degrees F up to 105 degrees F. As Figure 3-1 depicts, predicted specific gas production rate did not vary notably by changing the HRT, but increasing the temperature elevated the specific gas production rates. Predicted VSR increased as HRT and temperature increases. The effect of HRT was more pronounced than the effect of temperature, especially at lower HRT values. Based on the design loading conditions, the model predicts above 53 percent VSR at 98 degrees Fahrenheit and when HRT is above 20 days.

Table 3-1. Design Basis Loads for PS and TWAS		
Parameter	**TS content, lb/d**	**VS Content, lb/d**
Annual Average Primary Sludge Loading	232,700	197,800
Annual Average TWAS Loading, lb/d	144,600	108,200
Annual Average Combined Loading, lb/d	377,300	306,000

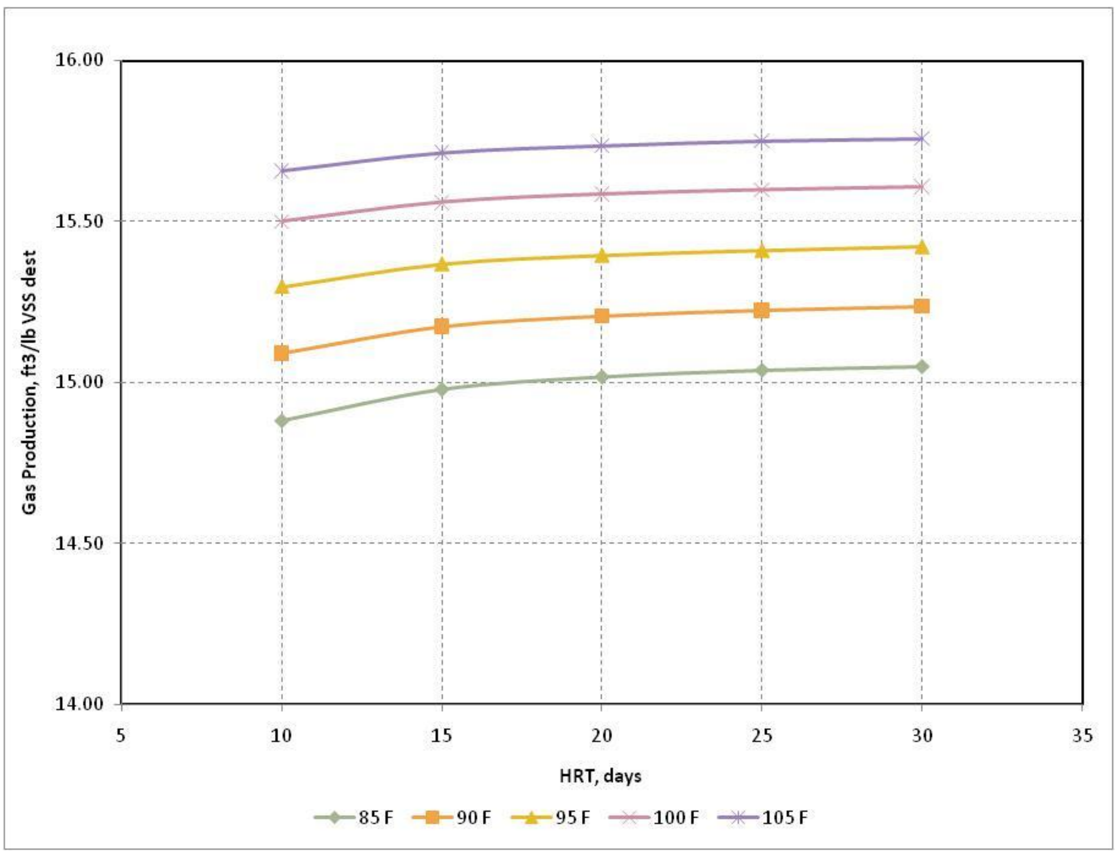


Figure 3-1. Predicted specific gas production as a function of HRT at different temperatures for 2030 design conditions

