

Underlying Mechanistic Principles and Proposed Modeling Approach for Waste Activated Sludge Reduction Technologies

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ABSTRACT

WERF's 05-CTS-3 *Evaluation of Processes to Reduce Activated Solids Generation and Disposal* aims to establish a comprehensive evaluation methodology for waste activated solids (WAS) reduction processes based on the in-depth consideration of a select number of technologies considered to be representative of the many options currently available in the marketplace. These technologies cover both those intended to reduce the generation of wastewater treatment residuals from the liquid process, as well as those designed to pre-condition solids in order to make it more susceptible to subsequent stabilization processes such as anaerobic digestion.

In conjunction with the previous paper titled "CURRENT STATE OF THE PRACTICE OF SLUDGE REDUCTION TECHNOLOGIES" (Sandino et al, 2008), this paper is intended to focus on the evaluation of the performance data collected from full-scale facilities. Laboratory analyses conducted at Virginia Polytechnic Institute from samples collected from these same facilities are included.

This paper will discuss the mechanisms behind the technologies, present performance data, and discuss the operational considerations influencing the observed performance (e.g. wastewater characteristics, activated solids operational practice, solids reduction technology design basis and operation).

KEYWORDS

Solids reduction technologies, anaerobic digestion pre-conditioning, increased volatile solids destruction, emerging technologies, innovative solids management

INTRODUCTION

The Water Environment Research Foundation's (WERF) project 05-CTS-3 *Evaluation of Processes to Reduce Activated Solids Generation and Disposal*, which started in the second quarter 2007, seeks to establish a comprehensive evaluation methodology for waste activated solids (WAS) reduction processes based on the in-depth consideration of a select number of technologies considered to be representative of the many options currently available in the marketplace. These technologies cover both activated sludge process reconfigurations aimed at reducing the generation of residual solids from the liquid treatment process, as well as those designed to pre-condition WAS in order to make it more amenable to a subsequent stabilization process such as anaerobic digestion. In general, the approach adopted for this project is as follows:

1. First, conduct a literature search of known technologies and processes used to reduce WAS mass. All those without full scale testing, or installations, will be eliminated from further consideration.

2. Secondly, those with full scale installations will be analyzed for non-financial issues (such as scalability, overall performance, etc.) in a desktop evaluation for both industrial and municipal applications. The top three technologies that results from this evaluation and that are considered representative of the main mechanistic principles currently available in the marketplace will be evaluated in more depth.
3. Thirdly, focusing on these three representative technologies, provide validation of the processes and determine the net present value, variability in process performance, operability, and maintenance issues. The validation will be based on field data provided by plants and team members.

This paper corresponds to the second of a series of papers related to this WERF project (the first, "CURRENT STATE OF THE PRACTICE OF SLUDGE REDUCTION TECHNOLOGIES," was presented in the 2008 WEF Residuals and Biosolids Specialty conference in Philadelphia (Sandino et al, 2008)), and is intended to focus on the second component of the approach described above, namely the evaluation of the performance data collected from full-scale facilities. These facilities and the incorporated processes are deemed representative of the main mechanistic principles associated with the current state of the practice of solids reduction technologies. Results from additional analysis conducted at Virginia Tech from samples collected from these same facilities will also be presented and discussed. Table 1 presents a summary of the facilities and the processes that will be the focus of this paper.

Table 1 – WAS Reduction Technology Installation List for this Paper

Manufacturer	Process	Location	Location
BIOLOGICAL TREATMENT PROCESS			
Siemens	Cannibal	North America	AL
Siemens	Cannibal	North America	Columbia, SC
Siemens	Cannibal	North America	SC
Siemens	Cannibal	North America	Peru, IN
PHYSICAL TREATMENT PROCESSES			
Cambi	Thermal Hydrolysis	North America	DC WASA
Cambi	Thermal Hydrolysis	Denmark (Naevsted)	Ved Fjorden 18 DK-4700 Næstved.
Crown	Pressure-release Disintegration	Germany	Ingelheim
Crown	Pressure-release Disintegration	New Zealand	Rosedale WWTP
Crown	Pressure-release Disintegration	Germany	Wiesbaden Biebrich
Crown	Pressure-release Disintegration	Germany	Taunusstein
Crown	Pressure-release Disintegration	Germany	Ginsheim
Crown	Pressure-release Disintegration	Germany	Münchwilen

MECHANISTIC PRINCIPLE DISCUSSION AND ASSESSMENT OF PERFORMANCE

The primary function of suspended and fixed film biological reactors is to convert biodegradable organics to suspended solids by creating an environment where biota can use the organic material as a food source. Especially in aerobic environments, an undesired product of this reaction is the creation of excess biota via anabolic metabolism. Carbon dioxide, nitrate, nitrogen gas, and water are other examples of byproducts of the cellular metabolism in an aerobic reactor. Anaerobic reactors reduce COD to methane and carbon dioxide. In an anaerobic environment, the cellular growth rate is slower and the metabolic reactions inherently result in lower yields, and therefore less excess biota are produced. Ideally the aerobic reaction would be mostly catabolic with minimal solids wasting.

