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Defining Full-Scale Anaerobic Digestion Stability: The Case of Central Weber Sewer Improvement District

Morris E. Demitry[1] & Michael J. McFarland[1]

[1] Utah Water Research Laboratory, USA

Correspondence: Morris E. Demitry, Utah Water Research Laboratory, USA. E-mail: morris.d@aggiemail.usu.edu

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Abstract

A full-scale anaerobic digester receiving a mixture of primary and secondary sludge was monitored for one hundred days. A chemical oxygen demand (COD), volatile solids (VS), and mass balance were conducted to evaluate the stability of the digester and its capability of producing methane gas. The COD mass balance could account for nearly 90% of the methane gas produced while the VS mass balance showed that 91% of the organic matter removed resulted in biogas formation. Other parameters monitored included: pH, alkalinity, VFA, and propionic acid. The values of these parameters showed that steady state had occurred. At mesophilic temperature and at steady state performance, the anaerobic digester stability was defined as a constant rate of methane produced per substrate of ΔVS (average rate=0.40 L/g). This constant rate can be used as stability index to determine the anaerobic digestion stability in an easy and inexpensive way.

Keywords: anaerobic digestion, mass balance, renewable energy, steady state, stability, stability index

1. Introduction

Producing renewable energy is a challenge for the world today because it is often more costly than the harvesting of fossil fuels. Finding new and economically sustainable sources of energy to fulfill the world energy demand is a technological and economic challenge. Use of the anaerobic digestion of sludge may represent a cost-effective approach to generate a sustainable and renewable energy source.

Anaerobic digestion produces biogas, which consists primarily of methane (50 to 75% on a volumetric basis) as well as carbon dioxide (25 to 50%). The methane produced from the anaerobic digestion of municipal sludge, animal and crop wastes can cover up to 20% of the natural gas consumption in the US (McCarthy, 1973). The average energy content of biogas is approximately 600 to 800 British Thermal Units (BTUs) per cubic foot (ft^3), which compares favorably to the energy content of natural gas (approximately 1,000 BTUs per ft^3).

A primary benefit of using anaerobic digestion for the generation of renewable energy is that it is a standard sludge treatment process utilized in many municipal wastewater treatment plants. In the anaerobic digestion process, specific groups of facultative and obligate anaerobic microorganisms act in concert to metabolize organic matter associated with sludge, resulting in the production of methane gas. The important groups of microorganisms found in anaerobic digesters include the hydrolytic, acidogenic and methanogenic bacteria (McCarthy, 1964).

Hydrolytic bacteria convert the complex organic matter, like carbohydrates, fats, and proteins to simple compounds like sugar, fatty and amino acids; the acidogenic bacteria are responsible for converting these intermediate compounds to fermentation products including volatile fatty acids (VFA), hydrogen, and carbon dioxide. The methanogenic bacteria utilized the fermentation products to produce methane. One group of methanogenic bacteria, the aceticlastic methanogens, split acetate into methane and carbon dioxide, while the other group, called hydrogen-utilizing methanogens, uses hydrogen and carbon dioxide to produce methane (Turovskiy & Mathai, 2006).

Defining stability is a challenge; many researchers reported different ways in order to indicate stability, but there is no simple and direct definition of the term “stability.” The best way to control the anaerobic digestion process is through studying the anaerobic digester steady state besides defining the term ‘stability.’ Steady state was assumed to be occurring when digesters were operating at or near their controlled and fixed-variable design levels and when gas production and gas rates were relatively constant (Kroeker et al., 1979). Process stability is dependent upon maintenance of the biochemical balance between acid formers and methane formers while instability is usually indicated by a rapid increase in the concentration of volatile acids with a concurrent decrease in methane gas production (Kroeker et al., 1979). Cohen et al. (1981) have discussed the influence of phase separation on the anaerobic digestion stability. Methane reactors with one-phase system and two-phase systems were subjected to gradually increasing feed rate of glucose until the maximum load was reached. The results pointed to the fact that the stability of the two-phase reactor was more than one phase since all the VFA broke down immediately unlike the one-phase reactor (Cohen et al., 1981).

At any rate, the previous studies for stability are confusing since there are several situations that can play a significant role in the anaerobic process's stability. For example, does the stability of the digestion process depend on the digester temperature, mesophilic or thermophilic? Does stability depend on VFA concentrations or un-ionized VFA concentrations or alternatively, does it depend on ammonia toxicity, and what are the toxic concentrations to the microorganisms such as nitrogen? Clearly, defining stability is a challenge, because there is no simple and direct definition of the term "stability."

