High Solids Anaerobic Digestion of Municipal Biosolids Pretreated by Thermal Hydrolysis

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Abstract

Anaerobic digestion of high solids municipal biosolids is feasible after pre-treatment that reduces the viscosity of biosolids and increases the fraction of soluble organic matter. The process is stable at organic loadings of up to 6 Kg VS/m^3 and hydraulic retention times of 9 to 12 days, can achieve more than 60% volatile solids destruction and produce more than 3 $m^3 CH_4$/ m^3.d, significantly increasing the treatment capacity of existing digesters or, in treatment plants without spare capacity helping postpone, reduce or even avoid costly infrastructure investments. Current pre-treatment technologies need to be optimized for high-solids single-stage mesophilic anaerobic digestion to show stable operation at 6-8d HRT with superior overall VS destruction and gas production, or the more complex to operate high-solids temperature-phased anaerobic digestion process must be employed in which further solubilization of organic matter occurs in the thermophilic stage for the mesophilic stage to operate at short hydraulic retention times.

Keywords: Ammonia toxicity, high-solids anaerobic digestion, mesophilic and temperature-phased anaerobic digestion, thermal hydrolysis pre-treatment

Introduction

Wastewater treatment plants generate biosolids as a by-product. Raw biosolids are a combination of settled sewage solids and excess biomass generated during secondary treatment of wastewater. Prior to their disposal or reuse, regulations require that biosolids be processed to reduce vector attraction and to inactivate pathogens. In the majority of wastewater treatment plants in North America and Europe, fermentation of biosolids in the absence of oxygen or anaerobic digestion (AD) has been the process of choice for this purpose for several decades because it is a relatively simple, stable process that yields methane gas that can be harvested thus recycling a portion of the energy in biosolids as heat and power.

AD is typically carried out at mesophilic temperatures in a single stage with long hydraulic retention time (HRT) of 15 days or more to ensure process stability and consistent performance while reducing cost of implementation and complexity of operation. Design HRT is controlled by the particulate nature of biosolids which, to become available as substrate to fermentative biomass and be transformed to mainly methane and carbon dioxide, need to undergo a slow, enzyme-mediated hydrolysis step. The particulate nature of biosolids also put a practical limit of around 5% total solids (TS) to the maximum solids concentration that can be processed in AD operations since mixing, heat transfer and pumping all become inefficient and non cost-effective due to high viscosity of the raw biosolids slurry at greater total solids contents.

Pre-treatment of raw biosolids that reduced their viscosity and increased the availability of organic substrate to the fermentative biomass would make possible the realization of high solids AD (Richards, *et al*., 1991) which could significantly increase the treatment capacity of a given reactor and in treatment plants without spare capacity help postpone, reduce or even avoid costly infrastructure investments. In addition, high solids AD could make the stabilization and disinfection of biosolids more efficient and less costly to build and operate thus perhaps changing the dynamics from centralized biosolids handling facilities which require expensive piping and pumping networks and are inherently environmentally discriminatory to a more decentralized model of biosolids management, or create new opportunities to generate revenue streams by importing external biosolids.

Technologies that can achieve this goal include:

- Sonication: Application of energy in the ultrasound frequency (typical operating frequency of 20 KHz) results in the formation, growth and eventual violent collapse of cavitation bubbles which generate intense local heating and high pressure on the liquid-gas interface, high shearing and turbulence in the liquid itself and form free radicals (Lehne, *et al*., 2001).
- Ozonation: Application of ozone at concentrations up to 0.5 g/g TS generates hydroxyl radicals, which rapidly oxidize dissolved and particulate organic matter in biosolids (Battimelli, *et al*., 2003).
- Thermal hydrolysis: Application of heat to 100-175 ^{o}C for 30 minutes followed by release of reactor pressure that generate shear force that can cause cells to rupture and, in combination with the initial pressure/heating step, contributes to the almost complete disintegration of sludge flocs (Haug, *et al*., 1978).
- High pressure homogenization: Alkaline pretreatment to weaken cell membranes followed by intense pressure gradient to burst cells (Stephenson, *et al*., 2004).

Although a few reports exist that describe pilot- and full-scale AD installations that incorporate some of these pre-treatment technologies (Kepp, *et al*., 2000; Skiadas, *et al*., 2005), little or no process data is available for high solids applications. Therefore, the operational limits of high solids AD and whether it may be a stable and reliable process is not known, in particular, in novel configurations such as the temperature-phased anaerobic digestion (TPAD) process which has been shown to enhance biosolids stabilization and disinfection when compared to single-stage mesophilic AD (Schafer, *et al*., 2003).

Objectives

The objectives of the pilot study were to demonstrate the feasibility of high solids anaerobic digestion of municipal sludge after thermal hydrolysis pre-treatment; to compare the potential for biosolids stabilization and gas production of high-solids, single-stage mesophilic and temperature-phase anaerobic digestion; and to analyze process performance during steady state operation.

Materials and Methods

The high solids anaerobic digestion options investigated included:

1. THMAD: A TH (170°C) pre-treatment step with 25 minutes contact time followed by mesophilic anaerobic digestion (MAD) with 12-15 days HRT.

