THERMAL HYDROLYSIS OFFERINGS AND PERFORMANCE

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Abstract

There is growing significant interest in the use of thermal hydrolysis technology in conjunction with mesophilic anaerobic digestion (AD) to manage biosolids in the North America marketplace. This is being driven by the desire to obtain Class A exceptional quality biosolids and to improve the dewaterability of the biosolids to reduce the amount of solids that subsequently must be managed. Because of this interest, a number of thermal hydrolysis vendors are entering the marketplace. Cambi has developed the majority of operating facilities worldwide. In North America, Cambi has one operating facility in Washington, DC (DCWater). Other vendors are aggressively working to enter the thermal hydrolysis marketplace including Veolia with their Kruger BioTHELYS® and Exelys™ offerings, Sustec/Turbotec and Haarslev. Nuances between traditional processing of the entire solids stream through these thermal hydrolysis processes (THP) and development of alternative processing of only a portion of the solids stream, processing after digestion, and even intermediate processing between stages of digestion are being developed. Many claims are made in vendor literature related to these technology offerings and only recently has information about performance been available. The purpose of this paper is to provide an unbiased review of the various thermal hydrolysis systems currently available in the marketplace to provide comparisons of actual performance of several full scale operating systems.

Keywords

Thermal Hydrolysis, Sewage Sludge, Anaerobic Digestion, Advanced Digestion, Biosolids

Introduction

There is growing significant interest in the use of thermal hydrolysis process (THP) technology in conjunction with mesophilic anaerobic digestion (AD) to manage biosolids in the North America marketplace. This is being driven by the desire to obtain Class A exceptional quality biosolids, to maximise volatile solids reduction and enhance biogas production from AD for use in combined heat and power systems, and to improve the dewaterability of the biosolids to reduce the amount of solids that subsequently must be managed. Further, the reduced viscosity of the hydrolysed sludge allows feeding AD at much higher solids content which in essence, reduces the needed digester capacity by half or more over conventional mesophilic digestion alone. Because of this increasing interest in THP, a number of thermal hydrolysis vendors are entering the marketplace. Cambi has developed the majority of operating facilities worldwide. Further, because Cambi has been developing systems for more than 20 years, their technology has been refined through several generations of improvements. In North America, Cambi has one operating facility at DCWater with several other installations in various stages of planning and design. Other vendors are aggressively working to enter the thermal hydrolysis marketplace in North America including Veolia with their Kruger BioTHELYS® and their newest Exelys™ offerings, Sustec/Turbotec, Haarslev and Eliquo Water. A listing of the number of facilities provided by these vendors that are on line or in design/construction is shown in Table 1 based on vendor provided information.

Table 1 - List of Thermal Hydrolysis Installations by Vendor

Vendor	Full-Scale Facilities Built (const.)	Capacities of Installed Base DT/day	Since
Cambi	43(+9)	6 to 360	1995
Veolia - BioTHELYS	6 (+2)	3 to 100	2004
Veolia - Exelys	1 (+3)	10 to 66	2014
Sustec – TurboTec	2 (0)	20 to 35	2012
Haarslev	2 (0)	20 to 25	2014
Lysotherm	2 (0)	3 to 33	2016

Further, nuances between traditional processing of the entire solids stream through these THP systems and development of alternative processing of only a portion of the solids stream, processing after AD, and even intermediate processing between stages of AD are being developed.

Many claims are made in vendor literature related to these technology offerings. Only recently has information about some of the newer full scale system performances been available in the published literature.

The purpose of this paper is to provide an unbiased review of the various thermal hydrolysis systems currently available in the marketplace to provide comparisons of actual published performance of several operating systems. The manuscript also provides details on the decision factors associated with each technology option, the expected benefits and compares the technical design and operating data for the various THP offerings in the marketplace.

Thermal Hydrolysis Technology Offerings

The following section provides a general process description of the offerings provided in the THP market as of this writing. The information in this section is provided largely by the system vendor suppliers with minor modification by the authors.