Failure to establish a reproducible digester stability metric(s) could result in catastrophic failure of the anaerobic digestion process as well as impairment in the discharged water quality.

In this study, the performance of a full-scale anaerobic digester operating at mesophilic temperatures (i.e., 36 °C or 98 °F) has been monitored for over one hundred (100) days. Collection and analysis of operational data from the anaerobic digesters at Central Weber Sewer Improvement District, Ogden, Utah, served as the scientific basis for defining stability. The goal of the study was to establish and quantify the range of specific operational parameters that could define digester operational stability. Enhancing the production of biogas from the digestion of sludge and other organic matter requires the development of a simple and cost-effective performance tool that can gauge the stability of the digester environment.

2. Objectives

(1) Collecting the digester's operational data including biogas production, percent methane in biogas, total solids, volatile solids destruction, influent and effluent chemical oxygen demand, digester pH, alkalinity, and volatile fatty acid concentrations in order to study steady digester operation.

(2) Using statistical analysis for the operational parameter behavior to determine a universal performance metric (stability index) that reflects steady state for the digester operation.

3. Background about Central Weber Sewer Improvement District

Central Weber Sewer Improvement District (CWSID) is located at 2618 West Pioneer Road, Ogden, Utah, 84404. It provides service for approximately 200,000 people in Weber and Davis counties. The plant was constructed in 1957. The existing treatment facility had a rated capacity of 45 million gallons per day (MGD), using a single-stage trickling filter process. Project upgrades completed in 2011, included construction of a new parallel 30-MGD activated sludge treatment plant, a new headwork's facility and a new raw sludge pump station. Focus was placed on value engineering directed at emerging areas of design where improvements could be made to reduce construction costs without affecting the process design or overall finished product.

The upgrades increased the treatment capacity to 70 MGD, supporting the District's goal of accommodating projected population growth in Davis and Weber Counties until 2025. The facility was also brought into compliance with current Environmental Protection Agency (EPA) and State of Utah regulatory requirements (CWSID, 2011).

4. Literature Review

One of the important parameters is the pH, which is defined as the negative logarithm of the hydrogen-ion concentration (Tchobanoglous et al., 2003). An important environmental parameter, pH indicates if the environment is healthy for the microorganisms in the anaerobic digester. The pH should be around neutral (or pH=7) according to McCarthy (1964), while Turovskiy & Mathai (2006) mentioned that the anaerobic microorganisms are sensitive to changes in pH lower than 6.8 and higher than 7.2. The pH inside the digester should be in the range of 6.8- 7.2 in order to keep the microorganisms in a healthy environment.

Due to the chemical reactions inside the anaerobic digester, the volatile fatty acids like acetic, propionic, valeric and butyric acids may accumulate as a result of a drop in the pH. The drop in the pH may occur because the carbon dioxide ranges between 30-50% of the produced biogas; the carbon dioxide may react with the water and form H_2CO_3, which leads to a drop in pH.

In case an insufficient buffer is present, the pH is subjected to a sudden drop, and that will affect the anaerobic digester's microorganism groups especially methanogensis. Methanogenesis archaea will not be able to convert the hydrogen and acetic acid to biogas and that will cause the accumulation of VFA.

The buffering capacity (alkalinity) of the system is important to avoid a sudden drop in pH. Alkalinity in water and wastewater results from the presence of hydroxide [OH^-], carbonate [CO_3^{-2}], and bicarbonate [HCO_3^-]. Alkalinity concentration is an important factor for the anaerobic digester; alkalinity in the range between 2000 to 4000 mg/L as $CaCO_3$ is typically required to maintain the pH at or near the optimum value for the anaerobic digester (Turovskiy & Mathai, 2006).

Another important parameter for the anaerobic digester is temperature. Usually anaerobic microorganisms are sensitive to the temperature in the anaerobic digester. Anaerobic digesters can be operated at different ranges of temperature like mesophilic (30-40°C), for best results. The important factor is to avoid sharp and frequent fluctuations in temperature in order to keep the methanogen microorganisms working in a healthy environment (Arsova, 2010).