2. THTPAD: A TH (170°C) pre-treatment step with 25 minutes contact time followed by temperature-phased anaerobic digestion (TPAD) with 9-15 days combined HRT.
3. Control: MAD and TPAD without TH pre-treatment with 15 days HRT.

Temperature of the MAD process was kept at 36±1 °C for all reactors whereas those of the TPAD process were maintained at 55±1 °C in the thermophilic stages and at 35±1 °C in the mesophilic stages.

A semi-automated pilot plant (Figure 1) was built that included four egg-shaped digesters with capacities of 113 and 227 liters. One 113-liter and one 227-liter digesters were plumbed and operated in series in the TPAD and THTPAD modes. The other 113-liter digester operated the THMAD process whereas the other 227-liter vessel was the control MAD digester.

All of the digester vessels were made of 0.3 cm thick steel sheet, and included stands. The stands allowed bolting to the floor and supported the reactor's weight when full. The vessel body consisted of a cylinder and two cones, one cone welded on top (30^o slope) and one at the bottom (60^o slope) of the cylinder. All ports were 2 cm half nipples (threaded) soldered onto the body. Vessels withstood 0.5 m WC interior pressure. The overflow line ran 30 cm below the liquid level. A liquid overflow collection box was installed on each digester for level control.

Mixing and heating was achieved through external pumping. The outlet port was located at the bottom of the lower cone while two inlet ports were located on top, one on each side of the upper cone. Four heat exchangers were used, one for each digester. Each heat-exchange system had a 40 cm heat exchanger coil made of 1.2 cm ID (1.6 cm OD) stainless steel piping. The diameter of the coil was 50 cm, and the length of the coil piping was 3 m. The heat exchangers were submerged in water baths which temperature was controlled automatically. Flow rates of 230-460 l/h were necessary to ensure sufficient heat transfer to maintain proper mesophilic or thermophilic temperatures in the reactors, which resulted in the pilot digesters being turned over 48 times per day.

Each digester had a gas outlet located at the top of the digester. Digester gas leaves the vessels through a U-Leg of 0.6 m to build enough pressure (0.4 m WC) to drive the wet-tip positive displacement gas meters. Each meter tripped at about 130 ml and can handle 700 liters per day of gas production. The tippers have an accuracy of ± 1 ml. The gas meters operated with a cyclic pressure buildup starting at about 5 cm of WC and built up to about 20 cm of WC and then expelled the gas and returned to the start of the cycle again.

Thermal Hydrolysis Prototype. Thermal hydrolysis was achieved by injecting live steam to thickened combined primary and waste activated sludge (CPAS) in a 2-liter reactor to maintain a temperature of 170 ºC for 25 minutes, after which pressure was released instantaneously by transferring sludge into an non-pressurized flash tank and holding it until cooling to less than 100 ºC. An electric steam boiler was used to provide instantaneous and reserve steam capacity. The boiler provided steam at 200ºC and 10 bar to the thermal hydrolysis unit.

Pilot Plant Operation. Digester feed pumps were controlled by automatic timers. Each digester had its own time switch, which was programmed individually to feed the digesters at a specified rate. Table 1 summarizes the digester feed rates during steady state operations. Control MAD and TPAD digesters were fed CPAS from the Southeast Water Pollution Control Plant (SEP) in San Francisco, CA. THMAD and THTPAD digesters were fed dewatered and hydrolyzed CPAS (HCPAS).

The TH and control digesters were allowed to reach steady state for at least 45 days or three hydraulic residence times before process performance data was collected. For all other tested processes, steady state was assumed after 30 days of operation. However, data was collected since start-up to gain information on the transitional performance of the different processes. In addition, the THMAD and THTPAD digesters were operated for approximately three weeks at a hydraulic residence time of 20 days to allow for acclimation of the bacterial seed from the full-scale mesophilic digesters at the SEP to the new feed quality and rate.

Routine parameters monitored in the influent streams included total and volatile solids and soluble and total COD whereas parameters monitored in the digested streams included total and volatile solids, soluble and total COD, ammonia, fecal coliforms, total volatile fatty acids, pH and total alkalinity. All analyses were performed according to Standard Methods (APHA, 1998). In addition, daily gas production and CO_2 content of the gas by the ferryte method were recorded.

Results

Thermal hydrolysis of CPAS resulted in a significant increase in sCOD concentrations (Figure 2) from a range of 8-10 g/L for CPAS to 18-30 g/L for HCPAS at comparable TVS concentrations and the sCOD/COD fraction increased from 0.16 to 0.25 for samples ranging from 3 to 11% TS. However, although there is a strong positive correlation (r=0.9) between COD and TVS of both CPAS and HCPAS samples, sCOD is not a function of TVS for any of the two streams and sCOD concentrations in HCPAS remain practically constant for TVS concentrations of 6% or higher.

Digester loadings for the various processes tested are presented in Figure 3. THMAD and control TPAD thermophilic digesters were similarly loaded at between 4 and 6 Kg VS/m^3.d due to high feed concentration (THMAD process) and reduced HRT (TPAD thermophilic stage). Control MAD and TPAD mesophilic digesters loading rates ranged from 1.4 to 2.2 Kg VS/m^3.d, typical of established US design practices. For THTPAD digesters operated at a combined HRT of 15 days, which combined high solids feed and reduced HRT, loading rates were significantly higher, with THTPAD thermophilic digester loading rates ranging from 9 to 15 Kg VS/m^3.d and from 4 to 6 Kg VS/m^3.d for the THTP mesophilic digester.