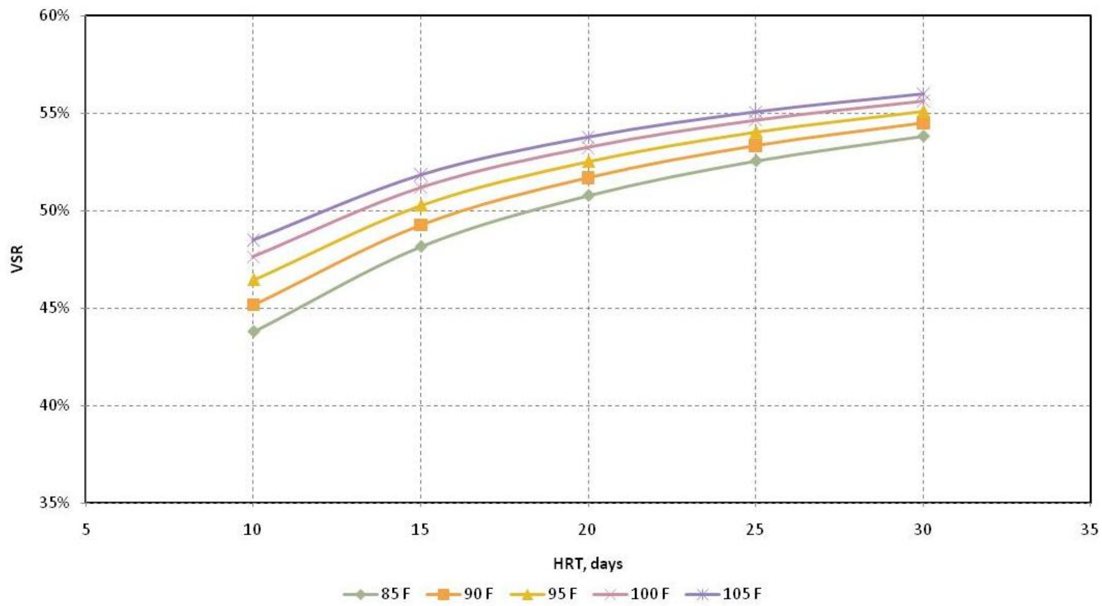


Figure 3-2. Predicted VSR as a function of HRT at different temperatures for 2030 design conditions

3.1.2 Effect of HRT and Temperature for Existing Conditions

A second model run was undertaken using current loading conditions to use in assessing expected performance and estimate impacts of process adjustments under today's conditions. The most recent data set starting from 12/01/2009 through 05/14/2010 (8 digesters in service) was assessed in order to evaluate the HRT and temperature effects on VSR and specific gas production rate. The same methodology used in Section 3.1.1 was utilized for this purpose. Table 3-2 provides the loading conditions adopted for process modeling and Figure 3-3 and 3-4 present the predicted specific gas production rate and VSR respectively for existing conditions when 8 digesters are on-line.

Table 3-2. Existing Loads for PS and TWAS Adopted for Performance Evaluations

Parameter	TS content, lb/d	VS Content, lb/d
Average Primary Sludge Loading	152,733	128,872
Average TWAS Loading, lb/d	124,767	85,390
Average Combined Loading, lb/d	277,500	214,262

In the performance evaluations, HRT was varied from 10 days to 30 days. Unlike Section 3.1.1, temperature was only changed from 95 to 100 degrees Fahrenheit, the range in which the facility currently operates the digesters. As Figure 3-3 depicts, predicted specific gas production rate increased slightly with increasing temperature. Modeling results indicated that by increasing the HRT from 10 days to 30 days, predicted VSR values could reach from approximately 48 to 57 percent (at 95 degrees Fahrenheit). Modeling predictions also revealed that changing the temperature from 95 to 100 degrees Fahrenheit would increase the VSR slightly

(Figure 3-4). Based on the existing conditions defined from plant reported values (12/01/09 through 05/14/10), the model predicts around 54 percent VSR when HRT is around 20 days.