Cambi™ Thermal Hydrolysis Process

According to Cambi™, more than 40 Cambi™ THP installations are operating in Europe. In the Cambi™ THP process schematic diagram shown in Figure 1 (Typical Mark II arrangement) pre-dewatered solids, up to 17 percent solids concentration, are added to the feed or pulper tank. The pulper tank is heated by recycled steam from the flash tank. The solids are held in the pulper tank until the reactor is ready for batch processing. Solids are pumped to the reactor where they are held for a minimum of 20 minutes at 170°C (338°F) and 6 bars (90 psi) pressure. Steam is added to achieve this temperature and pressure. At the end of the batch, solids are allowed to flow to the flash tank where the rapid expansion causes the bacterial cells to rupture and the resulting solids have considerably lower viscosity. The temperature is also reduced by flashing, but supplemental cooling is also required to reduce the temperature of the solids to feed the AD at about 37°C (99°F). By the addition of condensed water from the steam and further addition of dilution water, the resulting solids concentration fed to AD is 8 to 10 percent. Due to the cell rupture, the solids are easily pumped to the digestion process, allowing for a digestion feed solids concentration much greater than the typical 4 to 6 percent.

The Cambi THP process includes four main steps:

1. Heat recovery, thermal buffering and sludge heating in the pulper
2. Thermal hydrolysis in the reactor tanks
3. Pressure let-down and steam flash in the flash tank
4. Cooling of the hydrolyzed solids prior to AD

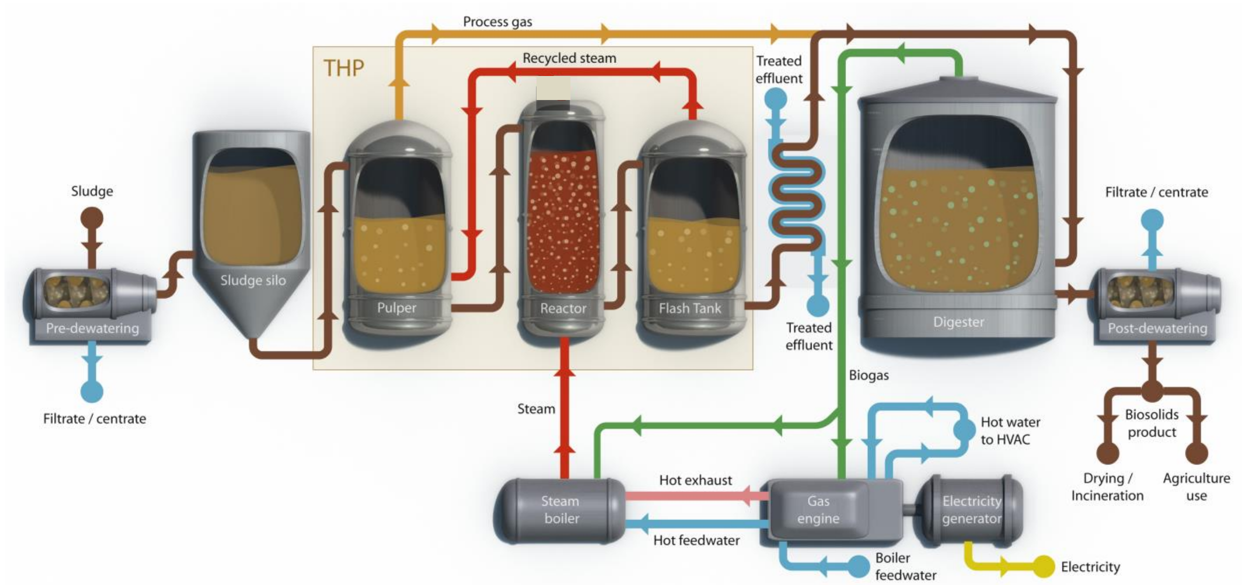

FIGURE 1 - Cambi™ Thermal Hydrolysis Process Schematic, Mark II System Configuration