In the activated solids process, biodegradable organic material in the influent wastewater is used by microbes, with some converted to cellular material for growth and reproduction of the microbes, some used as energy sources to maintain the microbes' metabolism, with byproducts, such as carbon dioxide and water. In activated solids systems the WAS observed yield is normally between 0.7 and 1.2 kg/kg BOD. The treatment process therefore produces excess biomass, although the yield is often less than the value of the influent organic load. The organic material contained in the biomass after death and decay is slowly biodegradable, largely due to the time required to break down the cell walls. In mesophilic anaerobic digestion this may take 8 days or more. All types of solids minimization technologies operate by increasing the consumption of the biomass decay products as a food source, thus reducing the overall production of solids. This consumption may take place within the activated solids process, in a downstream digester, or in an additional secondary treatment stage.

Extended aeration is a proven process for reducing solids observed yields, and has been implemented at many wastewater treatment plants (WWTPs) worldwide. This process operates by allowing sufficient solids retention time (SRTs) in the activated solids process to allow for higher levels of natural cell death and breakdown of cell walls. Extended aeration processes normally operate at SRTs between 20 and 25 days, and some plants operate at significantly longer SRTs up to 60 days. High mixed liquor suspended solids (MLSS) concentrations are a result of these long SRTs and this can affect the stability of the secondary treatment process as well as impact performance of the secondary clarifiers.

Other technologies rely on changing reactor environments and availability of oxygen to affect the biological processes and biodegradability of solids. This is accomplished through cyclic environments that alternate oxic, anoxic and anaerobic conditions, such as in the Cannibal[®] process.

Hydrolysis has long been held as the rate limiting step in the decomposition of biological solids. Cell lysis technologies aim to increase the rate of hydrolysis by lysing the cellular material, releasing the organic material into the substrate. Some technologies rely primarily on physical lysis, such as pressure-release (e.g. Crown Disintegration[®] process) and thermal hydrolysis (e.g. Cambi[®] THP), while others such as Microsludge[®] combine chemical and physical processes.

Extended aeration with cyclic metabolic environment - Cannibal[™]

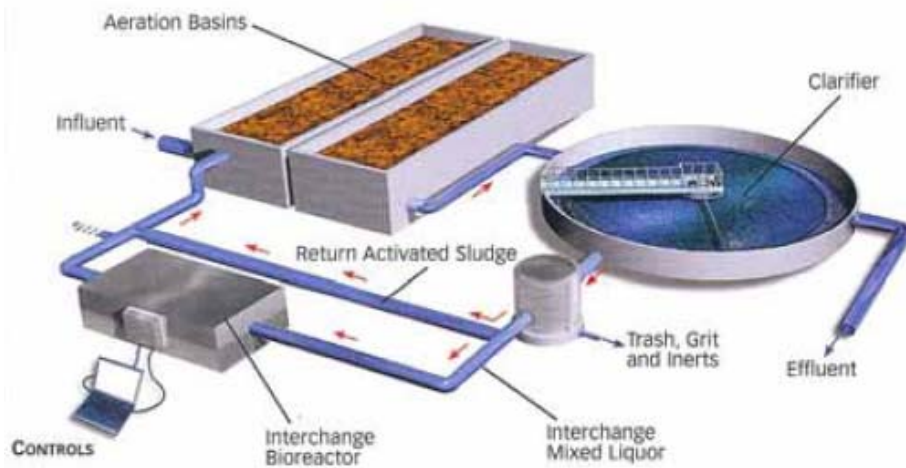
Sequential anaerobic-aerobic digestion has demonstrated solids reduction at bench and pilot scale. This process was investigated at laboratory scale and is known to have volatile solids removal as high as 60% and above. Moreover significant total nitrogen (TN) and total phosphorus (TP) removal in digested solids has been reported (Kumar, et al., 2006a) which implies decreased nutrient load on WWTP from dewatering return streams.