Despite organic loading rates 3 to 4 times higher than typical US practice, all high solids AD processes tested and TPAD were stable and achieved comparable or higher volatile solids destruction than the control MAD (Figure 4). Table 2 summarizes operational data for all tested processes during steady state operation.

THMAD digester initially showed a high Total Volatile Acids to Alkalinity (TVA/Alk) ratio of 0.4 compared to a ratio of 0.1 or less for the control MAD but, after four weeks of operation, converged with control MAD ratios suggesting an acclimating period of the anaerobic digestion bacterial consortium to the different feed quality and quantity to the THMAD digester. Similarly, an acclimation period was apparent for the control TPAD process, longer for the thermophilic than the mesophilic stage, likely as a result of the higher operating temperature and loading conditions of the former. In the THTPAD process, the mesophilic digester also presented TVA/Alk ratios around 0.1 during steady state operation, but this parameter ranged between 1.2 and 1.6 for the thermophilic stage in response to the very high loading rates, in particular at 3-day HRT when pH measurements consistently dropped below the neutral point. All other digesters had pH values between 7.1 and 7.9

During steady state operation at 15 days HRT, VS destruction in the control MAD digester ranged 50-55%, typical of full-scale anaerobic digestion processes while the THMAD process achieved comparable results (Figure 4). When HRT for the THMAD process was reduced to 12 days at the beginning of December 2001, however, VS destruction dropped to around 45% and TVA concentrations increased slightly suggesting that the digester did not have much reserve capacity. Control TPAD and THTPAD processes, on the other hand, achieved VS destruction higher than 65% during steady state operation at 15 days overall HRT (Figure 4). THTAP digesters overall HRT was reduced to 12 days without observable reduction in VS destruction (Figure 4) suggesting that the process may be resilient to shock loadings, although the feed TS concentration during this period was somewhat lower. In control TPAD process, VS destruction in the thermophilic stage ranged between 20 and 30% and the mesophilic stage removed the remainder up to the overall observed 60-70% VS destruction. However, in the THTPAD process, the thermophilic stage destroyed between 20 and 40% of incoming VS, the mesophilic stage VS removal rate was comparable to that of the control TPAD and, consequently, the overall THTPAD VS destruction was slightly higher that the TPAD process. This observation would suggest great flexibility in the THTPAD process with the first stage performance being dependent upon the feed composition and rate and the second stage being able to adjust to fluctuations in transfer sludge quality for an overall stable and steady performance.

Although the fraction of influent organic matter destroyed by the various AD processes tested differed by relatively small values, the mechanisms involved appear to be quite different (Figure 5). The control MAD and THMAD processes behaved similarly with approximately 25% of the total COD removed corresponding to the sCOD fraction, suggesting that the increased organic loading to the THMAD digester did not significantly impact the bacterial consortium responsible for MAD beyond concentrating it from 2% to 4% TS and thus approximately doubling the amount of organic matter digested to methane and carbon dioxide in THMAD. Therefore, the higher fraction and amount of sCOD present in HCPAS helps develop and support more biomass in the digester to allow for the higher rate of organic loading of the THMAD process as compared to the control MAD, but does not increase the rate of destruction of organic matter which rate limiting step is still the solubilization of particulate organic matter.

In the control TPAD process, the thermophilic stage was a net generator of sCOD, which gets formed at the expense of particulate COD, but also removed a great deal of total COD and functioned mostly as a methanogenic digester (Table 2) despite the reduced HRT and increased organic loading. The mesophilic stage mimics the performance of the control MAD and THMAD albeit at a reduced HRT (10 d compared to 5 d for control MAD and THMAD), likely due to the increased sCOD fraction generated in the thermophilic stage. The THTPAD thermophilic stage converted particulate into soluble COD at approximately half the rate it removed total COD and thus, when compared to control TPAD, hydrolysis of organic matter was much enhanced to the detriment of methane evolution. On the other hand, about 40% of the total COD removed in the mesophilic stage was in the form of sCOD as a result of the combined increases in sCOD and digester biomass (between 3 and 4% TS), which helps explains the higher degree of overall organic removal when compared with the control MAD process but also the remarkable stability of the THTPAD process at reduced overall HRT of 9 to 12 days (6-8 days for the mesophilic stage).

Gas production fluctuated over the course of the study owing to the fact that analyses were carried out three times a week whereas gas evolution was measured continuously. However, specific gas production for control MAD, THMAD, control TPAD and the THTPAD mesophilic stage was mostly stable and ranged between 800 and1100 liters per kilogram of VS destroyed (600 to 800 L/Kg VS destroyed for the thermophilic stage of THPAD), an indication that uninhibited digestion was taking place during steady state. Methane content in the gas ranged between 64 and 72%. Gas production from the thermophilic digester for THTPAD was lower and ranged between 400 and 600 liters per kilogram of VS destroyed, likely due to ammonia inhibition (Liu and Sung, 2001) and low pH. Methane content in the gas exceeded 60%. Owing to these results and the observed VS loading and destruction rates for the various processes tested, gas production per unit volume of digester capacity for all processes is presented in Table 3. Control TPAD and THTPAD processes increased gas production by 30 to 40% over their control MAD and THMAD counterparts whereas gas production of high solids anaerobic digesters (i.e., THMAD and THTPAD processes) exceeded that of the controls by more than 100%.