Wang et al. (2009) discussed the effects of VFA concentration on methanogen microorganisms and methane yield within anaerobic digesters. The result from this study confirmed that, when the highest concentrations of ethanol, acetic and butyric acid were 2400, 2400 and 1800 mg/L respectively, there was no significant inhibition in the activity of the methane bacteria. However, when the propionic acid concentrations had been increased from 300 to 900 mg/L, a significant inhibition appeared, and due to that, the methanogens bacteria concentration decreased from $6*10^7$ to $1*10^7$ mg/L. Wang et al. (2009) also discussed the effects of VFA concentration on methane yield and methanogen microorganism; these effects demonstrated the accumulation of ethanol and VFA while methane yield becomes very low. Galert & Winter (2006) additionally examined the propionic acid accumulation and degradation during restart of full-scale anaerobic digesters. Their results confirmed that an increase in VFA due to the increase of the organic wastes between the periods of 7 to 28 days, leads to a decrease of methane gas and a drop in pH values from 7.5 to 7.1. During this period of the restart of the full-scale anaerobic reactor, the propionic acid reached its maximum concentration of 6.2 g/L; after 5 days the propionic acid was degradable completely and the pH increased from 7.1 to 7.4; and methane content increased from 60% to 65%.

Other researchers concluded that VFA themselves are toxic to methane archaea at concentrations above 2000 mg/L (Buswell and McKinney, 1962), while McCarthy confirmed that VFA were not toxic to methanogensis bacteria at concentrations that occur in malfunctioning digesters (1964).

Accumulation of propionic acid above 300 mg/L may affect the methanogens. On the other hand, if propionic acid concentration is less than 300 mg/L, that indicates the methanogens are not stressed and are functioning under good conditions (Gallert & Winter, 2006).

In the anaerobic digestion process, Chemical Oxygen Demand (COD) usually is the best way to track the energy flow during biological oxidation of sludge; the test uses oxidize agent to oxidize organic compounds to carbon dioxide.

COD mass balance can be used to account for the changes in COD during digestion. The COD removed in the anaerobic digester is accounted for by the biogas production as shown in the mass balance equation below:

$$COD_{in} - COD_{out} = COD\ (Biogas) \qquad (1)$$

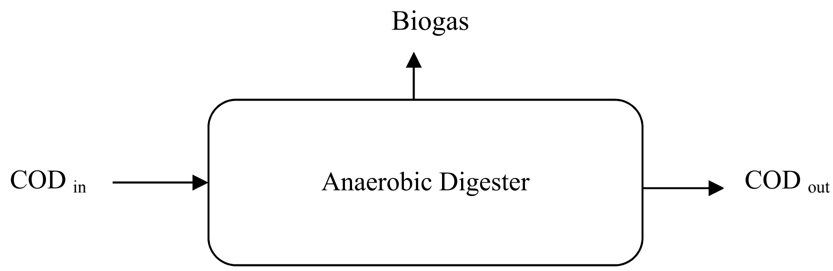

Figure 1. Schematic diagram for the flow through anaerobic digester

The COD mass balance equation is able to estimate methane production if other terms were measured.

Equation 1 is used to determine the methane gas production from the anaerobic digester at CWSID after COD removed was measured.

Sötemann et al. (2010) studied the steady-state model for the anaerobic digestion of sewage sludge, applying mass balance equation and measuring total COD from the sludge flow. The samples were taken from the influent and effluent side of the four laboratory reactors, using wastewater from a plant in Cape Town, South Africa. The results confirmed that 96, 100, 95, and 99% of the total COD had been recovered for the four lab reactors.

In this paper, the total COD concentrations and volatile solids in municipal (primary and secondary) sludge were monitored, in order to study the anaerobic digester performance at CWSID. Other important parameters were also measured for the same purpose (pH, alkalinity, VFA, and propionic acid). All the analysis and measurements are discussed in full detail.

5. Materials and Methods

In order to monitor the performance of the anaerobic digester operation, influent and effluent sludge samples were taken from a mesophilic digester operating at a 20-day hydraulic retention time. Duplicate influent and effluent sludge samples (ca. 500 milliliters) were analyzed for total solids; VS and COD twice per week using Environmental Protection Agency method (EPA, Method 1684). All sludge samples were collected in plastic bottles (500 milliliters) and mixed gently by inverting the bottles several times.

The percent total solids (TS%) consist of the solid residue remaining after the sludge sample had been evaporated and dried at 105°C. To measure percent total solids, approximately fifteen (15) milliliters of sample was placed on a pre-weighted fiberglass pad and then heated to 105°C (for 30 minutes) in a CEM microwave instrument (Model CEM001; Matthews, North Carolina). Percent volatile solids (VS%), which is the percentage of the total solids that can be volatilized at 550°C, was measured by taking the total solids sample and placing it in a muffle furnace set at 550°C for two hours (EPA, 2012). The remaining ash was measured and recorded to determine the percent volatile solids.