When the hydrolysis process is complete, the main outlet valve in the bottom of the reactor is opened, and the solids are transferred to the flash tank, where the pressure is reduced to about 1.5 bar. Flashed steam released in the flash tank is recycled to the pulper. The rapid release of pressure due to this single flash of the pressure release and blow down causes the cells to rupture, which significantly decreases the viscosity of the solids. After depressurising, the solids are diluted, mixed with recirculated digestate and pumped through a heat exchanger to cool and feed into the digesters. Because of the addition of steam and dilution water, the solids content at this point in the process is reduced to approximately 8 to 10 percent. Because of higher solids content in the digester feed which is about two to three times the solids content of the typical digester feed solids, the resulting digester volume requirements are decreased to one-third to one-half of normal.

The time cycle for the thermal hydrolysis process is approximately as follows:

- 29 minutes for filling the solids and injecting steam into the reactor
- 20 to 30 minutes' retention time in the reactor
- 15 minutes' blowdown to the flash tank

The total time for one cycle is thus approximately 64 to 74 minutes. Although the Cambi™ process is a batch process, multiple sequencing reactors can be operated to achieve a semi-continuous flow between the pre-dewatering and the AD system.

The solids in the digester following the Cambi™ reactor generally require no further heating. Although the Cambi™ THP requires considerable energy for steam, some heat is recovered in the process and is used to preheat solids prior to hydrolysis. To improve the heat balance of the process, an alternative approach has been used for applications that do not require Class A pathogen requirements to be met. Because the main hydrolysis benefit is on the secondary solids, thermal hydrolysis could be applied only to the secondary solids. This reduces the THP tankage size and volume and the amount of steam required. The thermally hydrolysed secondary solids can then be mixed with unheated primary sludge to bring the combined feed temperature to that required for AD thereby minimizing or eliminating the need for supplemental cooling.

Recently, Cambi has begun offering a variation of their THP system referred to as the SolidStream™ THP technology. Figure 2 shows the process schematic. SolidStream™ is installed downstream of AD. The digestate is dewatered to about 17%TS and hydrolysed. Following hydrolysis, the sludge is flashed, passed through a pressure/flow control vessel, then dewatered and cooled. The high strength centrate is sent to the AD to generate more biogas. This configuration was developed in an effort to enhance dewaterability even more than conventional THP since the first plant with this technology installed in Amperverband, Germany incinerates the treated solids and so the higher cake solids that results can be burned autogenously. Cambi claims the system increases biogas production in digestion by 25% and that the dewatered solids content is approximately 40 %, as well as reduced steam consumption, based on the performance of this 4000 tDS/year demonstration facility.

