DC WASA Adopts Thermal Hydrolysis for Anaerobic Digestion Pretreatment: Conceptual Design Details for the Largest Cambi™ System

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ABSTRACT

The District of Columbia Water and Sewer Authority (DC WASA) has decided to incorporate thermal-hydrolysis pretreatment in conjunction with mesophillic anaerobic digestion as the back-bone of a long-term biosolids treatment plan to produce Class A biosolids. The Authority has been lime stabilizing their raw solids from the Blue Plains Plant for many years, transporting them to the State of Virginia for land application. DC WASA began the process of identifying an alternative approach to lime stabilization. Selection criteria for the new process included a compact footprint, cost effectiveness, ease of operation by local staff, production of a Class A product, minimization of odor potential, elimination of indicator organism reactivation or regrowth in addition to maximizing energy recovery from biogas. A broad number of alternatives were evaluated and discarded, with thermal hydrolysis and thermal drying as the two remaining alternatives. After evaluating both remaining alternatives, including hybrid of both and sub-alternatives to reduce project cost and eliminate the risk from using only one alternative, thermal hydrolysis in conjunction with mesophillic anaerobic digestion was ultimately chosen as the two processes that best meet the needs of the Authority. This paper summarizes the decision making process for selecting thermal hydrolysis along with the conceptual design for the thermal hydrolysis process.

KEYWORDS: Thermal Hydrolysis, energy, Class A biosolids, anaerobic digestion

INTRODUCTION

Currently, dewatered solids from the 1.4 million m^3/day (370 mgd) Blue Plains Advanced Wastewater Treatment Plant (AWTP) are lime stabilized to produce Class B biosolids that are mainly land applied to farms in the State of Virginia. The impetus for DC WASA to re-evaluate treatment and reuse options was the recently imposed fee for land application of Class B biosolids originating outside the State of Virginia. DC WASA began the process of identifying an alternative approach by updating its existing Biosolids Management Program (BMP) which was established in 1999.

Background Leading to Review/Update of the Biosolids Management Plan

DC WASA developed a Biosolids Management Plan (BMP) to replace aging facilities: the goals were to improve solids processing system reliability, provide treatment capacity to cope with current and future needs, and address community concerns, including onsite and offsite odors. The BMP identified methods to improve the characteristics and consistency of the biosolids product to increase beneficial reuse of the material, and allow flexibility to adjust to evolving technologies and markets.

In September 1999, the DC WASA Board of Directors (BOD) adopted the recommendations of the BMP to digest all the solids produced at the Blue Plains AWTP. Thermal drying would be added in the future to further reduce the mass of biosolids, if and when regional land application was no longer financially attractive or otherwise not feasible. The solids handling facility plan, completed in 2001, defined the facilities needed to implement the BMP and recommended the following projects:

- A new anaerobic digestion facility using egg-shaped digesters to treat all solids produced at the plant
- A new biological sludge thickening facility to provide consistent thickened sludge feed to the digesters
- A future power generation facility to produce energy from the digester gas and a thermal drying facility to achieve Class A biosolids, as needed.

As the design of the Egg-shaped Digestion Facility (EDF) proceeded, the BOD approved a change to the design that would enable the facility to produce a Class A biosolids product. The design, completed in 2006, provided 136,275 m^3 (36 million gallons) of digester volume and 37,900 m^3 (10 million gallons) of multi-use and storage volume. The process would reduce the total mass and volume of biosolids cake produced in the plant by approximately 50 percent, and significantly reduces truck traffic, pollution, noise and odor. The project was packaged into two construction contracts. The first contract comprising the geotechnical, foundation and structural work (including the digesters) was bid in August 2006. However, only one construction bid was received, and it significantly exceeded the project budget.

An in-depth analysis of the bid was performed to determine whether to proceed with this contract. The updated estimate for the entire project was determined to be approximately $550 million. Based upon this estimate, as well as the work of an outside economist, in October 2006 the DC WASA BOD decided to defer the EDF project for three years. The 3-year-period was a result of the economist’s projection that construction bid prices for the EDF project would be more favorable after that time period.

The BOD specifically directed DC WASA management to monitor and report biannually on construction bidding market, regulatory initiatives that could impact land application practices, maturing biosolids treatment processes that may be applicable at Blue Plains AWTP, and DC WASA’s financial position.