COD of influent and effluent sludge samples was measured using a spectrophotometer (HACH 8000), with accuracy ±5%.

In addition to total solids, volatile solids and COD, effluent sludge samples (ca. 500 milliliters) were taken twice a week to monitor digester pH, alkalinity, and volatile fatty acid concentrations. The pH was measured using a pH meter (Orion 001, Model 230 A-Cole Parmer, Inc. Vernon Hills, Illinois) that was calibrated using pH buffer solutions of 4 and 10 (sodium bicarbonate, RICCA Chemical Company). The accuracy of the pH meter was ±0.02 pH units. Alkalinity measurements were conducted according to Standard Methods 2320B using an automated titration system (METER TOLEDO, Columbus, OH) having an accuracy of ± 0.02 milligrams per liter as $CaCO_3$. Prior to the analysis, the pH meter was calibrated using 4, 7, and 10 buffer standards (potassium acid, potassium phosphate and sodium bicarbonate respectively).

Biogas generation (cubic feet per minute), percent carbon dioxide, and hydrogen sulfide concentrations in biogas were measured twice per week. Biogas was measured using a gas flow meter (Sierra instrument company Model 640S-NAA-L09-M1-E2-P3-V4-DD-5 L Monterey, CA 93940). To measure the concentration of carbon dioxide and hydrogen sulfide in biogas, a one-liter sample of biogas was collected from the digester using a sealed polyvinyl fluoride (PVF) TedlarTM sampling bag. Dragger tubes (model, D-23560, Lubeck, Germany) were used to measure the concentration of carbon dioxide and hydrogen sulfide in the biogas. The accuracy of the dragger tube was ±5% for both kinds of tubes.

To measure volatile fatty acids (VFA) (acetic, propionic, butyric and valeric), 500 milliliter sludge samples were taken from the effluent side of the digester. Total volatile fatty acids were measured using a distillation method technique number 5550 C (APHA, 2012). From the sample, 200 ml was centrifuged for five (5) minutes. After that, 100 milliliter supernatant liquid was placed in a 500-milliliter distillation flask. Next, 100 milliliters of distilled water was added to the solution along with 0.3 grams of Polytetrafluoroethylene (PTFE) boiling stones and 5 milliliters of 95.9% sulfuric acid. The solution was mixed by inverting the bottle upside down several times, and then 150 milliliters of solution was placed in a 250 milliliter graduated cylinder. The solution was titrated with 0.1N NaOH and expressed as acetic acid content.

Propionic acid was measured in effluent sludge samples two times every week. The sludge samples were collected in a plastic bottle (500 milliliters) and preserved at 5°C. Within 24 hours, the samples were measured for propionic acid using a ThermoFisherTM ICS-5000 chromatograph equipped with an AS18-4um, 4X150mm capillary column and a thermal conductivity detector. The standards used to determine the detection limits for the various acids ranged from 0.5ppm to 2ppm.

6. Results and Discussion

Table 1 shows the results for pH, alkalinity, propionic and VFA respectively during one hundred days of study.

The results show stable performance during the period of study since the average pH was 7.31±0.12, and alkalinity at 4113±229 mg/L as $CaCO_3$, which indicates stable and optimum performance for the digester. Moreover, average propionic acid was 29.38±7.89 mg/L, while the VFA average was 65.72±14 mg/L, which confirms the supreme performance of the digester at CWSID.

Table 1. pH, Alkalinity, Propionic and VFA results

Process	pH	Alkalinity as $CaCO_3$(mg/L)	Propionic (mg/L)	VFA(mg/L)
Day 1	7.40	4275.00	12.90	26.40
Day 3	7.46	3900.00	27.54	69.40
Day 8	7.32	3550.00	25.80	69.11
Day 10	7.25	3892.00	33.00	55.50
Day 15	7.43	4125.00	24.96	55.00
Day 17	7.39	4200.00	15.84	41.60
Day 22	7.21	4450.00	26.40	52.00
Day 24	7.26	4325.00	32.64	55.50
Day 29	7.34	4350.00	41.47	66.20
Day 31	7.30	3825.00	31.20	69.11
Day 36	7.39	4125.00	20.40	41.40
Day 38	7.39	3562.50	24.18	54.40
Day 44	7.30	3992.00	41.64	86.11
Day 46	7.42	4200.00	31.20	69.40
Day 52	7.39	4430.00	45.60	78.23
Day54	7.26	4120.00	30.60	72.25
Day 59	7.36	4245.00	24.84	69.40
Day 63	7.37	4075.00	33.30	80.30
Day 68	7.29	3994.00	33.00	70.50
Day 70	7.05	4275.00	22.59	76.98
Day 75	7.34	4170.00	29.16	78.19
Day 77	7.07	4215.00	23.64	65.34
Day 82	7.00	4214.00	30.11	81.18
Day 84	7.35	4200.00	42.26	80.35
Day 90	7.41	4140.00	30.18	79.21
Average	***7.31***	***4113.98***	***29.38***	***65.72***
SD±	***0.12***	***229.14***	***7.89***	***14.71***