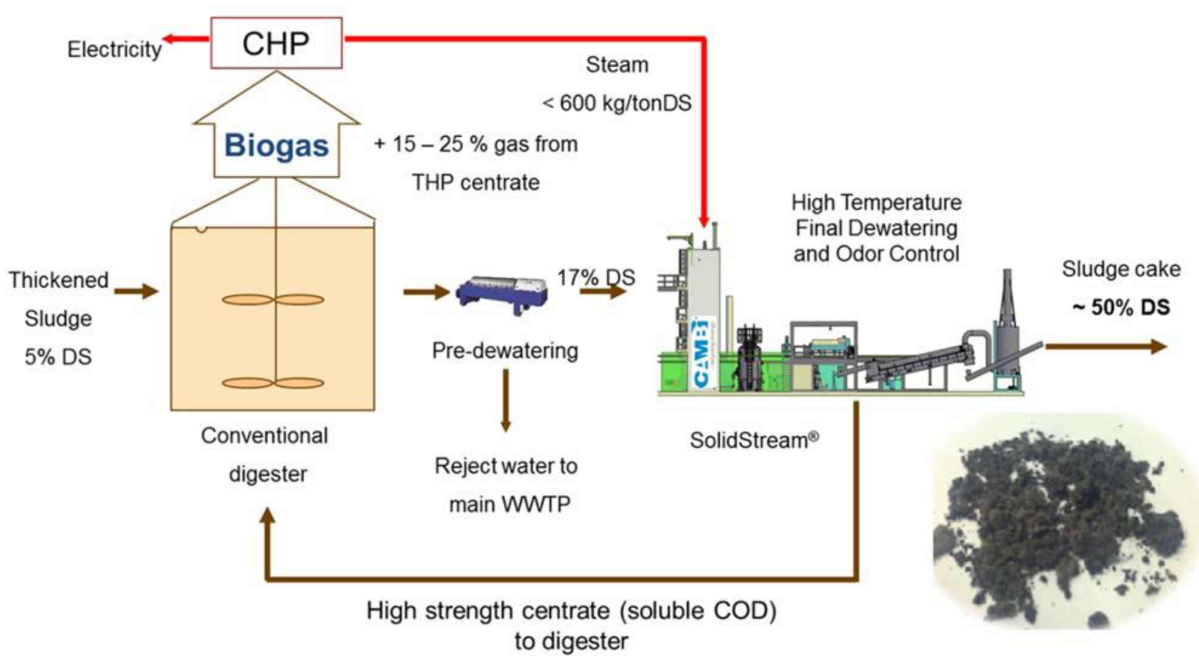

FIGURE 2 - Cambi™ Solid Stream Thermal Hydrolysis Process Schematic

Kruger/Veolia THP Processes

A similar THP system has been commercialised by Kruger/Veolia and installed in several European locations. As shown in Table 1, there are two primary configurations offered by Kruger/Veolia. The first configuration is BioTHELYS® as shown in Figure 3. The BioTHELYS® process is a batch thermal hydrolysis system that operates at a temperature range of 130°C to 150°C (285°F to 330°F) at pressures between 8 and 15 bars (130 to 220 psi). Dewatered solids from a storage silo or hopper are fed to the BioTHELYS® process via a progressive cavity pump. After the solids are loaded into the reactor, both live steam and flash steam recovered from another reactor is added to the solids until the temperature within the reactor is raised to the required level for thermal hydrolysis to occur.

After the solids are at the required temperature and pressure for thermal hydrolysis, the solids are held in the batch reactor for 30 minutes to allow hydrolysis to occur. After the reactor, the solids are flashed into a buffer tank to partially cool and then fed from there to a heat exchanger to further cool the solids and allow addition of dilution water to dilute and cool the solids as required by the downstream AD process.