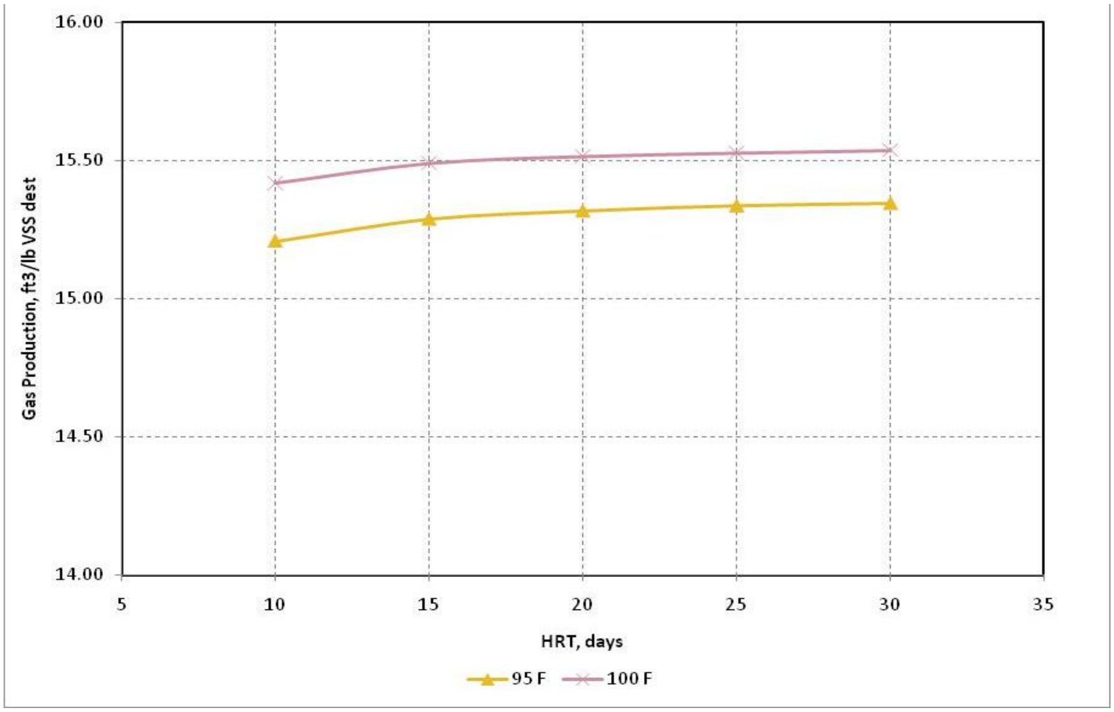


Figure 3-3. Predicted specific gas production as a function of HRT at different temperatures for existing conditions

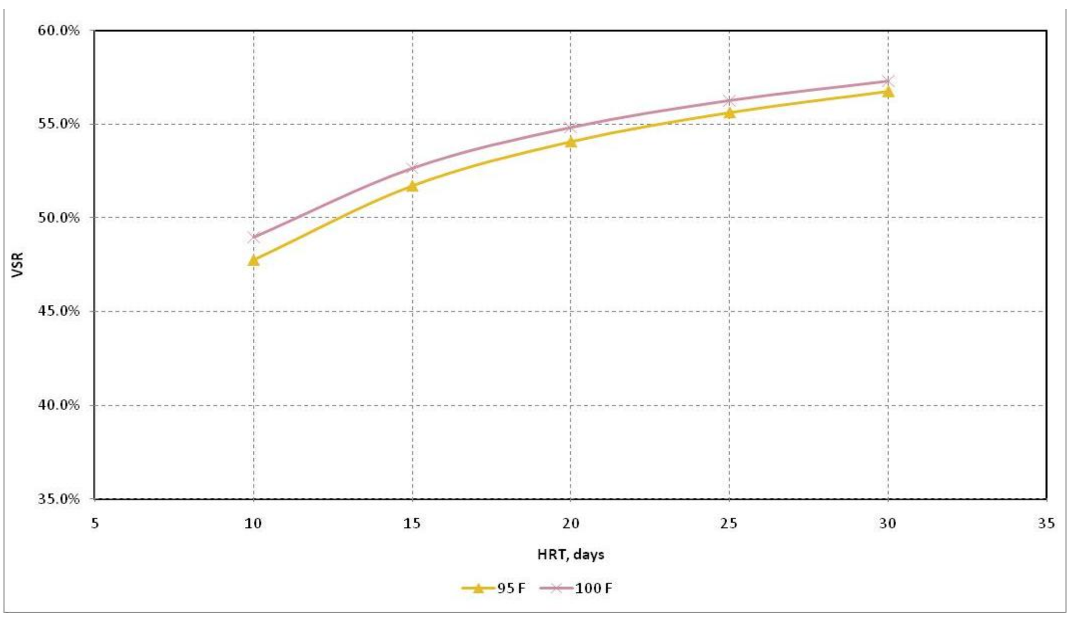


Figure 3-4. Predicted VSR as a function of HRT at different temperatures for existing conditions

3.1.3 Gas Production

The impact of intermittent feeding on gas peaking was evaluated by selecting a single day and feeding one digester 10 minutes each hour for 24 hours. Figure 3-5 illustrates the feeding regime of this digester for a 24-hr period. For this analysis, primary sludge and TWAS VS loading values were adapted from the historical data for 06/08/2009. For this specific day, 11 digesters were in service (2 @ 1.47 MG and 9 @ 2.43 MG volume). Figure 3-6 shows the predicted gas flow rate under this intermittent feeding assumption. Although there is a slight variation in daily gas flow rate of the digester, the gas production stays almost constant for the entire day. The average predicted gas flow rate was around 108.6 ft³/min, where the maximum predicted value was only 109.3 ft³/min. These results indicate that intermittent feeding of once per hour does not have a significant impact on overall gas production rate.