Note: SD = Standard Deviation

Table 2. COD, Equivalent CH_4, Actual CH_4 and Percentage recovery

Process	[1]COD $_{inf}$ (mg/L)	[2]COD $_{eff}$ (mg/L)	[3] net COD (lb/L)	[4]Equivalent CH_4 (Ft^3/d)	[5]Actual CH_4 (Ft^3/d)	[6]Percentage %
Day 1	64930	30850	16371.49	102338.00	90923	88.85
Day 3	65610	33450	15449.15	96572.00	87043	90.13
Day 8	85160	24490	29144.90	182184.00	166011	91.12
Day 10	71294	24895	22289.34	139330.00	122821	88.15
Day 15	73000	23147	23948.58	149702.00	128999	86.17
Day 17	81245	27450	25842.26	161539.00	143999	89.14
Day 22	79745	25575	26022.40	162666.00	145003	89.14
Day 24	83230	27860	26598.86	166269.00	148215	89.14
Day 29	87450	32125	26577.24	166134.00	153031	92.11
Day 31	92090	33970	27919.92	174527.00	160762	92.11
Day 36	90950	33815	27446.74	171569.00	158037	92.11
Day 38	87845	29375	28088.05	175578.00	153035	87.16
Day 44	98400	31375	32197.74	201268.00	179413	89.14
Day 46	89175	35125	25964.76	162305.00	139859	86.17
Day 52	88067	34075	25936.89	162131.00	141315	87.16
Day54	85800	28295	27624.48	172680.00	157351	91.12
Day 59	77125	23200	25904.71	161930.00	145951	90.13
Day 63	81500	22890	28155.31	175998.00	158631	90.13
Day 68	68500	28875	19035.22	118980.00	107247	90.13
Day 70	84437.5	26925	27628.08	172703.00	152239	88.15
Day 75	74593	22754.5	24902.39	155664.00	138762	89.14
Day 77	96580	32393	30834.41	192745.00	173725	90.13
Day 82	91885	32916.5	28327.52	177075.00	159601	90.13
Day 84	91880	31883	28371.26	177505.85	160128	90.21
Day 90	90905	30831	28407.67	177733.66	161276	90.74
Average	***83255.86***	***29141.6***	***25959.57***	***162285.06***	***145335.08***	***89.51***
SD±	***9365.5***	***4029.20***	***3984.32***	***24914.64***	***22950.07***	***1.68***

Note: SD = Standard Deviation

The mass balance for COD has been calculated in order to determine the methane gas from COD (equivalent COD) and to compare it with the actual methane gas produced from the digester. As mentioned before, the actual gas has been measured using the flow meter. Percentage recovery between equivalent and actual methane was calculated as shown in Table 2.

The average percentage recovery was 89.51% ±1.68; the anaerobic digester was successful in producing a renewable energy (methane gas beside carbon dioxide) and converting the organic wastes (COD) to methane with 89.51% recovery. This ratio, (89.51%) of recovery, demonstrated the superior performance of the digester and also demonstrated the stability and steady state for the anaerobic digester.