Scope of the Biosolids Management Plan Update

DCWASA staff decided to revisit the basis of the 1999 BMP to determine if the plan is still applicable and how to proceed with biosolids management for Blue Plains AWTP. The goal of this effort was to develop an updated plan for biosolids management that is affordable, cost effective, energy efficient, environmentally sound, and sustainable for the next 25 years. The review process to investigate alternative processes and technologies was conducted at two levels of screening. The first level identified the full array of processes that are available at the time of conducting the study, some of which were not mature in 1999, and narrowed the alternatives from sixteen to five. The second level provided a more detailed analysis of the screened alternatives. The work undertaken at each development and screening step included consideration of reliability, energy efficiency, life cycle costs, product marketability, and environmental impacts. The work was also reviewed by DC WASA's principal stakeholders, the Blue Plains AWTP user jurisdictions.

Alternatives Development

In developing alternatives for biosolids management, it was important to start with consideration of the biosolids end products and end use options. This approach provided the basis for the analysis, evaluation, and selection of the alternatives. Various biosolids process pathways and end-use options were developed, including land application of Class A and Class B biosolids cake; use of end product as an energy source such as dried pellets for providing supplemental fuel in cement kilns; and use of ash produced from incineration and gasification facilities for beneficial use.

The potential biosolids processes and technologies were combined to form complete treatment trains that are capable of producing various end products that can be managed through multiple end-use options. Two or more processes and/or technologies were combined to form a complete sequence of treatment alternatives from sludge thickening to end product and end use options. Sixteen process trains shown in Table 1 were identified for initial screening. These alternatives were grouped into two main categories: those that don't use anaerobic digestion (Alternatives A.1 through A.7) and those that use anaerobic digestion (Alternatives B.1 through B.9).

Alternatives Evaluation

At this initial screening phase, the alternatives were evaluated based on three main criteria: 1) overall risk, 2) process and implementation, and 3) biosolids end product. In considering overall risk, only those processes or technologies that are classified as established or innovative (EPA, 2007) were considered for further evaluation. In addition, DC WASA required that a process train include only those processes technologies that are considered proven. This was defined by DC WASA as processes or technologies that have been operating at least one facility in North America with an average flow of greater than 76,000 m^3/day (20 million gallons per day, mgd) with municipal sludge for at least twelve months. A 76,000 m^3/day (20-mgd) facility produces about 6,350 dry tons (metric) per year of biosolids. Sub-criteria were developed for evaluating the process itself and its implementation and the end product. Process criteria include process reliability, ease of operation and ease of maintenance. Implementation of the process included construction timeframe, air quality impacts, ease implementation, ease of permitting, compatibility with existing Blue Plains's AWTP processes and public perception. The criteria for biosolids end product were defined in terms of: acceptability/marketability, ease of diversification, and sustainability/risk of the end product. Forms of products evaluated included raw dewatered cake, Class A and Class B biosolids cake, pellets, bricks from ash, and glass aggregates. The initial screening reduced the list of alternatives from sixteen to five. The screened alternatives recommended for further evaluation are highlighted in Table 1.

Table 1. Alternatives developed for preliminary evaluations.

ID	Process Train
A.1	Thickened Sludge → Centrifuge Dewatering → Lime Stabilization → To Land Application
A.2	Thickened Sludge → Centrifuge Dewatering → Drying → To Land Application
A.3	Thickened Sludge → Centrifuge Dewatering → Drying → Vitrification → Glass Aggregate
A.4	Thickened Sludge → Centrifuge Dewatering → Composting → To Land Application
A.5	Thickened Sludge → Centrifuge Dewatering → Incineration → Ash to bricks
A.6	Thickened Sludge → Centrifuge Dewatering → To Landfill
A.7	Thickened Sludge → Centrifuge Dewatering → SlurryCarb → Fuel
B.1	Thickened Sludge → Temp Phased Anaer Digestion → Centrifuge Dewatering → To Land Application
B.2	Thickened Sludge → Acid-Gas Mesophilic Dig → Centrifuge Dewatering → Drying → To Land Application
B.3	Thickened Sludge → Enhanced Enz Hydrolysis → Mesophilic Anaer Dig → BFP Dewatering → To Land Application
B.4	Thickened Sludge → Thermophilic Anaer Dig → Centrifuge Dewatering → To Land Application
B.5	Thickened Sludge → Mesophilic Anaer Dig → Centrifuge Dewatering → To Land Application
B.6	Thickened Sludge → Acid-Gas Anaer Dig → Centrifuge Dewatering → To Land Application
B.7	Thickened Sludge → Auto Thermal Aerobic Dig → Temp Phased Anaer Dig → BFP Dewatering → To Land Application
B.8	Thickened Sludge → Pasteurization → Mesophilic Anaer Dig → BFP Dewatering → To Land Application
B.9	Thickened Sludge → Centrifuge Dewatering → Cambi → Mesophilic Anaer Dig → Centrifuge Dewatering → To Land Application