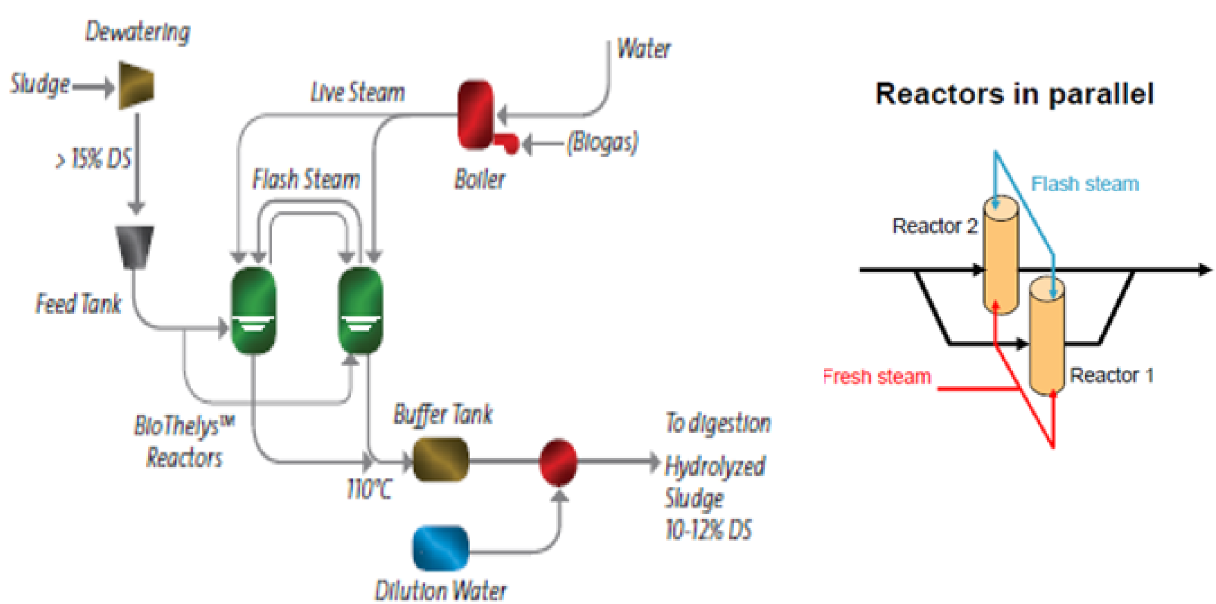

FIGURE 3 - The Veolia BioTHELYS® Process Schematic

Figure 4 presents a process schematic of the continuous feed Exelys™ process.

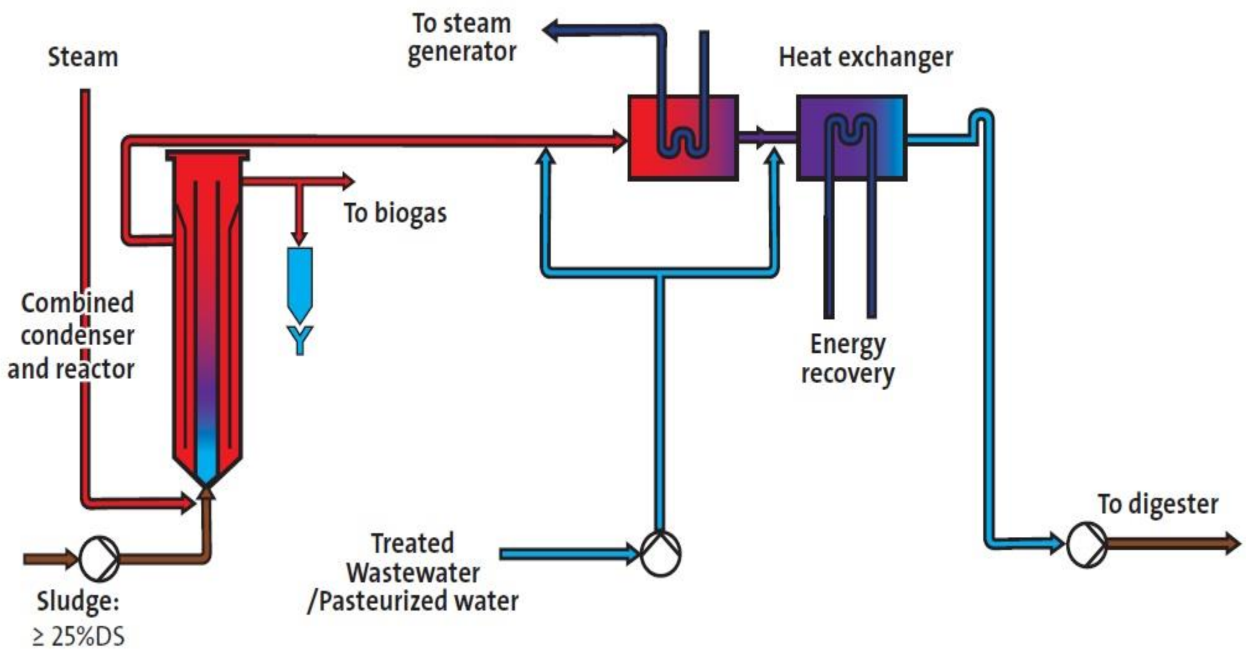

FIGURE 4 - The Veolia Exelys™ Process Schematic

The Exelys™ process is a continuous plug-flow thermal hydrolysis system that operates in a temperature range of 130°C to 150°C (285°F to 330°F) at pressures between 8 and 15 bars (130 to 220 psi). Veolia claims this continuous configuration is less costly to build and to operate than the batch THP configuration due to less complex equipment layout and more optimised energy usage.