Table 4 provides a comparison of biosolids treatment and handling performance with MAD (data for 2005) and THTPAD (projected from results from this study) for the SEP, which pure-oxygen activated sludge system treats an average daily flow of 10,000 m^3/h. For the SEP, implementation of the THTPAD process would result in a 23% increase in VS destruction, a 44% reduction in biosolids hauling and disposal costs and a 30% increase in energy generation from biogas.

Discussion

High solids anaerobic digestion is an attractive option for the design of biosolids handling facilities in highly urbanized areas where land is at a premium, the cost of hauling and reuse of the end product is elevated and energy is a highly valuable commodity. It should also be of great interest as a means to defer costly capital improvements for AD facilities with capacity and, therefore, compliance problems. As shown by the results of this research, it is also technically feasible since typical operating parameters for conventional MAD and TPAD also generally apply to the high solids versions of these processes. However, the mineralization of organic carbon in high solids processes is rendered more efficient, and therefore can be accomplished at higher rates, by the increase in biomass in the digesters and the solubilization of particulate matter during the pre-treatment of raw biosolids. Mass loading of anaerobic digesters can thus be at least tripled from conventional organic loading rates for conventional MAD digesters without negative effects on process performance thus generating significant savings in necessary digester capacity and ancillary equipment (e.g., for pumping, mixing, heating and dewatering biosolids) at the cost of installing raw sludge pre-treatment and adding complexity to the overall process. Similarly, methane gas generation also doubles (in THMAD) or triples (in THTPAD) per unit volume of digester capacity installed in high solids AD when compared to conventional MAD, adding to the perceived advantages of the process.

Although more complex to operate, THTPAD appears to be superior to THMAD in its ability to stabilize biosolids and produce biogas at an HRT of 15 days, paralleling how conventional MAD and TPAD compare. THTPAD also appears to be more stable and should clearly be the option of choice when high solids anaerobic digestion processes are considered. At an overall HRT of 9 days, the THTPAD was still capable of consistently achieve a 55%VS destruction although the mesophilic stage was being operated close to the washout rate for methanogens of 5 days (Li and Noike, 1992). The extremely high organic loading rate to the thermophilic stage of the THTPAD process (9 to 15 $kgVS/m^3d$) appears to shift its performance to that of an acid digester with high concentrations of volatile fatty acids and acidic pH, resulting in a net production of sCOD across this stage. Thus, the THTPAD process would benefit from a segregation of functions with the thermophilic stage mostly carrying out hydrolysis and solubilization of particulate COD and the mesophilic stage doing the bulk of the methanogenesis. The literature abounds with examples (Gosh, *et al*., 1995; Alexiou and Panter, 2004) describing the benefits of two-phase digestion for biosolids stabilization. The net result is increased destruction of organic matter and thus production of biosolids that are going to be more stable upon disposal or recycling and increased evolution of methane gas.

Pre-treatment of raw biosolids increased the fraction of sCOD and made possible the higher organic loadings of THMAD by developing and sustaining an increased amount of biomass in the digester after a period of acclimation of a MAD biological seed to the new feed quality and rate by operating the digester at a HRT of 20 days for 3 weeks. As acclimation was gradually achieved, TVA to alkalinity ratios for the THMAD process converged with those of the control MAD digester, but TVA, alkalinity and ammonia concentrations were approximately twice as much in the THMAD digester than in the control MAD as were the total solids. Therefore, contrary to information published elsewhere (Kepp, *et al*., 2000; Jolis, *et al*., 2002), given the results in Figures 4 (similar VS destruction for control MAD and THMAD) and 5 (identical ratios of sCOD/tCOD removed for control MAD and THMAD), the above information suggests that THMAD is a concentrated MAD process subjected to its limitations with respect to the rate limiting step (hydrolysis of particulate matter), extent of VS destruction or minimum HRT for stable operation.

This is mostly caused by the leveling off of sCOD content in HCPAS for TS concentrations above 6-7% which results in soluble to total COD ratios for HCPAS with TS content of 7-10% and CPAS with TS content of 2.5-4.5% to similarly range between 0.15 and 0.3. This outcome may have been affected by the usage of a low efficiency pilot scale thermal hydrolysis unit as compared to full-scale systems and by employing CPAS for the tests as no benefits in sludge degradability should be expected for pre-treatment of primary sludge (Clark and Nujjoo, 2000) while energy is being consumed. However, reported COD removal results (Kepp, *et al*., 2000) for the HIAS Wastewater Treatment Plant, Hamar, Norway, which incorporates thermal hydrolysis of combined primary and activated sludge compare well at 52-59% at 17d HRT with observed results of 50-56% at 15d HRT in this study, and strongly suggest that thermal hydrolysis pre-treatment is not efficient enough at solubilizing particulate COD to promote stable high solids (e.g., 8-12% TS feed) MAD operation at short HRT (less than 10 days) and achieve superior VS destruction and methane gas production as demonstrated for thermally pre-treated WAS (Li and Noike, 1992). Existing pre-treatment technologies need to be optimized or new approaches developed before this goal can be achieved, or the more complex and expensive to operate high solids THTPAD process must be employed as the thermophilic stage produces sufficient sCOD for the mesophilic, methanogenic stage to show stable operation at 6-8d HRT with superior overall VS destruction and gas production. On the other hand, pre-treatment of raw sludge remains critical in reducing the viscosity of the feed that increases the efficiency of pumping, mixing and heat-exchange operations that make the THMAD and THTPAD processes technically feasible.