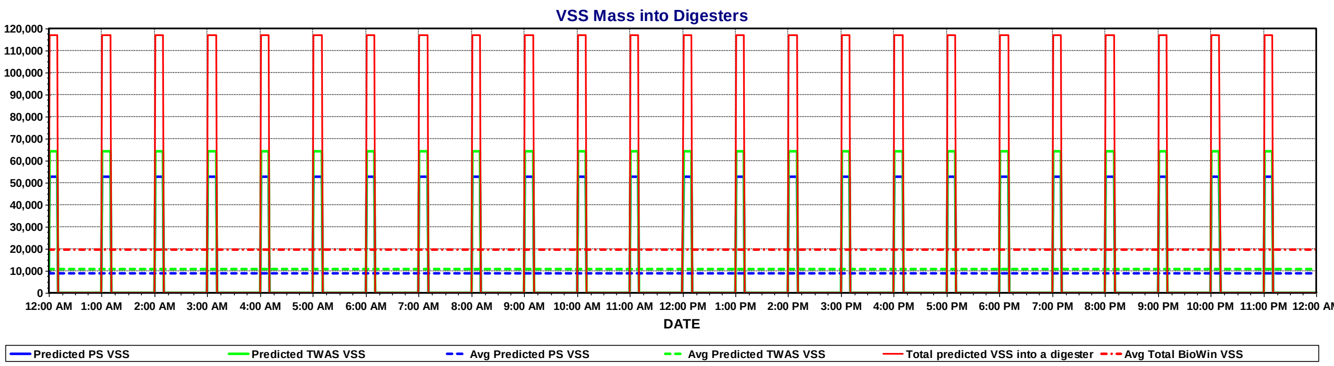


Figure 3-5. Simulation of daily digester VS loading for 10 min/hr feed (digester volume = 2.43 MG)

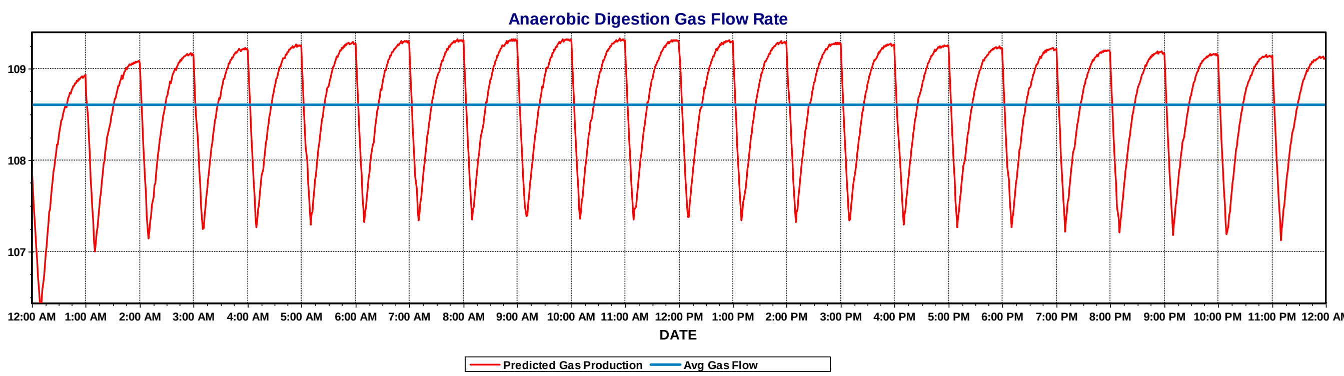
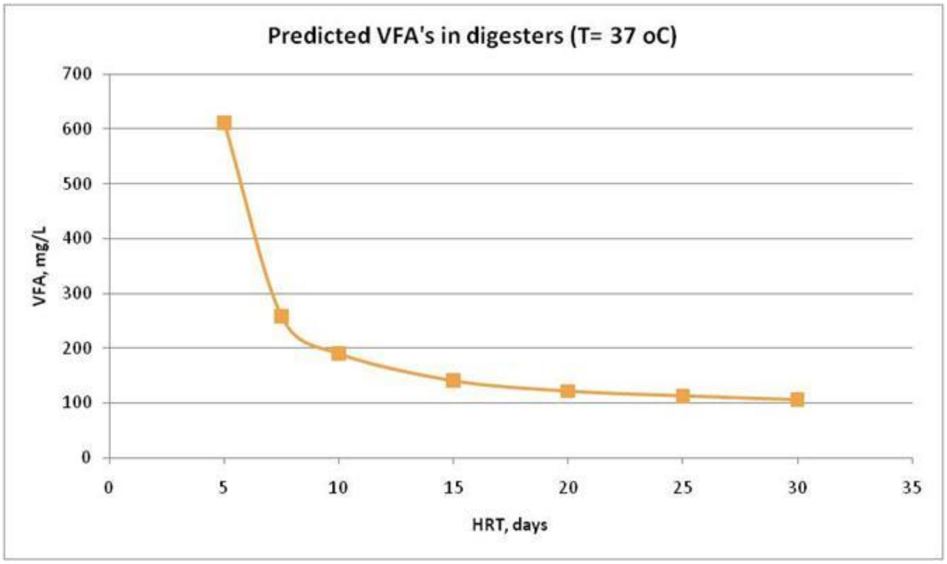


Figure 3-6. Predicted gas flow rate of a digester at 10 min/hr digester feed

3.1.4 Volatile Fatty Acids

The model was used to predict the concentration of volatile fatty acids in the digested sludge at various HRTs. The results of that analysis are shown in Figure 3-7. As anticipated VFAs increase as HRT is shortened. At HRTs below 10 days, VFAs rise very rapidly, approaching conditions that could represent impending process instability below 7 days. .