It was found during laboratory investigations that various fractions of polysaccharides and proteins are present in wastewater and waste activated solids. These fractions and associated cations play a central role in solid digestion process (Park et al., 2005). Novak & Higgins (1997), Novak, et al. (2003), and Novak & Park (2004) found that the major cations associated with the solids floc are sodium, potassium, calcium, magnesium, iron and aluminum. Frølund et al. (1996) proposed a solids floc model in which a floc consists of micro-consortia embedded in matrix of biopolymers including proteins, polysaccharide, DNA and humic acids. Extracellular polymers prefer to bond with divalent ions as they form more stable complexes (Rudd et al., 1984). These biopolymers are bound in the solids matrix and are associated with different cations. During aerobic digestion, divalent cations accumulate in the solution resulting from the release of lectin-like proteins which are then degraded, while during anaerobic digestion, ferric bound biopolymer is released upon the reduction of Fe (III) to Fe (II) and is degraded (Park et al., 2006). However, it has also been shown that the breakdown of lipids to long chain fatty acids can also inhibit anaerobic digestion (Jeganathan et al., 2006).

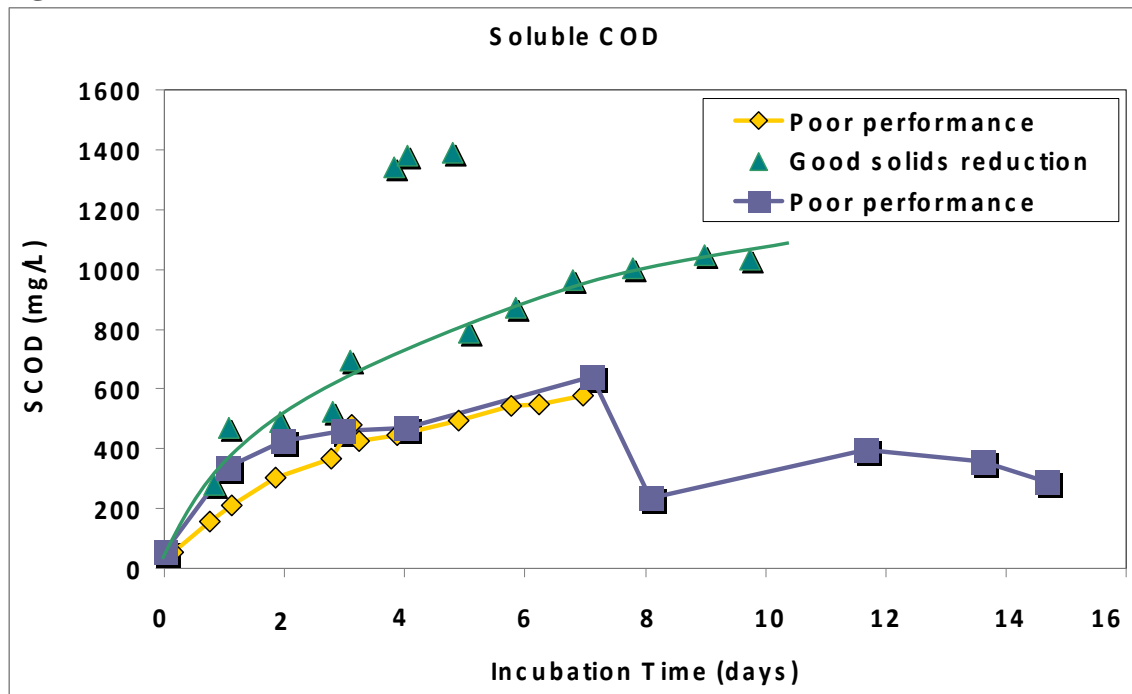
Sequential anaerobic-aerobic digestion helps in removing all of the above mentioned fractions of biopolymers and hence achieves more solids reduction than conventional “only anaerobic” or “only aerobic” digestion process. Bench tests were conducted with primary solids and WAS from the Blue Plains WWTP, Washington D.C (Novak et al., 2005). Anaerobic digestion was conducted at mesophilic and thermophilic temperatures, followed by aerobic digestion at 3, 6 and 9 days. Aerobic digestion at 3 days provided an additional 10 percent VSr and 12 percent was achieved at 6 days. Ammonia was reduced 80 to 90 percent, and dewaterability was improved. Endocrine disrupting activity in the filtrate was also found to be significantly lower after the aerobic digestion step. Additionally, Kumar et al. (2006b) have shown that solids treated under sequential anaerobic-aerobic digestion process are less odorous than conventionally treated solids.