THMAD did not show signs of ammonia toxicity although concentrations of total ammonia as nitrogen (TAN) exceeded 2g/L. Thus, methane production was uninhibited and ranged around 1 m^3/ Kg VS destroyed whereas %VS destruction and VFA/Alk ratio values were comparable to those of control MAD. However, inhibition of gas production may have been observed in the thermophilic stage of the THTPAD process, which may be explained in part by TAN concentrations in excess of 2 g/L. Since the concentrations of free ammonia for the range of observed pH values for the thermophilic stage were below 150 mgNH_3-N/L, an accepted threshold for the onset of toxicity caused by free ammonia (McCarty and McKinney, 1961), the high levels of ammonium ion (Liu and Sung, 2001) most likely contributed to the observed reduced gas production, since the threshold for ammonium ion inhibition to thermophilic cultures has been shown (Lay, *et al*., 1998) to be lower than that for mesophilic-tolerant bacteria. However, the acidic pH of the thermophilic stage of THTPAD could have also affected gas production, since gas production and methane content of gas from acid digesters tend to be lower than that of methane digesters (Gosh, *et al*., 1995).

Conclusions

After a pre-treatment step that reduces sludge viscosity and increases the fraction of soluble COD, high solids anaerobic digestion is stable, produces highly stabilized biosolids suitable for reuse and more than doubles biogas generation when compared to conventional mesophilic digestion. High solids temperature-phased anaerobic digestion was found superior to single-stage mesophilic digestion with respect to process flexibility, biosolids stabilization and biogas generation because significant solubilization of particulate organic matter occurs in the thermophilic stage that allows the mesophilic methanogenic stage to operate efficiently at hydraulic residence times of only 6 days. Ammonia inhibition of methanogens was not observed in high solids mesophilic anaerobic digestion but some effect was apparent at thermophilic temperatures as measured by a decrease in biogas evolution.

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Figure 1. Pilot Plant Schematic