HRT, days	VFA
5	610.72
7.5	257.55
10	189.92
15	140.61
20	121.90
25	113.07
30	106.15

Figure 3-7. Model prediction of volatile fatty acid concentrations at various hydraulic residence times

4. RESULTS AND DISCUSSIONS

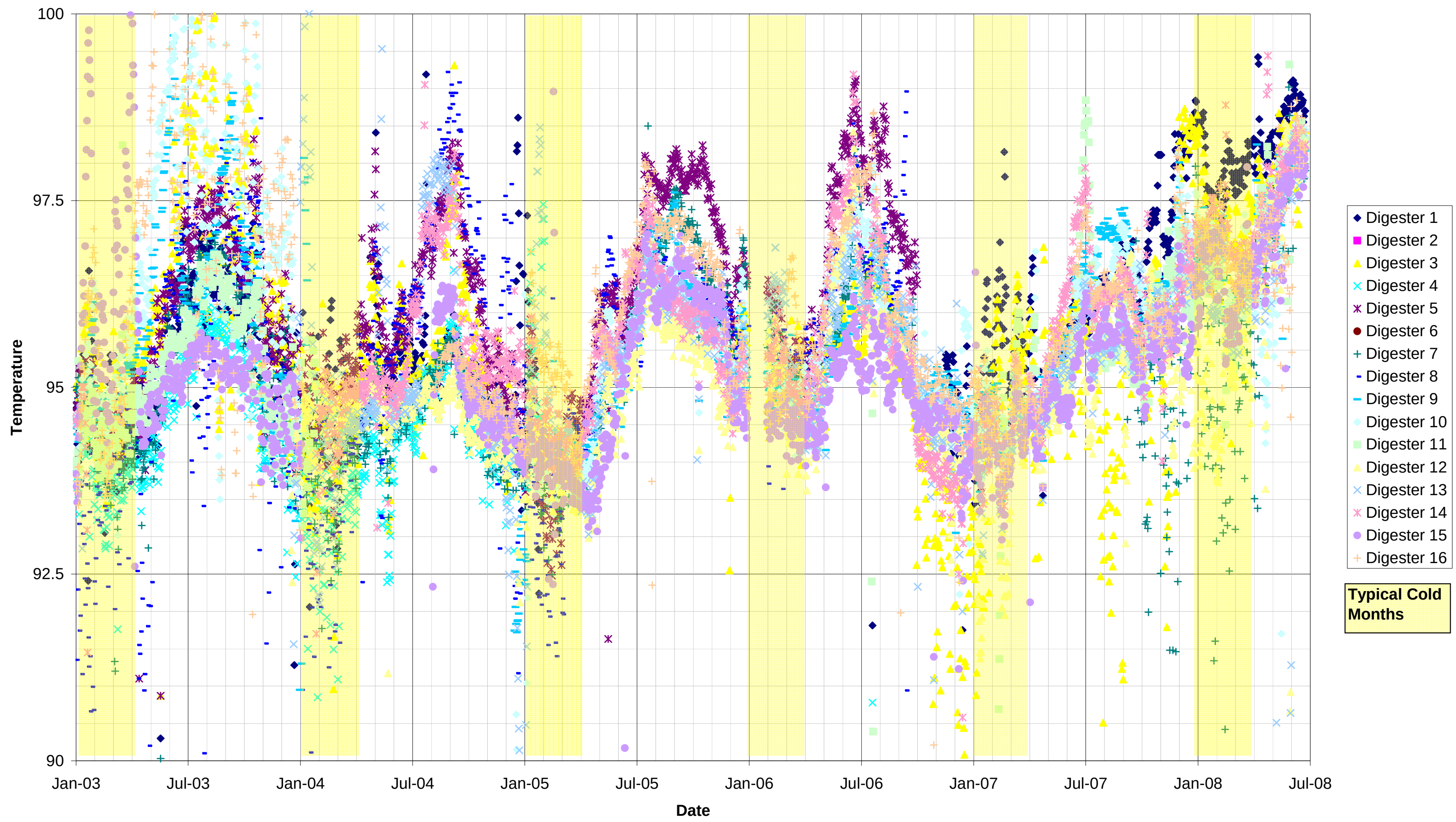
A model was constructed to represent the digesters at the WPCP. The model was calibrated and validated using historical data. The BioWin simulations showed that depending on the assumption for sludge production arising from the liquid stream simulation, it is possible to match plant reported VSR. However, if the BioWin digester is input directly with the plant reported values of primary and TWAS VS loadings, the predicted VSR is slightly lower than the plant reported value on a mass balance basis, for August 2007 data. This conclusion was also valid when the plant reported values of primary and TWAS VS loadings for 2009 were input into the model. However, once actual VSR is adjusted to account for grit deposition (see Attachment A), modeled and plant reported VSR match well.