Dewatered solids from a storage silo or hopper are continuously fed to the Exelys™ process via a progressive cavity pump. As the solids enter the system, steam is continuously added to the system through a dynamic mixer to the reactor vessel. As the mixture moves through the vessel, the steam condenses transferring heat to the solids and raising the temperature to a required level for thermal hydrolysis to occur. After the solids reach the required temperature and pressure for thermal hydrolysis, the solids continue through the reactor and flow at a low velocity resulting in plug flow. According to Veolia, this plug-type flow ensures there is no short-circuiting and all the solids are under thermal hydrolysis conditions for the required residence time.

After the reactor, the solids enter a heat exchanger system to cool the solids to a suitable temperature for the downstream mesophilic or thermophilic digestion process without requiring supplemental heating in the digesters. The heat exchangers are a tube-in-tube design. After the heat exchanger system, there are provisions to inject treated wastewater into the solids. The water injection can be used to dilute and cool the solids as required by the downstream AD process.

The final component of the Exelys™ thermal hydrolysis system is the pressure holding pump. This pump is controlled to maintain a pressure set point in the Exelys™ system. In most cases, the pressure holding pump can also be used to feed the downstream AD process.

As illustrated in Figure 4, both the primary and secondary solids are processed in the Exelys™ system. After the solids have been hydrolysed, heat is first recovered for use in the steam generator. The second heat exchanger recovers process energy that can be exported from the system. Dilution water is added, and the hydrolysed solids are then added to the digester recirculation line. Due to the thermal hydrolysis process, the solids concentration into the digester can be up to 8 to 10 percent.

Kruger/Veolia offer several configurations of both THP systems including the LD configuration placed before digestion or the DLD configuration which places the THP unit between a primary and secondary digester. The Exelys™ DLD process is offered as an option with the intent to minimize the THP system size and potentially increase the overall volatile solids reduction (VSR) of the THP digestion system. Operating performance data supports the assertion that higher VSR is possible with this configuration but at a somewhat lengthy SRT in digestion (Gurieff et al, 2012 and Djafer et al, 2016).

Sustec TurboTec® Process

Figure 5 presents a process schematic of the TurboTec® THP system. There are two TurboTec® THP plants in operation in Europe processing domestic wastewater solids. This continuous feed THP process is only used to treat secondary sludge currently, but a mix of primary and waste activated solids could also be used. Secondary sludge is fed to a mixer where the hydrolysed sludge is blended to heat it up. The secondary sludge temperature of about 20°C is mixed with partially cooled hydrolysed sludge at 105°C. This heats the mixture to approximately 65°C. Because of the difference in viscosity between the hydrolysed sludge and that of the un-hydrolysed secondary sludge, the TurboTec process uses its patented Mobius mixer/separator to separate the thinner sludge and feed it to the digester whereas the thicker sludge is fed through a heat exchanger and then into the hydrolysis reactor. Sustec claims that by utilising this process a minimal amount of steam is required to heat up the already preheated sludge to the reactor temperature of 140° C (Pereboom et al, 2014). Sustec also claims the amount of COD that is carried out in post digestion dewatering centrate/filtrate is less by operating at the lower reactor temperature than other THP system suppliers. Data was not available in the published literature at the time of this writing to substantiate that claim although other researchers have drawn similar conclusions in laboratory trials.