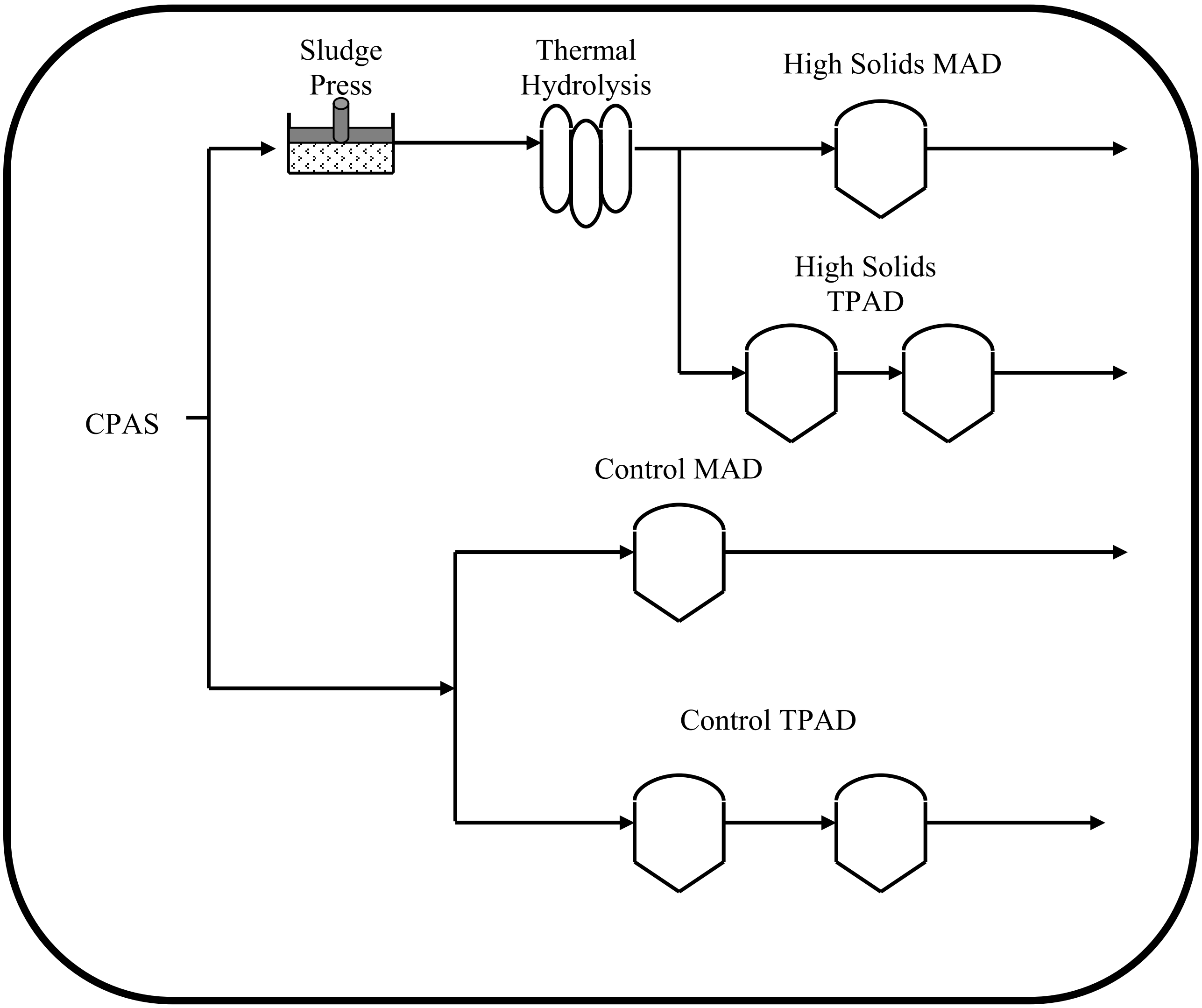

Figure 2. Total and Soluble COD Concentrations for CPAS and HCPAS

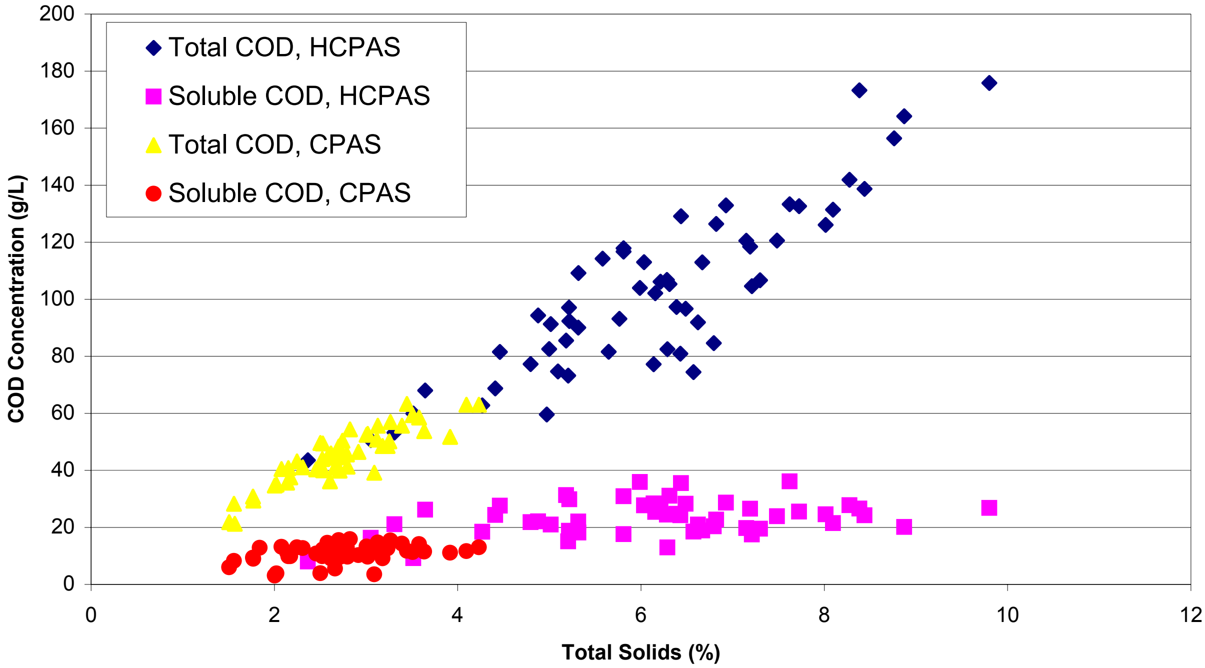

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Figure 3. Total Volatile Solids Loading