Besides hydrolysis rate and hydrolysis half saturation constants, the model-predicted digester performance was determined to be relatively insensitive to the kinetic parameters included in the BioWin anaerobic digester simulator. However, parameters such as HRT, the ratio between primary and secondary sludge loads, VS loading, and temperature strongly influence performance of the digesters. By changing plant influent wastewater characteristics, up to two of the following performance parameters could be matched fairly well: digester feed VS loading, digester VSR, or gas production. Matching all three simultaneously was not possible.

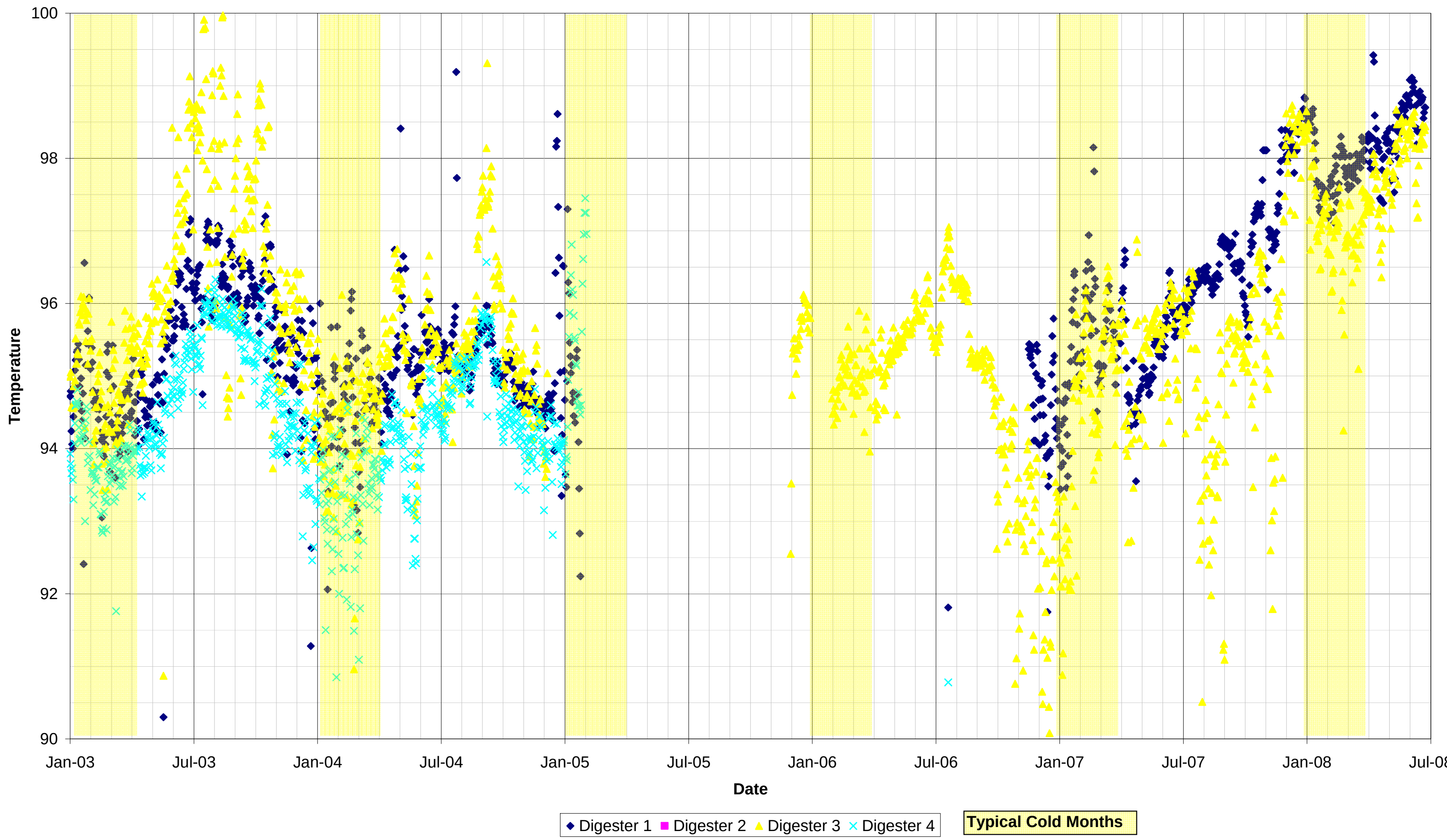
Parameters of importance in the modeling are influent COD, Fup (unbiodegradable particulate fraction of COD) and Fxsp (non colloidal slowly biodegradable fraction of COD). However, when matching VS loading, VSR, and gas production, these parameters would need to be changed quite significantly, to values that are unlikely to be realistic. However, the analyses conducted and described in Attachment A to TM 3.3 adjusted VSR to account for grit deposition and, using model predicted performance, hypothesized a lower adjusted VSR due to a lower actual active digester volume than assumed for the modeling. As described in Attachment A, although the calculation method is new and requires further validation at other plants and under different conditions, the results offer a plausible explanation for differences in model results and adjusted actual VSR and gas production values. Therefore, the conclusion is that the most likely plant reported parameters that require correction to match reported digester performance are effective digester volume, primary and secondary sludge quantities and digester temperature.