Detailed Evaluations of the Screened Alternatives

It should be noted that except for the baseline lime stabilization alternative, the remaining four solids processing alternatives involve anaerobic digestion and producing Class A biosolids, in concert with the BMP. These solids processing alternatives employ different forms of anaerobic digestion, including: (1) acid gas digestion followed by thermal drying; (2) enhanced enzymic hydrolysis followed by anaerobic digestion; (3) dual digestion (DD) employing autothermal thermophilic aerobic digestion (ATAD) followed by temperature phased anaerobic digestion

(TPAD); and (4) Thermal Hydrolysis (TH) as practice by Cambi™ followed by mesophilic anaerobic digestion (MAD). Detailed evaluation of the five screened alternatives was performed. The evaluation established design criteria and considered mass and energy balances; conceptual facility layouts including major equipment and appurtenances; energy management systems; and finally benefits analysis.

Energy Management for the Screened Alternatives

Along with the energy and mass balance analysis, an energy analysis was performed for each of the digestion alternatives. Assumptions for energy management are available elsewhere (DC WASA, 2008). The biogas produced from anaerobic digestion was used to generate heat and power through a combined heat and power (CHP) facility. For this analysis, gas turbines were assumed for generating electricity and waste heat from the exhaust was used to produce steam for process heating. For alternatives which involved sludge drying, the additional energy required for drying beyond that generated from the biogas was supplied through boilers fueled by natural gas.

The energy analysis also evaluated adding sludge drying (as maybe necessary in the future) to the Cambi™ Thermal Hydrolysis, Dual Digestion (ATAD-TPAD) and Enhanced Enzymic Hydrolysis (EEH) process trains. Fluidized bed drying was assumed for this initial analysis because of the ability of this technology to effectively use waste heat generated from the CHP system. The results of the analysis are shown in Table 2.

Table 2 shows the energy consumption for heating fuel, electricity, and transportation for each of the four digestion alternatives. In this table, Acid-Gas Digestion required drying to obtain Class A product. The three other alternatives not utilizing drying actually generate energy (negative net energy consumption) with Cambi™ generating the most energy followed by EEH and dual digestion (ATAD/TPAD). Table 2 also shows the energy consumptions when drying is considered for all the alternatives. In this scenario, the Cambi™ process still offers the best overall energy efficiency. All assumptions for energy analysis are provided in DC WASA (2008).

Table 2. Initial energy management analysis for the screened alternatives.

	Acid Hydrolysis	**Enhanced Enz Hydrolysis**		**ATAD/TPAD**		**Cambi**	
	Drying	No Drying	Drying	No Drying	Drying	No Drying	Drying
Net Heat Fuel Consumption MMBTU/hr	54.4	-4.2	57.5	-22.9	37.0	-5.7	34.3
Net Electricity Consumption MMBTU/hr	-28.7	-37.5	-30.8	-16.7	-10.0	-33.9	-30.4
Net Transportation Fuel Consumption MMBTU/hr	2.1	8.6	2.0	8.5	2.0	5.6	1.9
Total Net Energy Consumption, MMBTU	27.8	-33.1	28.7	-31.0	29.0	-34.0	5.9

A more rigorous benefit analysis was conducted for the five alternatives and the results showed that the two top-ranked alternatives were acid-gas digestion followed by drying and Cambi™ TH followed by mesophilic digestion. Further more, evaluation of the facilities layout of the EEH and dual digestion processes (ATAD/TPAD) showed that these processes don't fit within allocated space for the solids upgrade plan and thus were not considered for further evaluations.