The Cannibal® process is a patented process currently owned by Siemens. The process (depicted in Figure 1 below) includes a reactor, known as the interchange reactor (IR), which operates in a facultative mode, on the cusp of anoxic and anaerobic environments. Rather than being wasted, the WAS is sent instead to the IR. The same volume is returned daily from the IR to the activated solids process. SRTs in the whole system may be as high as 100 days. This process includes most of the biological solids reduction mechanisms discussed. The process name implies that a key mechanism for solids reduction is predation; however, research by Novak et al. (2006) shows that the anaerobic-aerobic sequencing mechanisms described above are more likely the primary mechanism reducing solids mass in the Cannibal® process. This is supported by findings reported by van Loosdrecht and Henze (1999) who summarized that it is impossible to differentiate between cell maintenance, endogenous metabolism, lysis, decay and predation in operating systems with anoxic recycle reactors. Data from full-scale Cannibal® installations show that waste activated solids yields of approximately 0.1 g TSS/g BOD can be achieved, provided that inert solids are removed by a solids separation module. For municipal wastewater installations the inert solids removed are typically 0.1 to 0.3 kg TSS/kg BOD ($\pm 10\%$) applied to the bioreactor at a plant without primary clarification. Currently there are at least 10 plants operating in the United States, including nine municipal and one industrial, with capacities between 1.9 MLD and 61 MLD.

Figure 1. Flow Schematic of the Cannibal™ Process Integration with an Activated Solids Plant (Siemens Literature).



Cannibal™ consists of two main processes, (1) physical separation step, and (2) biological treatment step. Biological treatment utilizes an anaerobic/anoxic unit (Interchange Reactor) through which a portion of the recycle solids passes prior to being returned to the aeration basin. Discussions with vendors and experts in the Cannibal™ process suggests that cycling mixed liquor between aerobic reactor and IR put environmental stresses on microbes, which helps in converting normally non-biodegradable decay products to degradable substrate. This results in very low yield and higher nutrients removal. Novak, et al. (2006) through bench scale lab tests proved that low yield are achievable but various protein fractions associated with cations play very important role in the Cannibal™ process. More recent research by Novak and presented in Figure 2, illustrates that soluble COD releases from solids going to the Interchange Reactor are stored under anaerobic conditions. As illustrated in Figure 2, two plants have poor solids reduction (as indicated by low soluble COD levels in the IR) while one has good solids reduction by the Cannibal Process (i.e. higher soluble COD).

Figure 2. Soluble COD data from Cannibal™ WWTPs

Physical separation using microscreens and hydrocyclones is used to remove inert material from mixed liquor in the Cannibal™ Process. All or a portion of the RAS is passed through fine screens regularly to remove inert organic material, and hydrocyclones are intermittently operated on screened RAS to remove grit and dense inorganic material.

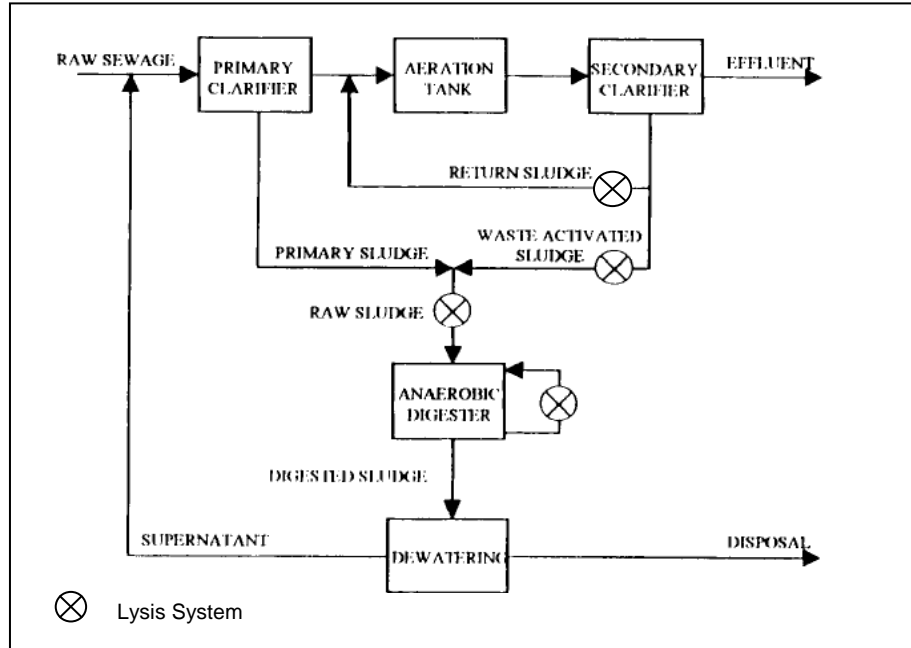
Some of the early research on this type of combination process for solids reduction was conducted by Mr. Boris Khudenko. He has developed a similar process, known as CATABOL. There have been three installations, of which one is no longer operational due to industrial reuse and one pilot plant that is also not operational. His process is reportedly the basis for the design of the 57 MLD Cartersville Plant in Georgia, which is currently under construction.