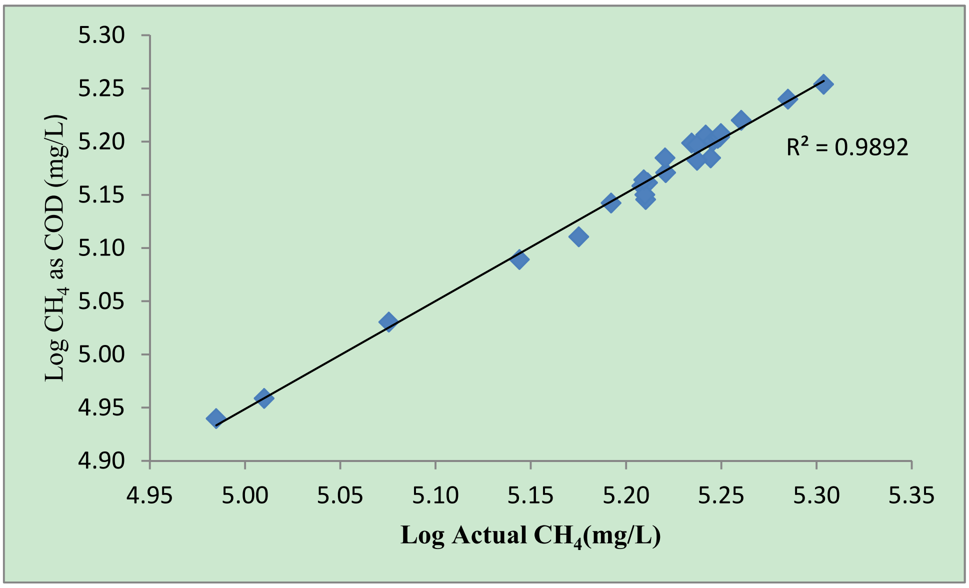

Figure 2. The relationship between theoretical (CH_4 as COD) and actual methane gas

Figure 2 shows the relationship between theoretical (CH_4 as COD) and actual CH_4; linear relationship and high correlation between the two variables were noticed. The data was transformed to log transformation to improve data interpretability. The difference between the two averages has been calculated by applying t-test function using R programming.

At 99.96% confidence, there was no difference between theoretical and actual mean of the methane determined and produced, demonstrating the steady state and stability of the anaerobic digester at CWSID.

The percentage of VS destroyed (ΔVS) was determined and converted to equivalent CH_4 during the period of study; the results and percentage recovery of methane gas were determined and displayed in Table 3.

Table 3. Equivalent CH_4, Actual CH_4 and percentage recovery results

Process	CH_4 as VS (L/d)	Equivalent CH_4 (Ft^3/d)	Act CH_4(Ft^3/d)	Recovery %
Day 1	2,982,435.00	105,386	90923	86.28
Day 3	2,853,506.22	100,831	87043	86.33
Day 8	4,850,354.40	171,391	166011	96.86
Day 10	3,994,021.14	141,131	122821	87.03
Day 15	3,935,884.01	139,077	128999	92.75
Day 17	4,233,591.29	149,597	143999	96.26
Day 22	4,194,233.60	148,206	145003	97.84
Day 24	4,579,952.00	161,836	148215	91.58
Day 29	4,745,208.00	167,675	153031	91.27
Day 31	5,076,446.40	179,380	160762	89.62
Day 36	4,703,089.51	166,187	158037	95.10
Day 38	4,987,000.00	176,219	153035	86.84
Day 44	5,876,765.00	207,660	179413	86.40
Day 46	4,621,902.20	163,318	139859	85.64
Day 52	4,825,382.17	170,508	141315	82.88
Day54	4,533,550.27	160,196	157351	98.22
Day 59	4,911,462.28	173,550	145951	84.10
Day 63	4,621,902.20	163,318	158631	97.13
Day 68	3,726,590.32	131,682	107247	81.44
Day 70	4,396,687.40	155,360	152239	97.99
Day 75	4,848,107.33	171,311	138762	81.00
Day 77	4,963,958.00	175,405	173725	99.04
Day 82	5,392,226.00	190,538	159601	83.76
Day 84	5,187,218.00	183,294	160128	87.36
Day 90	4,678,750.00	165,327	161276	97.55
Average	***4548808.91***	***160735.30***	***145335.08***	***90.41***
SD±	***675158.30***	***23857.18***	***22950.07***	***6.01***

Note: SD = Standard Deviation

The mass balance for the ΔVS was calculated; the equivalent amount of methane gas from ΔVS has been calculated, and the percentage recovery was determined. High percentage recovery was noticed (90±6) %. This result confirmed again the stability and the steady situation of the digester. The relationship between actual and equivalent methane is plotted in Figure 3.