Construction and operation and maintenance (O&M) costs were developed for the two digestion alternatives. The construction cost for the two digestion alternatives were essentially the same, as were the O&M costs. However, construction costs for these digestion alternatives were about $520 million. This is well over $200 million more than the existing capital improvement program (CIP) budget for the digestion facilities. As a result, the need to develop an affordable digestion project emerged. Several steps were taken to reduce the cost of the facilities in each of the three alternatives but also to develop sub-alternatives that would permit phased construction to stay within the CIP budget. Furthermore, the external technical expert panel that was consulted periodically recommended that DC WASA investigate a 'hybrid' alternative that would include both Cambi™ and heat drying. The sections below describe the development and evaluation of sub-alternatives.

Development of Sub-Alternatives

At this stage of evaluation, the list of alternatives had been reduced to digestion followed by thermal drying, TH followed by digestion, hybrid alternative incorporating TH and digestion and drying, and finally Lime stabilization as the base case. To address the need for affordable alternatives, twelve sub-alternatives were developed. The sub-alternatives were made up of various configurations and combinations of Cambi™ TH trains, digesters, dryers and lime stabilization trains. Conceptual design criteria for each of these sub-alternatives were also developed.

Table 3 presents the 12 sub-alternative where alternatives 1 through 4 are Cambi™-based alternatives with lime stabilization as the backup process. The sub-alternatives include lime stabilization to process peak solids. Sub-alternatives 5 through 9 are combinations of both Cambi™ TH and indirect drying with lime stabilization again as the backup process. Sub-alternatives 10 and 11 are indirect drying with lime stabilization as the backup process. Sub-alternative 12 is a continuation of lime stabilization with sufficient improvements to have the same capacity as the other alternatives.

The sub-alternatives were developed from a risk mitigation perspective. The perception was that Cambi™ as a new process to North America posed some level of risk to DC WASA. This risk could be mitigated by combining Cambi™ TH with drying, providing operational flexibility and two biosolids products.

The new digesters were proposed to be located at the digester site, between the solids processing building (SPB) and nitrification sedimentation basins. Citing of the Cambi™ process was evaluated at two different locations including the incinerator building of the SPB and at the digester site. In both instances the existing blend tanks and centrifuges were incorporated into the proposed flow train. Because Cambi™ TH produces a Class A biosolids, the digested biosolids must be maintained separate from Class B biosolids to avoid product contamination. In other words, digesters and centrifuges cannot be shared or be considered as backup to a Class A product if also being used for non-Class A product.

Table 3. Description of sub-alternatives combining th, drying, digestion and lime stabilization.

No.	No. of Cambi™ Trains	No. of Post-Cambi™ Digesters	No. of Dryers	No. of Pre-Drying Digesters	Location of Cambi™ Units
1	6	5			Digester Site
2	4	4			Digester Site
3	2	2			SPB*
4	2	2			Digester Site
5	2	2	3	5	Digester Site
6	2	2	1	1	SPB
7	1	1	2	4	Digester Site
8	1	1	1	2	Digester Site
9	1	1	1	2	SPB
10			5	8	Digester Site
11			3	4	SPB
12					SPB

*SPB refers to solids processing building

The Cambi™ TH alternatives were based on a 6-reactor train as discussed in the following sections. Existing structural components within the SPB precluded the installation of more than two standard trains in the incinerator area. The heat drying alternatives this evaluation were based on an indirect heat paddle dryer, which provides certain synergies with Cambi™ including: use 150 psig steam, upstream dewatering, digestion, and production of Class A biosolids. The present lime stabilization system has a rated capacity of 450 dtpd (metric). This system needs to be expanded to process the maximum solids produced by the liquid process train.

Evaluation of Sub-Alternatives

Table 4 shows the estimated project and total Present Worth costs (Sum of Present Worth of project cost and Present Worth of O&M) for the sub-alternatives. Construction costs were escalated to midpoint of construction (2012) at 5% interest and project cost was estimated from construction cost with use of mark-up factor of 1.26. O&M Present Worth cost is reported in 2008 dollars over 20 years at 3.5% interest.

Table 4. Solids processed by each sub-alternative and perspective project cost and total present worth.