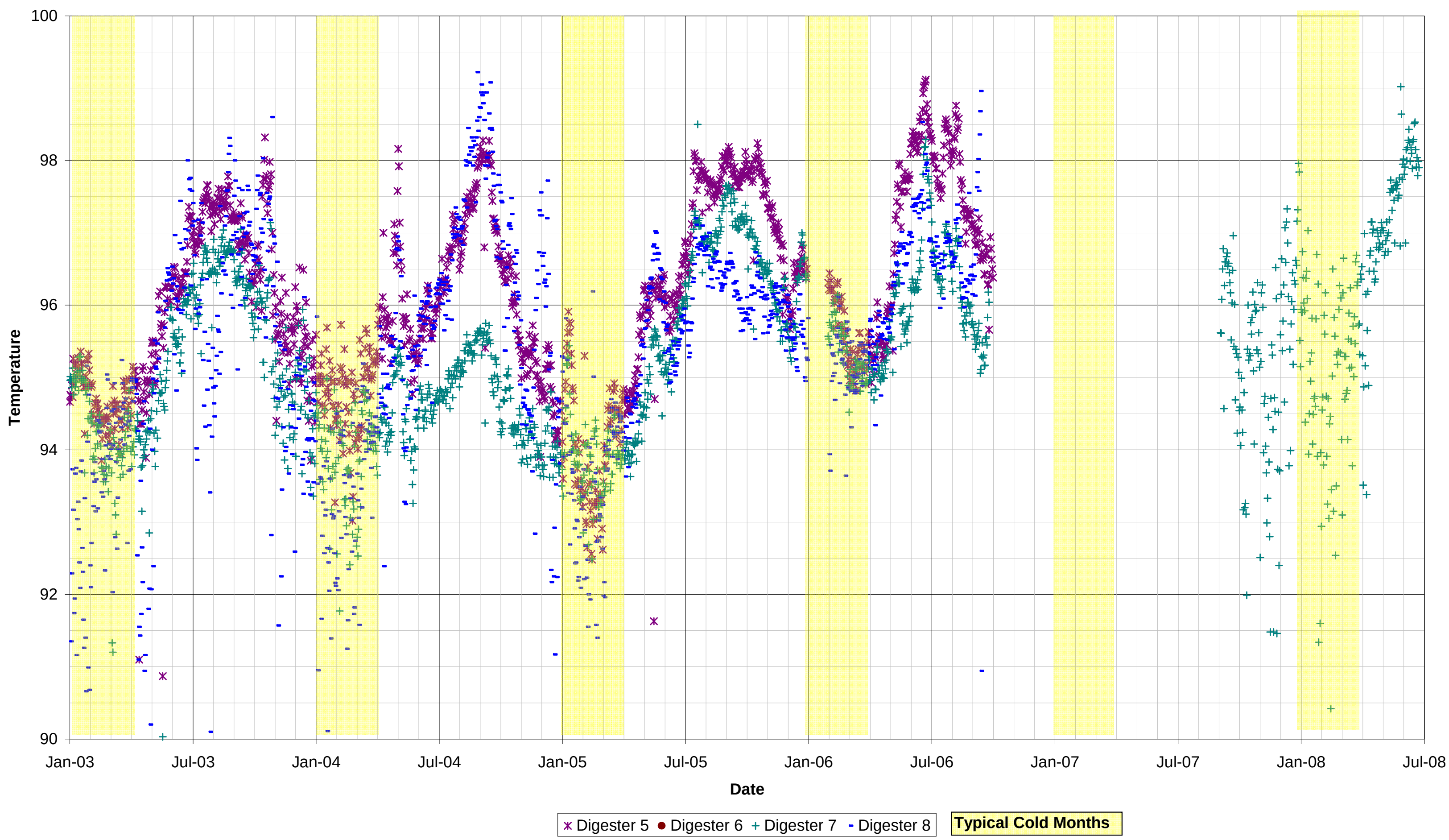
Although this calibration and validation effort does not accurately represent the exact plant performance, it can be used to assess relative differences in gas production and VSR as a result of changes in operating temperature and/or HRT. A fully calibrated model would require a program of wastewater characterization and bench-scale testing, along with validated information on actual active digester volume.