Roxburgh et al. (2006), Mesloh et al. (2007) and Rickermann et al. (2007) suggests that the Cannibal™ Process is economically favorable for small to medium size plants and for those plants which already have aerobic digesters, which could be retrofitted for use as IR tanks. This makes this process particularly applicable to industrial wastewater treatment applications.

Physical Treatment Processes

All physical solids treatment processes are focused on causing floc disintegration and cell lysis, releasing the organic material in the cells for consumption, either in the secondary treatment process or the solids digestion process. Most of these processes operate on a continuum from cell wall damage to complete cell disruption, depending on the energy and intensity input. These processes use different physical methods to cause lysis, from ultrasound and pressure drop processes that cause cavitation, high temperature and pressure, electric pulses, shearing and homogenization. Some systems can be installed at a number of the different process locations shown in Figure 3, while others are more suited for particular locations. All the systems are sized on a volume basis, therefore the thicker the solids concentration the more cost effective the system to the maximum concentration limit of each system.

Figure 3. Potential Location of Physical Lysis Systems at a WWTP (adapted from Neis, 2000).



Thermal Hydrolysis - Cambi

Thermal hydrolysis uses temperature and pressure to convert cellular material to more biodegradable forms. Research into thermal hydrolysis for improved anaerobic digestion was started in the 1970's and was considered in process evaluation conducted by CH2M HILL for the City of Los Angeles in 1977. However, at that time, the technology faced a number of operational and maintenance problems, including high pressure pumping of the feed solids, fouling of heat exchangers and wear on equipment. In the 1990's thermal hydrolysis was evaluated in Norway, and has since developed into a viable technology, using newer technology, such as direct steam injection rather than heat exchangers. This process has received considerable attention in Europe, primarily through the efforts of Cambi AS, a company that grew out of the research in Norway. In the U.S. pilot-scale work has been done by the San Francisco Public Utilities Commission (SFPUC), using a two liter thermal hydrolysis unit (Panter et al., 2006). The systems that have been commercialized to date are based on a batch operation mode. Continuous thermal hydrolysis systems are being developed. Due to the high temperature and pressure conditions that occur in thermal hydrolysis, the cost of the equipment is high, and means that demonstration-scale equipment requires a significant investment and may not be cost effective if it is done at a small scale.

The technology may be retrofitted ahead of existing digesters, or may be incorporated into new facilities. Key advantages of thermal hydrolysis include the ability to operate digesters at high feed solids concentrations, of around 10 percent, due to improvements in viscosity through the process, improved biosolids dewaterability and the ability to achieve Class A pathogen reduction through operation of a batch treatment process. Increased hydrolysis of the feed solids provides

for improved gas production and solids destruction. However, the cost of high-pressure stainless steel tanks, heating and the need for operators trained in high pressure systems has impacted the cost and the acceptability of this process in North America. It has been realized that the cost of the system and some of the complexity may be reduced by treating only the WAS, rather than the primary and waste activated solids combined. This provides some important advantages over the previous approach:

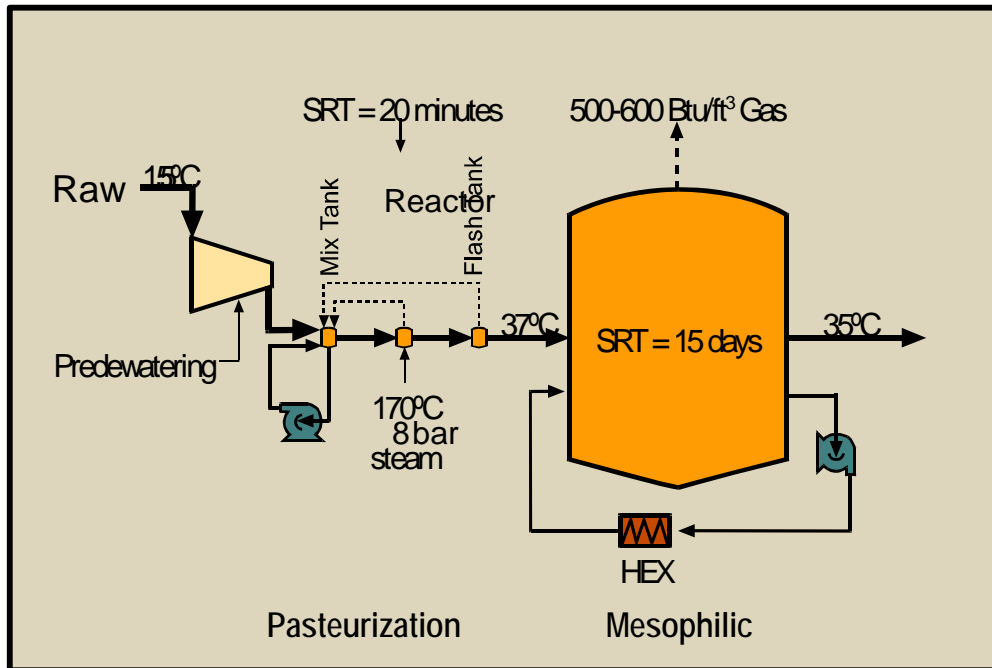
- Smaller system as only the WAS is treated, reducing costs.
- Heat recovery heat exchangers may be avoided as the heated WAS can be used to heat the primary solids, when heated WAS combines with primary solids in the anaerobic digesters.
- Treating only the WAS focuses the costs on the portion of solids with the highest return for improved digestion.

The continuous steam hydrolysis is in the early stages of development, this process review will focus on the Cambi[®] batch system. There are 13 Cambi[®] thermal hydrolysis process (THP) installations in Europe.

In the Cambi[®] THP process, shown in Figure 4, a three tank system is typical. Pre-dewatered solids, up to 15 percent solids concentration, are added to the feed tank. The feed tank is heated by the steam from the reactor and the flash tank. The solids are held in the feed tank until the reactor is ready for a batch. Solids are pumped to the reactor where they are held for a minimum of 20 minutes at 170°C and 8 bar pressure. Live steam is added to achieve this temperature and pressure. Steam is vented to the feed tank. At the end of the batch, solids are allowed to flow to the flash tank where the rapid expansion causes the cells to rupture and the resulting solids have considerably lower viscosity. The temperature is also reduced by flashing, so the temperature in the digester is about 37°C. By the addition of the water in the steam and the cell rupture, the resulting solids concentration to digestion is 10 to 12 percent. Due to the cell rupture, the solids are now easily pumped to the digestion process.

Normally, the solids in the digester will require no further heating. Although the Cambi[®] THP process requires considerable heat for steam, some heat is recovered in the process and is used for digestion. In order to improve the heat balance of the process, an alternative approach has been proposed for applications that do not require Class A pathogen requirements to be met. Applications of Cambi[®] THP in Europe treat the entire solids stream, including primary and secondary solids. However, the main hydrolysis benefit is on the WAS.

Figure 4. Cambi® THP Schematic (Cambi AS Literature).



Tests conducted in Germany on WAS only hydrolysis indicate that digesters could be fed at 8 percent TS combined WAS and primary solids, depending on viscosity and primary solids thickening efficiency.

Proteins and exopolymeric substances (EPS) have also been linked to reduced dewaterability. Thermal treatment above 100°C has been shown to denature proteins and EPS. The higher temperature and pressure of the Cambi® THP denatures and dissolves proteins improving dewaterability (Kopp et al., 2007). Bench scale tests on hydrolyzed WAS combined with untreated primary solids for anaerobic digestion showed a 25 percent increase in gas production and 8 percentage points improvement in dewatered solids content compared with the control although the polymer demand was higher with the Cambi® THP.

Research was recently conducted by Novak on DC Water and Sewer Authority (DCWASA) Pilot Plant Studies at Virginia Tech. During this pilot testing, volatile solids reduction, ammonia concentration, and dewatering were investigated. Pilot testing was performed on a control, conventional mesophilic digestion, and two Cambi® at 150° C with mesophilic digestion tests: 15 day SRT and 20 day SRT. Table 2 summarizes the results of this data. Volatile solids reduction improved by 15-19%. In the mesophilic digester with Cambi® system upstream there were significantly higher ammonia concentrations. According to Novak's ongoing research, there is some evidence indicating that in the thermal hydrolysis process, a derivative of protein hydrolysis is ammonia. There was a 37% increase in solids cake percent dry solids. The solids dewatering mechanism was a centrifuge simulation.