No.	Annual Average dtpd to Treatment	Max 3-day dtpd to Lime Stabilization	Annual Average dtpd to	Project Cost $MM	Total Present Worth $MM
1	336	0	0	498	698
2	**336**	**145**	**0**	**406**	**547**
3	200	371	136	276	749
4	200	371	136	284	755
5	336	73	0	491	687
6	237	319	99	378	759
7	265	259	71	447	903
8	183	370	152	325	934
9	183	370	152	299	913
10	336	114	0	520	779
11	181	356	154	292	785
12	0	596	336	173	902

As the table shows, the least cost effective alternative is Alternative 2, which uses 4 trains of Cambi™ TH and 4 MAD. However, from a budget standpoint, Alternatives 3 and 4 best fit the available project CIP. A detailed breakdown of the estimated O&M costs for each alternative is available in DC WASA (2008). Alternatives 3, 6 and 9 were developed with the intent of reducing cost by locating the Cambi™ trains inside the existing SPB. This arrangement allows use of the existing centrifuges for the pre-dewatering step prior to the Cambi™ process since the centrifuges are located adjacent to the incinerator room of the SPB. A review of these arrangements with Cambi's design personnel indicated that only 2, six-reactor trains would fit in the tall section of the room. Accommodating additional trains would require modifications to their standard design. Cambi has also noted that their system is mainly designed for outdoor service. DCWASA didn't want to depart from Cambi's standard design and therefore the SPB Cambi™ configurations were eliminated.

Alternatives 7, 8, and 11 include drying. The drying options require more energy and produce less electricity than the Cambi™ option. The latter use about one third as much heat as the comparable drying alternatives. Accordingly, the drying alternatives were eliminated based on cost effectiveness, concerns over safety of dryers, and finally confidence gained by DC WASA staff during visiting various Cambi™ sites around Europe.

Because the process chosen by DC WASA include the Cambi™ TH alternative, the remainder of this paper focuses on conceptual design aspects of TH process as based on Cambi™.

THERMAL HYDROLYSIS AND DIGESTER TRAIN

Thermal hydrolysis is a thermal conditioning process that operates at lower temperatures than the typical heat treatment process (150-200°C versus 200-250°C) and functions as a pretreatment step before MAD. There is currently two commercially available TH processes, one is called Cambi™ and is provided by Cambi AS, Finland and the other is called BioThelys™ and is provided by Veolia Water Systems, France. The analysis for DC WASA focused on the process developed by Cambi AS, Finland. There is now about 20 wastewater treatment plants world wide using Cambi™ process, but none in North America. The cited benefits of the process include: 1) break down of longer organic polymer chains to shorter chain organic matter to enhance anaerobic digestion and gas production, 2) production of Class A product under the time and temperature stipulations of the EPA Part 503 biosolids rule, 3) enhancement of digested biosolids dewatering characteristics, and 4) significant reduction of digestion volume through reducing treated solids viscosity allowing higher solids concentrations to be pumped and mixed during digestion. Additional information on the Cambi™ process parameters relative to the Blue Plains AWTP solids digestion is available elsewhere (Wilson et al., 2008).

As illustrated in Figure 1, the thermal hydrolysis step consists of three basic units: the Pulper, the Reactor and the Flash Tank. In reality there is more to the process train than those three units. The sludge needs to pass through some type of sludge screening facility ahead of the TH to remove damaging materials from the sludge stream. It must be pre-dewatered to slightly higher than 18% total solids (TS) and then the cake solids is transferred to a silo or bin that is large enough to provide equalization of inflow variations allowing the THP to operate at a uniform flow rate. The sludge can then be transferred to the Pulper Tank via augers in the bottom of the storage bin and pumps. The concentration of solids to the pulpier is diluted to a concentration between 14.5 and 16.5% TS using dilution water, probably plant effluent. The sludge is mixed in the Pulper and preheated using steam that is recycled back from the Flash Tank. The preheated sludge is pumped to the Reactor vessel where it will be heated to about 329°F (165°C) and a pressure of approximately 90-100 psig. By the time the sludge is heated in the reactor by direct steam injection, the concentration will be about 14.8%. After the appropriate hydrolyzing time, the sludge is transferred from the Reactor to the Flash Tank. The pressure release from the Reactor is thought to rupture the organic cells in the sludge. The Flash Tank received the treated sludge with a solids concentration about 3% less than the raw sludge due to the steam injection.