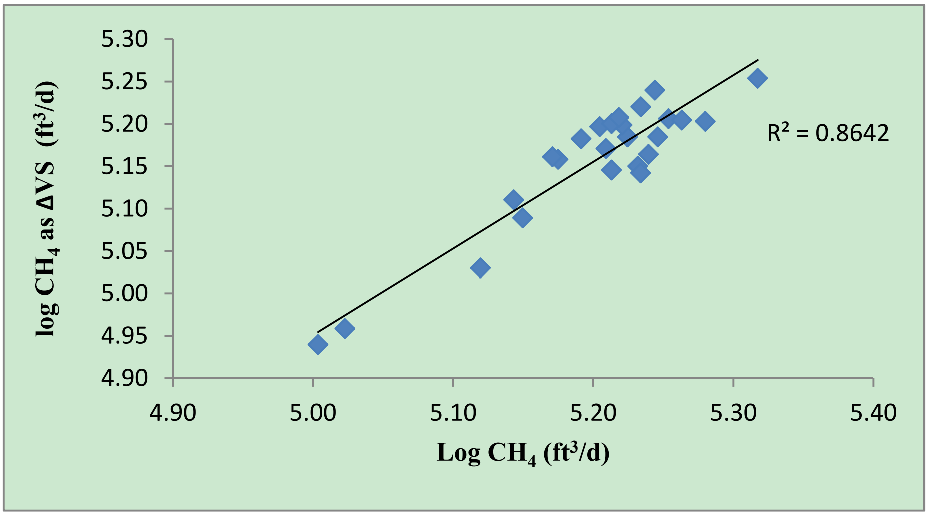

Figure 3. The relationship between theoretical (CH_4 as ΔVS) and actual CH_4

Linear relationship with strong correlation was demonstrated, t-test using R programming was applied in order to determine the difference between the two averages. At 96% confidence, there was no difference between the two means, which leads the research to confirm the stability and steady state of the digester.

Stability means stable performance during period of time. For more clarification about the stability of the digester at CWSID, Figure 4 below shows the variations of the pH, alkalinity, propionic, VFA and COD, respectively, and was plotted with time (days) to study the anaerobic digester stability.

Figure 4. pH, alkalinity, Propionic acid, VFA and COD variation with time

In Figure 4, there is no significant variation noticed for the monitored parameters (pH, alkalinity, propionic acid and COD) over time; all parameters vary within the allowable range for each parameter. For example, maximum pH was 7.46, and minimum pH was 7.0. Alkalinity readings vary between 3500mg/L to 4450mg/L. Accordingly, pH is considered neutral, and the alkalinity results reflected strong buffering capacity to the change in pH inside the digester. Moreover, stable variation in both VFA and propionic acid within the period of time was noticed, which demonstrates the stable rate of converting these intermediate products to acetic acid and hydrogen. The stable rate of conversion keeps the dynamic relationship between the acidogensis bacteria and the methaongensis archaea in good status.

The digester is considered to be at a steady-state condition because it was operating at or near the controlled and fixed-variable designed levels. Furthermore, gas production rates were relatively constant during the period of study. According to that, a universal metric function was determined to define the anaerobic digestion stability. The rate between methane gas produced from the digester and ΔVS in liter per gram has been determined during one hundred days of study as shown in Table 4. Daily rate of (0.40±0.017)L/g has been remarkable, which demonstrates that stability is achievable as long as the constant rate of (0.4±0.017)L/g is reached or maintained.

The rate of CH_4/ΔVS (L/g) can be used as a universal metric to indicate the stability of the anaerobic digester as applied at CWSID. Because ΔVS and methane gas are required to be measured daily at the wastewater treatment facilities, only two parameters can be used to examine the stability.

In Table 4 the rate has been calculated and plotted with propionic acids that are shown in Figure 5.

Table 4. Stability index (CH_4/ΔVS (L/g)) and propionic acid results

Process	CH_4/ΔVS(L/g)	Propionic (mg/L)
Day 1	0.439	12.90
Day 3	0.400	27.54
Day 8	0.404	25.80
Day 10	0.391	33.00
Day 15	0.407	24.84
Day 17	0.436	15.84
Day 22	0.400	26.40
Day 24	0.394	31.200
Day 29	0.388	41.64
Day 31	0.397	30.60
Day 36	0.430	20.40
Day 38	0.420	24.18
Day 44	0.388	42.26
Day 46	0.395	31.20
Day 52	0.386	45.60
Day54	0.398	30.18
Day 59	0.415	24.96
Day 63	0.391	33.30
Day 68	0.394	32.64
Day 70	0.429	22.59
Day 75	0.400	29.16
Day 77	0.424	23.64
Day 82	0.391	33.6
Day 84	0.389	41.47
Day 90	0.391	33.00
Average	***0.404***	***29.51***
SD±	***0.017***	***7.93***