Table 2 – DCWASA Performance Data Summary for the Cambi[®] Pilot Study

Parameter	Conventional Mesophilic Digestion	Cambi [®] – 15d SRT	Cambi [®] – 20D SRT
VSR	50%	57.7%	59.6%
Ammonia		2,446 mg/L	2,134 mg/L
Dewatered %DS	24.4%	33.5%	33.5%
Cake Odor*		Improved by 10%	Improved by 10%
* measured as volatile organic sulfur compounds			

The initial DCWASA pilot testing performance of solids reduction for the Cambi[®] was similar to the conventional digester but over a year of operation, the solids destruction increased by 8 to 10 percent. This is believed to be because the biota become acclimated to the high ammonia concentration; hence, ammonia inhibition declined or was eliminated. This suggests that short term testing may not provide data that will be consistent with full scale operation.

Pressure Release – Crown Biogest

BIOGEST[®] PLC Crown[™] disintegration system, Taunusstein Germany, is a multiple stage system without chemical preconditioning. It may be used on a RAS side stream to reduce solids production from the secondary treatment process, or on the WAS feed to improve digestion. System components include:

- Homogenizer or macerator
- Crown[™] disintegrator nozzle
- Control system
- Pressurization pump
- Recirculation tank
- Discharge pump

The Crown[™] disintegration system uses the principle of a carefully controlled cavitation process. This type of cavitation is generated by operating the system at 12 bar and pumping through the disintegrator which is a pressure reduction nozzle. Cavitation occurs in the second part of the nozzle due to the sudden pressure drop. Between 30 and 100 percent of the WAS flow may be treated through the system. Typically the WAS is cycled round through the disintegrator three times. For anaerobic digester applications the vendor claims at least 20 percent increase in gas production and 15 percent reduction in dry solids volume.

Figure 5. Crown™ Disintegration System at Rosedale WWTP, North Shore, NZ.

The Crown™ installation list includes 17 permanent facilities. Most of the existing installations are in Germany. The Crown™ system was also installed at North Shore City's Rosedale WWTP in New Zealand. North Shore City decided to install a Crown™ system to improve digester and control foaming. As most cell lysis systems are sized on flow rate, to reduce the size and cost of the system a WAS thickening system was included as part of the bid package. Flo-Dry Ltd., the local representative of the Crown™ system, won the project and installed a gravity belt thickener and the disintegration system. Thickening increased the digester retention time from 17 days to 24 days. The system met the performance requirements to achieve 23 percent increase in gas production (Susarla et al., 2006). There were some initial problems, primarily related to pumping the solids when WAS TS concentration was higher than 6.5 percent. Tables 3 and 4 summarize the data from several Crown™ installations. According to this data summary, volatile solids reduction (VSr) improved on average by 28 percent and percent dry solids of cake improved by an average of 18 percent.

Table 3 – Crown™ Performance Data Summary

Site Name	PE	Location	Vol Trtd (m3/h)	VSr %			Biogas production cf/lb VS des		
				Before	After	% increase	Before	After	% inc
Wiesbaden Biebrich	130,000	Germany	12	32%	38%	20.0%	25.1	24.7	-1.7%
Taunusstein	30,000	Germany	6	32%	44%	38.9%	22.6	20.8	-7.8%
Ingelheim	200,000	Germany	6	36%	49%	34.1%	17.0	17.7	4.4%
Ginsheim	32,000	Germany	6	45%	54%	19.9%	14.7	14.3	-3.1%
Münchwilen	30,000	Germany	4	32%	43%	32.0%	20.2	19.1	-5.3%
Rosedale WWTP	650,000	New Zealand	6	51%	62%	21.6%	18.2	17.9	-1.8%
Average			7	38.1%	48.3%	27.7%	19.6	19.1	-2.6%

Note: Analysis of data not by WERF

Table 4 – Crown™ Dewatering Performance Data Summary

Site Name	DS after dewatering %		
	Before	After	% increase
Wiesbaden Biebrich	31	36	16.1%
Taunusstein	31	36	16.1%
Ingelheim	28	34	21.4%
Ginsheim	20	23.4	17.0%
Münchwilen	22	26.4	20.0%
Rosedale WWTP	18.5	22.2	20.0%
Average	25.1	29.7	18.4%
Note: Analysis of data not by WERF			

MODELING METHODOLOGY

As part of the WERF 05-CTS-3 *Evaluation of Processes to Reduce Activated Sludge Solids Generation and Disposal*, a modeling approach will be developed to better assess the performance of these systems. The primary mechanisms claimed for solids reduction include:

1. Breakup of cellular material and flocs to improve hydrolysis rates
2. Conversion of non-biodegradable organic material to material biodegradable under normal treatment conditions
3. Cultivation of predator organisms to reduce overall yield
4. Anaerobic conversion of biodegradable material

The modeling of solids reduction is proposed to include both items 1 and 2. Item 3 does not yet have adequate supporting evidence, and item 4 is already a well understood and captured process.