The sludge temperature at this point is too hot to feed a mesophilic digester and required cooling and dilution if needed. Again, the water used for dilution is required to lower the concentration of the sludge to between 10 and 12% for feeding into the digester. The temperature must also be reduced to about 42-44C by heat transfer. The sludge at 10 to 12 % TS is then transferred to the MAD facility. Finally the digested biosolids are transferred to final dewatering before being ready for reuse. The final product has very good properties for soil blending and for land application. In addition to the sludge process train there must be a source of fresh steam for heating the Reactors, so there will be at least a boiler as part of the train. Usually, the biogas generated from the MAD is processed via a combined heat and power (CPH) facility for producing electricity and the necessary steam for the THP.

The following sections discuss Cambi Reactors operating scheme, sizing the THP for the Blue Plains AWTP, Reactors sequence operation, and some aspects of the MAD process.

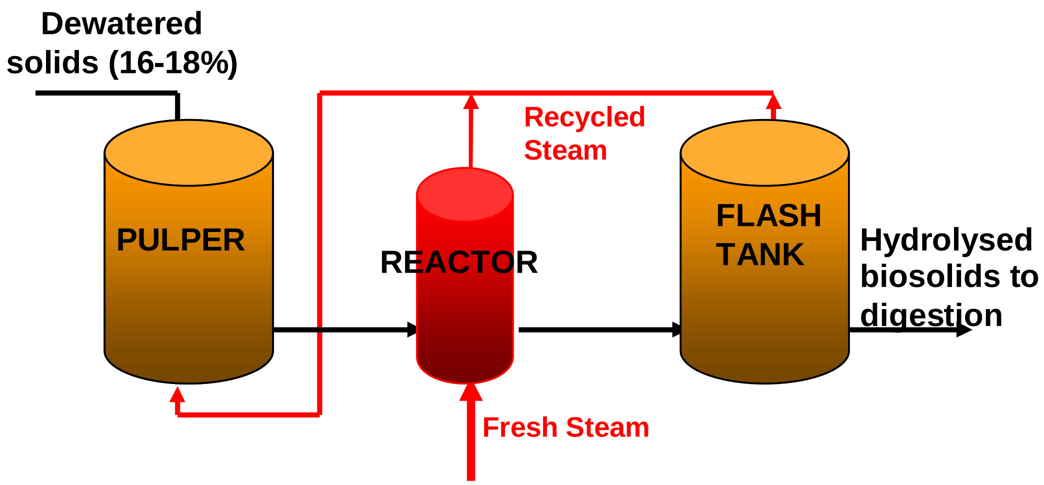


Figure 1. Main components of a Cambi™ Systme.

Reactor Operation Scheme

The Reactors operate in a batch mode with a typical volume of 12 cubic meters and receive approximately 7.6 cubic meters (~70% of total volume) of sludge in each batch. Once the sludge is transferred, approximately one metric tone of fresh steam is injected per one dry ton of sludge. After the reaction period elapses, the sludge is released to the Flash Tank. When the steam is released from the Reactors, it passes to the Pulper and preheats the raw sludge. A Foul Gas Skid is also provided with each reactor, which draws gas from the Pulper and discharges it into the digester feed piping ahead of the heat exchangers. The Pulper and the Flash Tanks are usually sized twice the size of one Reactor. The batch steps for a typical 90 minutes cycle for each reactor are shown in Table 5 below.

Table 5. Steps for Cambi 90 minutes cycle operation.

Step	Action	Time	Description
1	Fill	15 min	Fill Reactor with 7.6 m^3 of sludge
2	Steam injection	15 min	Inject steam in the Reactor
3	React	30 min	Hold Reactor at 160C and 90 psig
4	Steam out	15 min	Release steam to Pulper
5	Empty	15 min	Transfer sludge to Flash Tank by pressure release.

Cambi™ System Sizing

The overall Cambi™ system sizing is based on a single reactor capacity. Usually it is assumed that solids are delivered to the Reactor at 14.7%. The reactor capacity is based on the cycle time and the concentration of the solids in the reactor. For a standard 90 minute cycle as described in Table 5 and 7.6 cubic meters batch of sludge at a 14.7% solids concentration, the capacity of a single reactor is about 17.88 dry metric tons per day or 19.66 dry tons per day (dtpd).