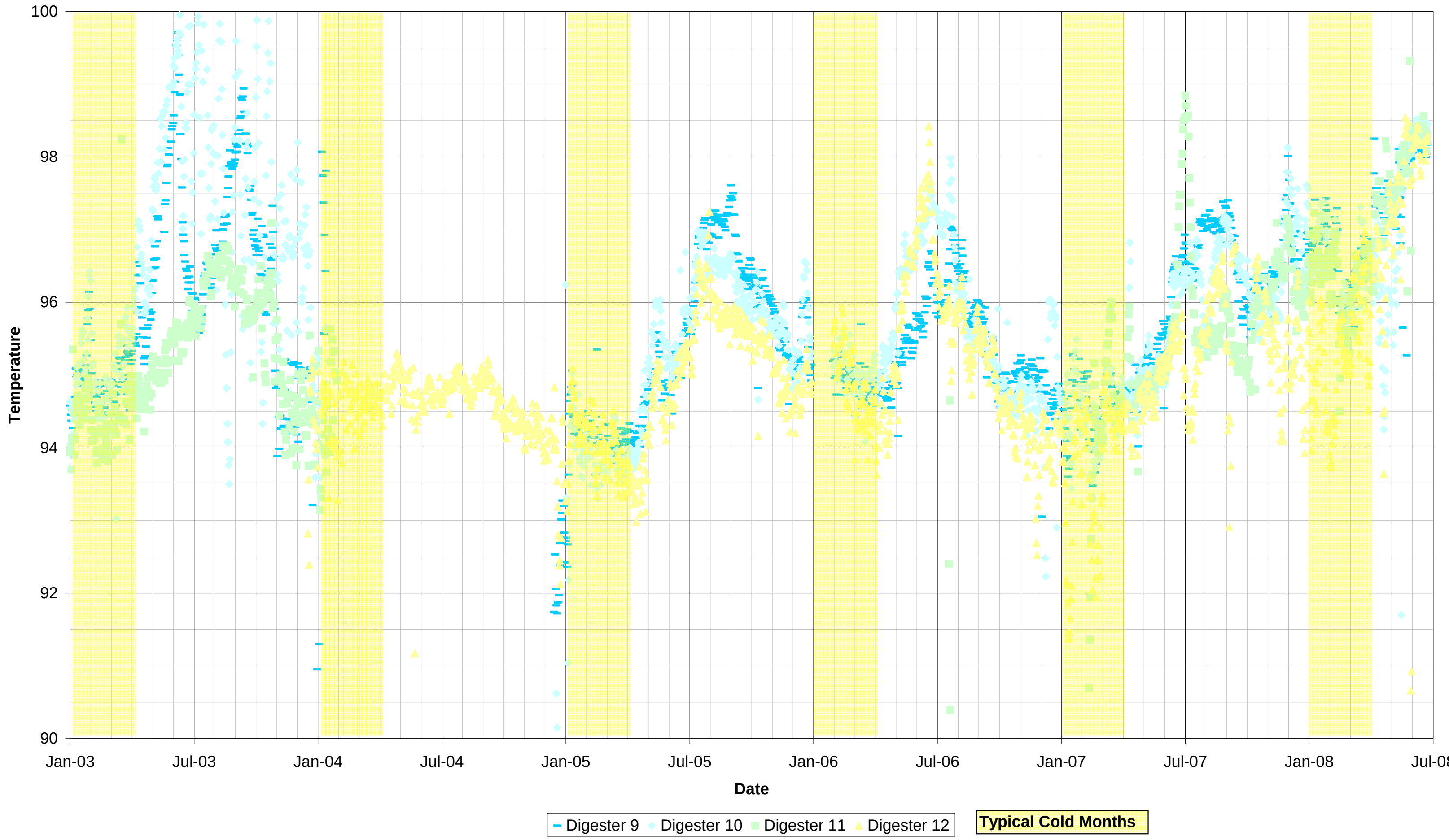
ATTACHMENT C: SUMMARY OF HISTORICAL DIGESTER TEMPERATURE DATA



100
97.5
95
92.5
90
Temperature
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Date
Digester 1
Digester 2
Digester 3
Digester 4
Digester 5
Digester 6
Digester 7
Digester 8
Digester 9
Digester 10
Digester 11
Digester 12
Digester 13
Digester 14
Digester 15
Digester 16
Typical Cold Months


100
98
96
94
92
90
Temperature
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Date
Digester 1
Digester 2
Digester 3
Digester 4
Typical Cold Months


100
98
96
94
92
90
Temperature
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Date
Digester 5
Digester 6
Digester 7
Digester 8
Typical Cold Months


100
98
96
94
92
90
Temperature
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Date
Digester 9
Digester 10
Digester 11
Digester 12
Typical Cold Months


100
98
96
94
92
90
Temperature
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Date
Digester 13
Digester 14
Digester 15
Digester 16
Typical Cold Months