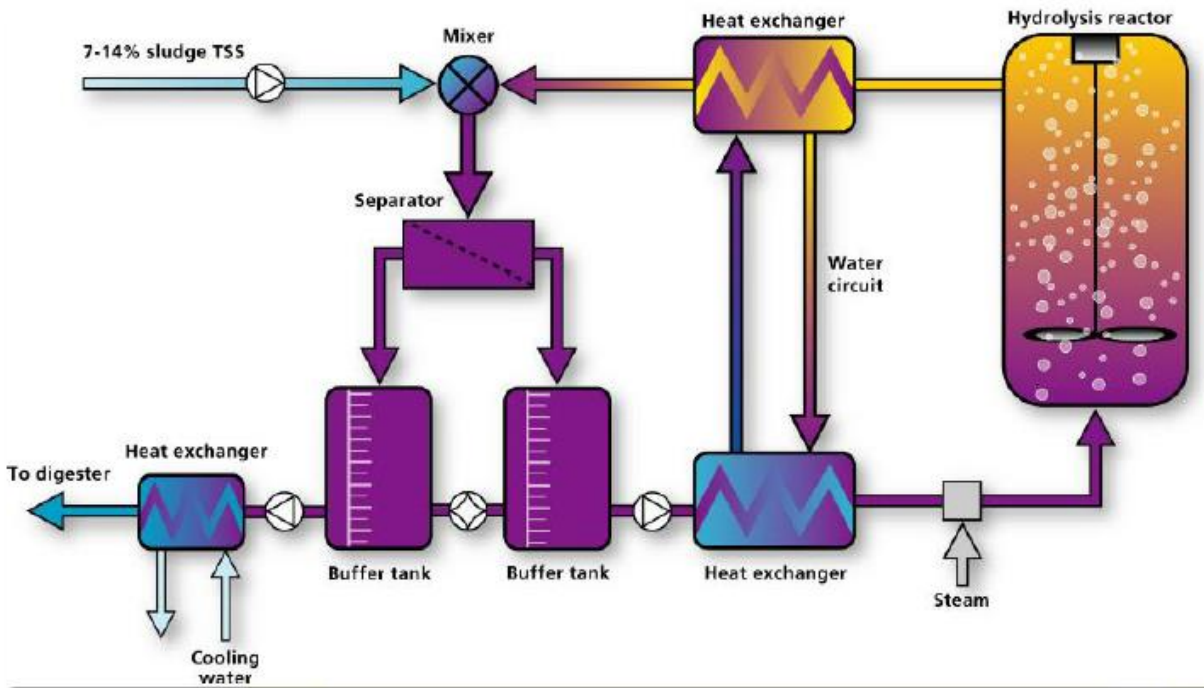

FIGURE 5 - Sustec TurboTec® Thermal Hydrolysis Process Schematic

HAARSLEV Continuous Hydrolysis System (HCHS) Process

Haarslev has two THP plants in Europe processing domestic wastewater solids. One plant has been in operation since 2014 and the other has been in intermittent operation since 2014 due to other WWTP improvements. The Haarslev Continuous Hydrolysis System (HCHS) THP process schematic is shown in Figure 6. Dewatered sludge is fed to the enclosed preheater hopper which uses waste vapours from the pressuriser and the economiser tanks to heat the sludge up to about 85°C. Sludge is then pumped to the pressurizer in 60-120 second cycles where steam is added to increase the pressure to 6.5-8 bars. The reactor operates at 6 bars and 165°C so when the pressuriser discharge valve is opened, the solids are released to the reactor. Sludge is fed to the top of the reactor vessel and maintained in the reactor for 20-30 minutes. The hydrolysed solids are discharged out the bottom through a flash valve to the economiser tank which operates at approximately 0.2 - 0.5 bar and 105°C where the solids are held for another 10 minutes. Steam vapour is vented back to the sludge preheater. A second flash happens when the sludge is then released to the cooler tank which operates at negative 0.5 - 1.0 bar. This vacuum cools the sludge to an operator adjustable set point of approximately 60°C. Cooled condensate and/or effluent is added to the hydrolysed sludge to achieve the desired AD input temperature of 40°C and provide the desired solids content being fed to the digester. In secondary sludge only applications, the primary sludge can be used for this purpose. The system is semi-continuous. The reactor, economiser and cooler operate in continuous plug flow mode. 10 bar, 185°C steam is required to operate the system (Hilstrom, 2015).