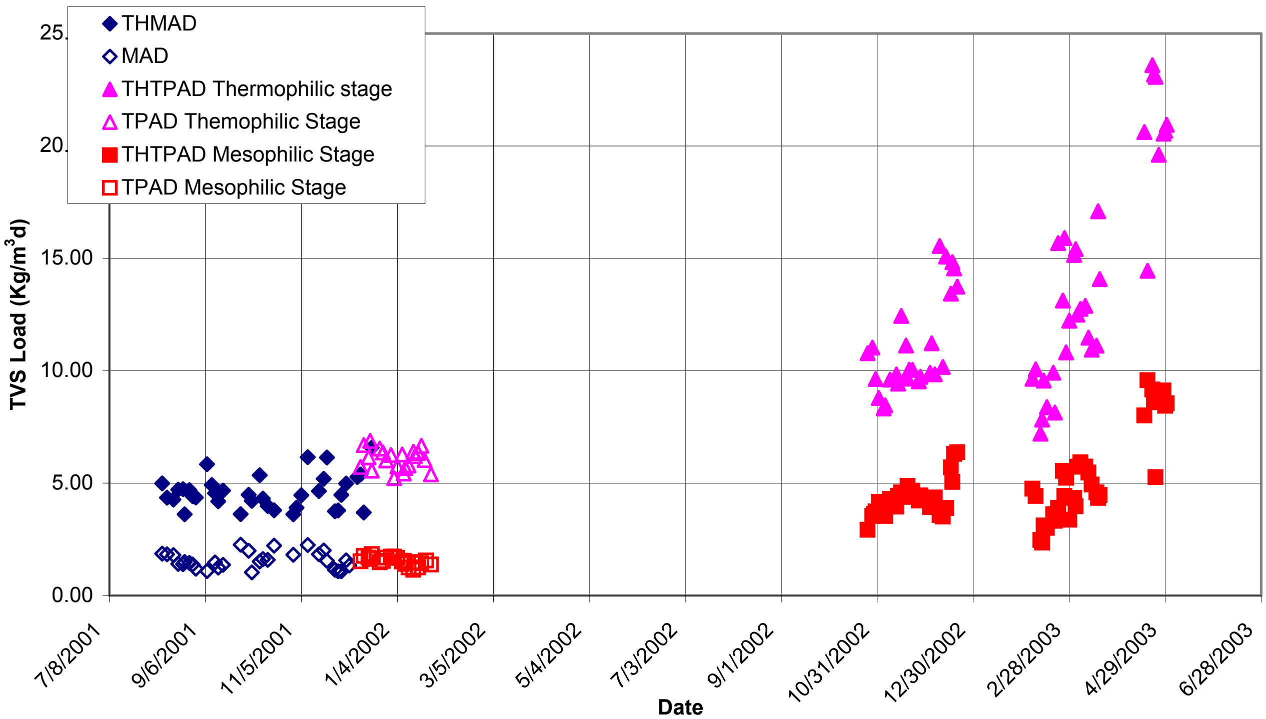

Figure 4. Total Volatile Solids Destruction

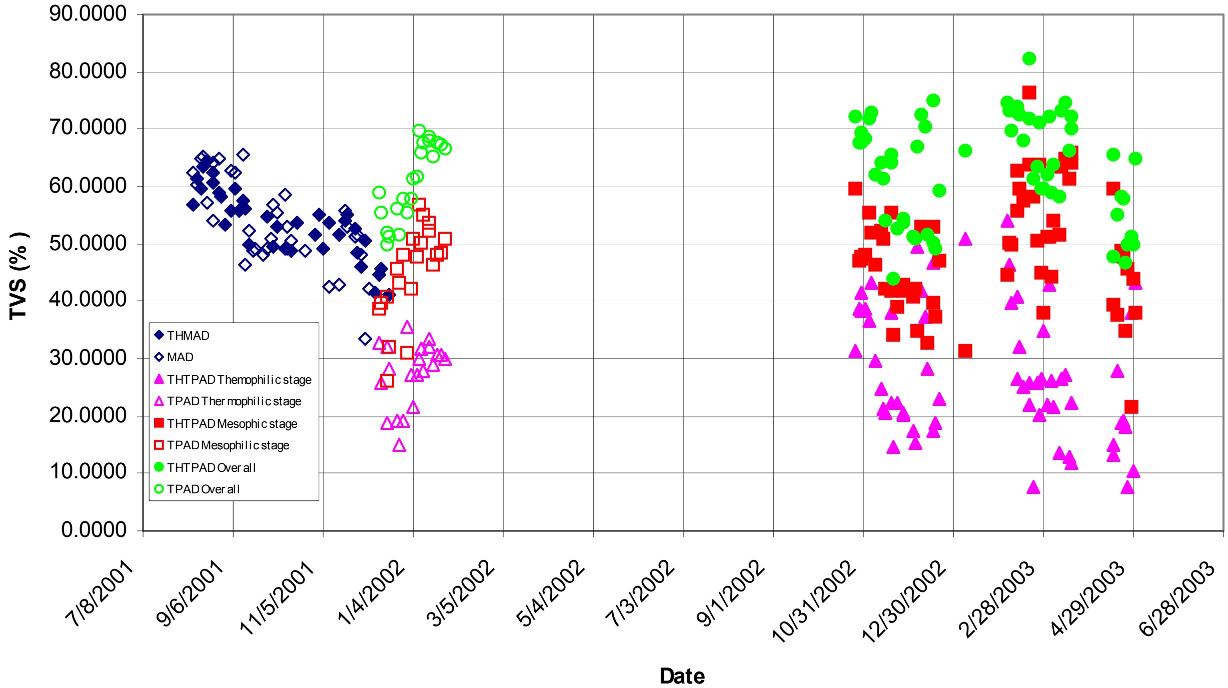

Figure 5. Total and Soluble COD Removed

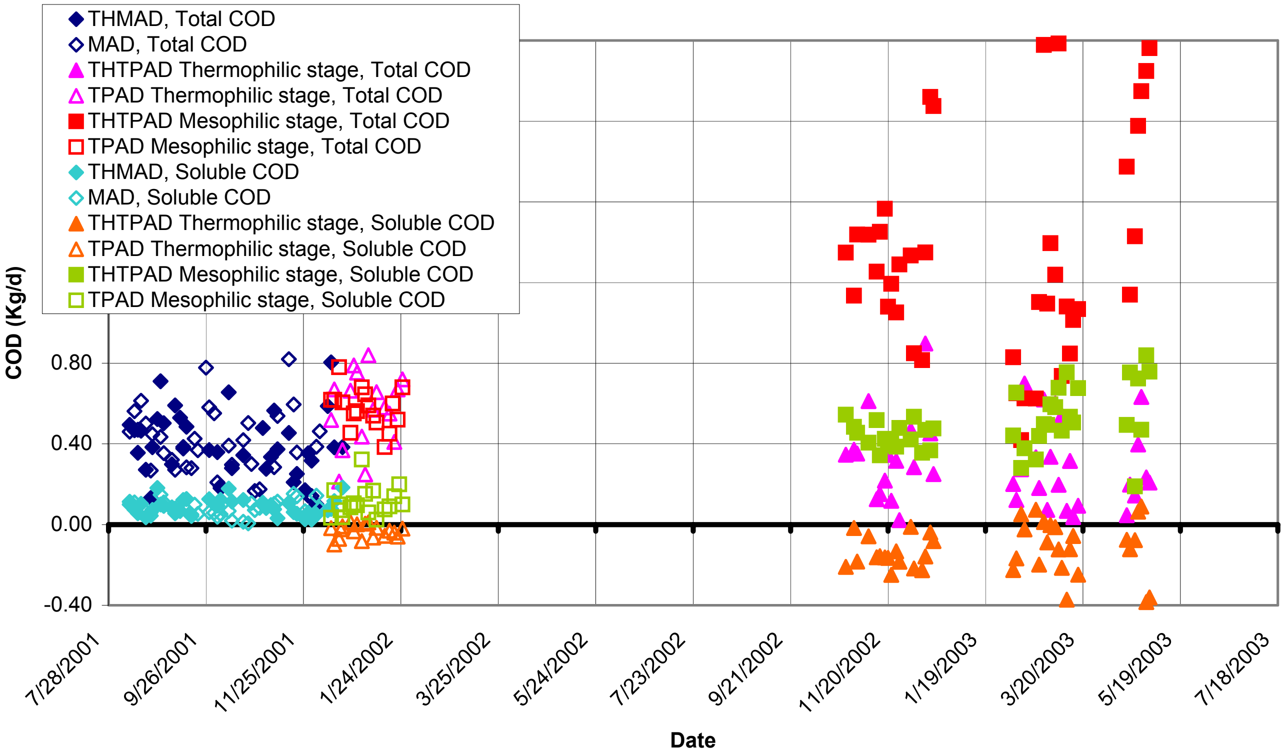

Table 1. Digester Feed Schedules, Total Solids and HRT

Digester	**Feed Volume (L)**	**Periodicity (min)**	**TS (%)**	**HRT (d)**
Control MAD	0.63	60	2.5-4.5	15
THMAD	0.75 0.94	144 144	7-10 7-10	15 12
Control TPAD Thermo Stage	0.95	60	3-4	5
Control TPAD Meso Stage	0.95	60	2-3	10
THTPAD Thermo Stage	0.95 1.18 1.57	60 60 60	7-10 6-8 8-9	5 4 3
THTPAD Meso Stage	0.95 1.18 1.57	60 60 60	5.5-8.5 4.5 -6 6.5-7.5	10 8 6

Table 2. Operational Data During Steady State Operation of Pilot Digesters

Process	**HRT (Day)**	**pH (Unit)**	**Alkalinity (mg/L)**	**Total Volatile Acids (mg/L)**	**Ammonia (mg/L)**
Control MAD	15	7.2-7.6	3500-4500	200-500	1000-1500