Note: SD=Standard Deviation

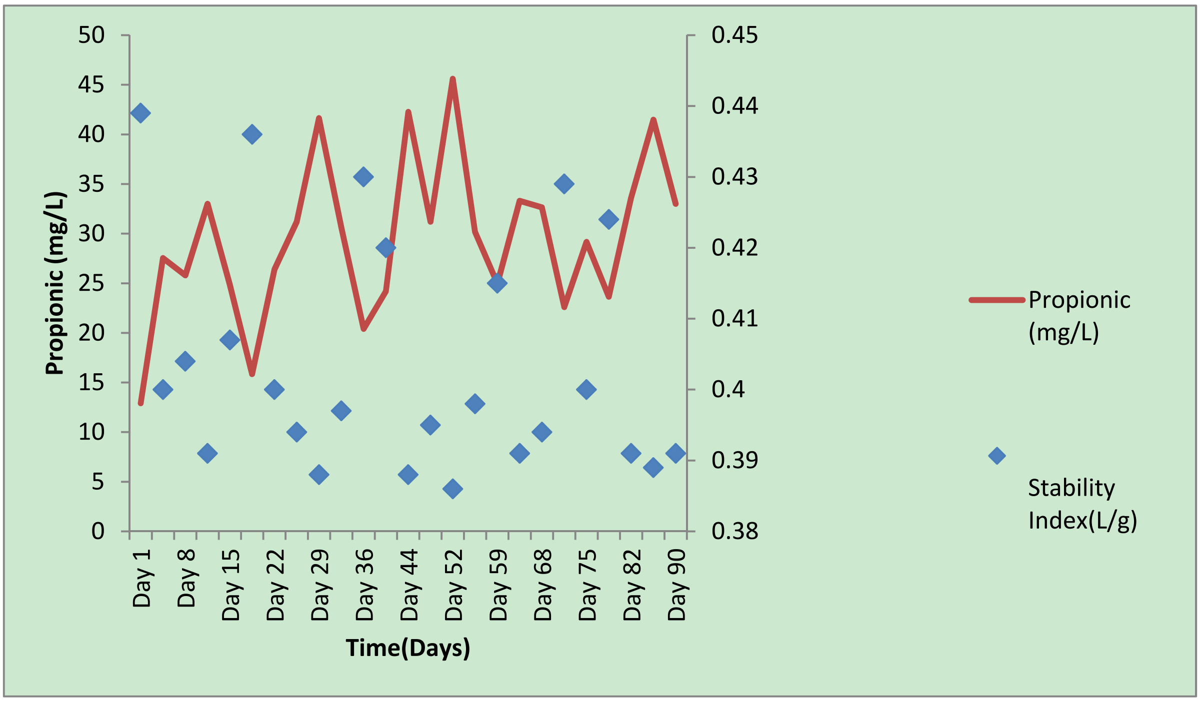

Figure 5. The relationship between propionic acid and stability index during the study

Direct relationship between the stability index ($CH_4/\Delta VS$) and propionic acid was observed, as shown in Figure 5. Inverse proportion between the two variables was noticed. An increase in propionic acid will affect the rate of methane gas produced per ΔVS ($CH_4/\Delta VS$). However, the increase in the stability index indicates low accumulation in the propionic acid inside the digester. Methanogensis archaea may get stressed partially when propionic acid accumulates and reaches 45 mg/L, which causes the low stability index readings as shown in Figure 5.

7. Conclusion

In this paper, full-scale anaerobic digester stability at CWSID was tested and monitored during one hundred days of study. The municipal primary mixed with secondary sludge was characterized as COD.

Snap shots of the anaerobic digester parameters during the period of study were monitored. The COD mass balance was applied to the anaerobic digester in order to study its stability and its capability of producing methane gas. The anaerobic digester mass balance showed promising results in terms of wastewater treatment and energy production. There was a 10% loss of the methane gas (the best gas recorded was 90% of the organic wastes loaded). Mass balance of ΔVS was calculated, and 91% recovery was possible. Essentially, this research indicates that anaerobic digesters are a good source of renewable energy.

The monitored parameters for the anaerobic digester were pH, alkalinity, VFA, and propionic acid. All the results confirmed a superior performance for the anaerobic digester.

Finally, at mesophilic temperature and steady state performance, anaerobic digester stability has been defined as a constant rate of methane produced per substrate of ΔVS (average rate = 0.40 L/g). This definition (the stability index) can be used as a new and inexpensive way to define and examine the anaerobic digestion stability. Since defining “stability” was considered an initial problem, this research also furthered the ability to define or redefine it more simply by using the consistent results of this study.

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