The design conditions for the Blue Plains AWTP are shown in Table 6. Based on 95% guaranteed Reactor availability, 24 reactors can process peak month and almost maximum 15-day loading. Accordingly, it was recommended that 4 Cambi™ trains of 6 reactor each train is used for sludge processing. The throughput capacity of the Cambi™ system can be increased by increasing the solids concentration (maximum would be 17 to 17.5%) or shortening the cycle time without compromising the reaction time of 30 minutes that is necessary to achieve Class A biosolids according to Part 503 Regulations. For example, by increasing the solids concentration to the rector to 16.5% and operating 24 reactors at 100% availability, the 24 reactor system has to the potential to process a throughput of 481.5 dtpd (metric), which is 530 dtpd (US). Thus, the system can handle max week conditions, which would require a sludge at 18% TS be delivered to storage cake silo, enabling 16.5% feed to the Reactors. In this case storage ahead of Cambi™ system would be required for max 3 day and max day only. Each train will have a dedicated cake storage silo. The required storage silo ahead of each Cambi train was recommended to be 500 m with cake solids residing in these silos only about 16 hrs before being processed during max month.

A three-dimensional representation of the system recommended for treating all of the solids at the Blue Plains AWTP is shown in Figure 2.

Table 6. Cambi™ sizing calculations for Blue Plains AWTP.

	To pre dewatering	To Cambi	To Cambi	# Reactors	# of Reactors
Design conditions	dtpd	dtpd	Metric dtpd	95% availability 14.7% solids	100% Availability 16.5% solids
Max 3day	657	591	538	32	28
Max week	530	477	434	26	23
Max 15d	495	446	405	24	20
Max month	433	390	354	21	19
Average day	370	333	303	18	16

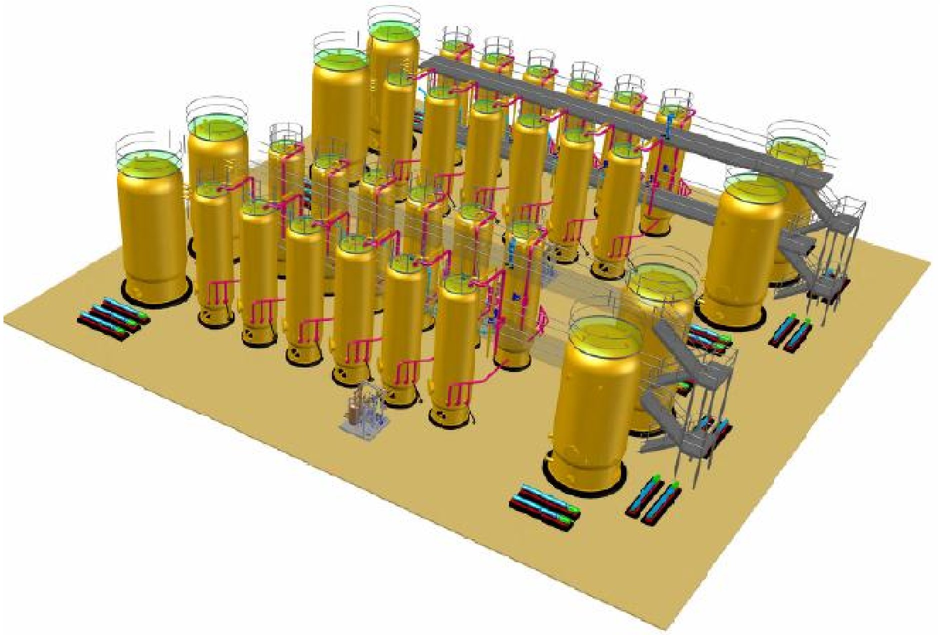
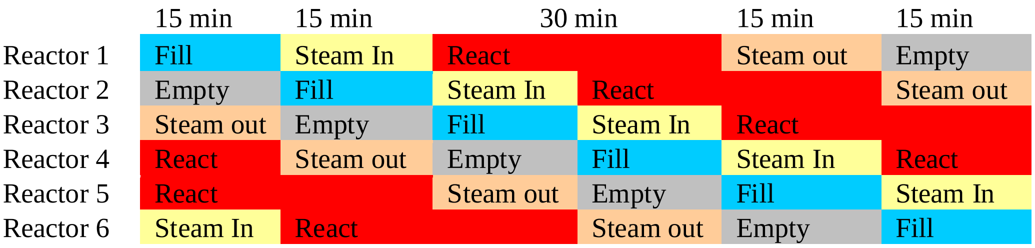


Figure 2. Three dimensional rendering of the six-reactor Cambi™ process layout proposed to pre-treat solids prior to anaerobic digestion.