THMAD	15 12	7.7-7.9 7.3-7.7	7200-9000 5100-5600	300-800 400-900	2200-2700 2000-2200
Control TPAD Thermophilic	15	7.1-7.5	2900-3300	700-1400	1300-1500
Control TPAD Mesophilic	15	7.3-7.6	4500-4700	300-800	1500-2000
THTPAD Thermophilic	5 4 3	6.7-7.2 6.9-7.3 6.6-6.9	4400-5800 4300-5400 4200-5000	6700-8400 4900-6400 6700-8100	2000-2600 1800-2200 2300-2500
THTPAD Mesophilic	10 8 6	7.3-7.7 7.5-7.8 7.3-7.7	6000-7800 6200-7600 6200-7300	600-1200 400-700 400-1300	1700-2300 1700-2300 1700-2100

Table 3. Daily gas production per unit volume of digester capacity installed

Process	**Gas Production $m^3\ CH_4/m^3.d$**
Control MAD	0.8-1.2
THMAD	2-3
Control TPAD	1.1-1.7
THTPAD	2.8-4

Table 4. SEP Average Daily Biosolids Inventory

Parameter	2005 Data	THTPAD Projections	Change (%)
Dry Solids (Mg/d)	82	82	-
VS Destruction (%)	53	65	+23
Truck Loads	216	120	-44
Biogas (m^3/d)	44000	54000	+23
Energy in biogas (MWh)	270	350	+30