In terms of modeling these processes for floc and cellular breakup, activated solids and digestion use different state variables and processes. IWA's Anaerobic Digestion Model 1 (Batstone et al 2002) uses a two step process to model the break-up and hydrolysis of flocs and cells. The first step is disintegration that converts composite particulate material to individual particulate components. Hydrolysis then acts upon the individual particulate components. Most mechanical solids reduction methods can be modeled by assuming higher fractions of material go directly to the hydrolysis step, rather than having to pass through the disintegration step. This disintegration step is not standard in activated solids modeling, so the only method of capturing increased rates of solids reduction is to increase the rate of hydrolysis of particulate organic matter and increase biological decay rate.

Calibration of ADM 1 for sludge reduction may be done in three steps. First, the influent fractionation of sludge into ADM 1 can be estimated through the modeling of the liquid stream processes. Current modeling practice has a very good understanding of the transformations within liquid stream processes, and this can be used to develop a relatively accurate fractionation of the ADM 1 influent solids. Once this is done, the two items that need calibration are the rate

expressions for disintegration and hydrolysis. These rate expressions only become significant when digestion is operated at high rates, or in acid phase digestion. Batch testing can be done to determine these rates for a given sludge. The second aspect is the amount of influent non-biodegradable COD that is converted to biodegradable COD by the sludge reduction process. This can be determined by running parallel digestion reactors at extended SRTs with and without the sludge reduction process. The difference between the two will give that conversion.

It is not believed that the mechanical solids reduction processes significantly affect the fraction of non-biodegradable material created by cell decay. Processes such as Cannibal™ and thermal hydrolysis both exhibit solids reduction capabilities that are beyond that achievable through simple increased hydrolysis and decay rates. In related research (Johnson et. al. 2008), it was hypothesized that these processes convert non-biodegradable material to a form that is biodegradable. Johnson was able to model the Cannibal™ process through the conversion of particulate inorganic (Xi) to slowly biodegradable (Xs) material under anaerobic conditions. Similarly, it is hypothesized that the high pressure and temperature of the thermal hydrolysis process converts a portion of the Xi material to material that is degradable under anaerobic digestion conditions.

Calibration of biological sludge reduction processes, such as Cannibal, can be based on either historical experience or upon pilot testing, when using ASM based models. Once the performance is known, the appropriate parameters (discussed above), can be manipulated to give the measured performance.

DISCUSSION

The state of development of solids minimization technologies continues to advance, both for applications within the liquid treatment process and for digester pre-treatment. Most technologies have full-scale applications on industrial and/or municipal wastewater in Europe and Australasia, with a much slower implementation rate in North America. The exceptions to this trend are the combination biological processes such as Cannibal™, which have been developed in North America and found wider acceptance. However, many technologies have a limited number of installations (e.g. chemical treatment technologies) and some technologies have shown mixed performance, particularly on applications in North America (e.g. physical pre-treatment for digestion). Solids reduction performance reported in the literature ranges from around 20 percent for some of the physical lysis processes to 80 percent for combination biological processes and some chemical treatment processes.

NEXT STEPS

Understanding the mechanisms and process parameters is important in evaluating the applicability of the technology for a particular waste stream and economic conditions. The WERF 05-CTS-3 *Evaluation of Processes to Reduce Activated Sludge Solids Generation and Disposal* is an important step in further understanding these processes. The project is expected to be complete in the third quarter 2009. It will provide a modeling approach as discussed herein that will enable users to determine the potential benefit of various WAS reduction processes. The evaluation methodology will include an Excel spreadsheet based life-cycle cost module to consider both capital and ongoing O&M costs. The life cycle analyses will use standard Net Present Value and payback period approach to provide a quantitative comparison of the selected solids reduction technologies and a baseline or 'do nothing' project alternative. Non-financial criteria will be evaluated by multi-criteria analysis methodology to provide a framework to

qualitatively assess each the potential of each candidate WAS reduction technology to meet desired objective in site-specific Key Result Areas which will include non-financial type criteria as well as technical and economic project criteria.

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