Reactor Sequence Operation

The preferred smallest Cambi process train will have two reactors; otherwise it will be a batch operation. With two reactors the train works as a continuous operation. Figure 3 below shows a sketch portraying sequential status of a six reactor Cambi™ process train based on solids residence of 90 min within each reactor. Process staggering allows continuous operation of all major mechanical equipment.

As shown in Figure 3, one reactor would always be filling sludge, one would always be receiving steam, one would always be releasing steam, and one would always be emptying treated sludge. This means that the sludge feed pumps and the steam plant would always be operating and that only valves would be opening and closing to direct the flow to and from the reactors.



	15 min	15 min	30 min		15 min	15 min
Reactor 1	Fill	Steam In	React		Steam out	Empty
Reactor 2	Empty	Fill	Steam In	React		Steam out
Reactor 3	Steam out	Empty	Fill	Steam In	React	
Reactor 4	React	Steam out	Empty	Fill	Steam In	React
Reactor 5	React		Steam out	Empty	Fill	Steam In
Reactor 6	Steam In	React		Steam out	Empty	Fill

Figure 3. Sequential status of a six reactor Cambi™ process train.

Mesophilic Anaerobic Digesters

When coupled with Cambi^{TM}, the MAD serves to further stabilize the sludge, reduce the odorous nature of the heat treated sludge, and produce biogas for the purpose of energy recovery. The THP alters the physical structure of the cell materials and organic substrate in the sludge to be digested, but it does not destroy the mass of matter to be digested. The input mass to the Cambi process equals the output mass, equals the mass fed to the digesters.

As mentioned before, one advantage of TH pretreatment or conditioning is that the sludge can be fed to the digesters at concentrations of up to 12% TSS and still be properly handled and mixed. The land area available for digester construction at the Blue Plains AWTP has dimensions that are not conducive to many small digesters, but rather best fit a few large digesters. The digester dimensions that best fit the site were between 95 and 110 feet in diameter. The maximum number of digesters that could be placed in the given area was ten. If part of the area was consumed by a TH facility, then the maximum number of digesters would be limited to eight. Each digester would have an operating volume of 13,250 m^3 (3.5 million gallons).

The preferred solids retention time (SRT) was 20 days at average day design conditions and 15 days based on the maximum 15-day design condition. On this basis, the operating volume of the digesters at 10% TSS would be about 16 million gallons, requiring 5 tanks at 12,115 m^3 (3.2 million gallons) each. If the feed solids concentration were increased to 11% TSS and the tank volume can be increased to 13,630 m^3 (3.6 million gallons), the number of tanks could be reduced to 4. If the feed solids were increased to 11.5%, the number of tanks could be reduced to 4 using the 13,250 m^3 (3.5 million gallon) tanks. As a result, it was concluded that 4 tanks at 13,250 m^3 (3.5 million gallons) each would be recommended.

Gas production from the digesters was assumed to be 0.94 m^3 per kg (15 scf per lb) of volatile suspended solids (VSS) converted. Further it was assumed that of the total solids fed to the digester, 80% would be VSS. The VSS conversion ratio for TH is expected to be 50 to 60%; 55% VSS conversion was assumed, producing about 135,655 m^3 (4.79 million scf) of biogas produced per day at final design conditions. A 2-4-hour production volume of gas storage was recommended, followed by gas treatment for hydrogen sulfide, moisture, and Siloxanes.

CONCLUSIONS

Thermal hydrolysis followed by mesophilic anaerobic digestion seems to be the process that meets the future needs for DCWASA Blue Plains AWTF for processing solids. The district is continuing to further investigate methods of delivery for constructing the thermal hydrolysis facility along with energy recovery and generation system from the biogas.

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