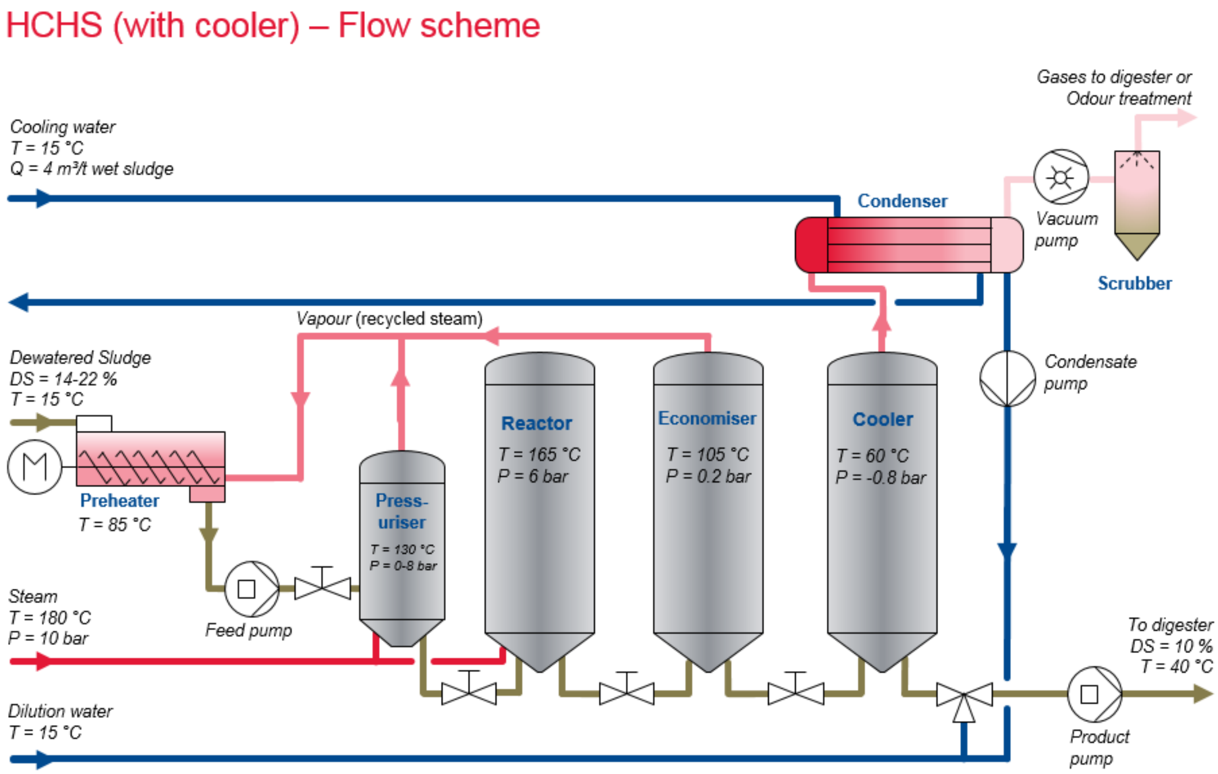

FIGURE 6 - HAARSLEV HCHS Thermal Hydrolysis Process Schematic

Lysotherm® Sludge Hydrolysis Process

Lysotherm offered by Eliquo Water Group has two facilities constructed and still in start-up mode, one in Amersfoort, Netherlands and one in Lingen, Germany. The Lysotherm® process allows continuous operation and is based on the indirect heating of sludge with two heating circuits. A closed regenerative water circuit to pre-heat and after-cool the sludge and a thermal oil circuit with heat recovered from the CHP. No steam is used. In the first stage of the heat exchanger system the sludge is preheated using recovered heat from the cooling phase. The thermal oil circuit provides the tubular hydrolysis reactor with the required process heat. This heat is extracted with a heat exchanger from the flue gas of the associated CHP engines or from a boiler system. Hydrolysis takes place at 140-170 °C in the reactor zone for 15-30 minutes. After hydrolysis, the sludge is cooled in the heat exchanger to the temperature required for feeding the digester. The regenerative circuit uses water as the heat transfer medium. This circuit recovers the heat from the hydrolysed sludge cooling system so it can be used for preheating the first stage (Geraats, 2014). Figure 7 shows the process flow of the Lysotherm® sludge hydrolysis system.

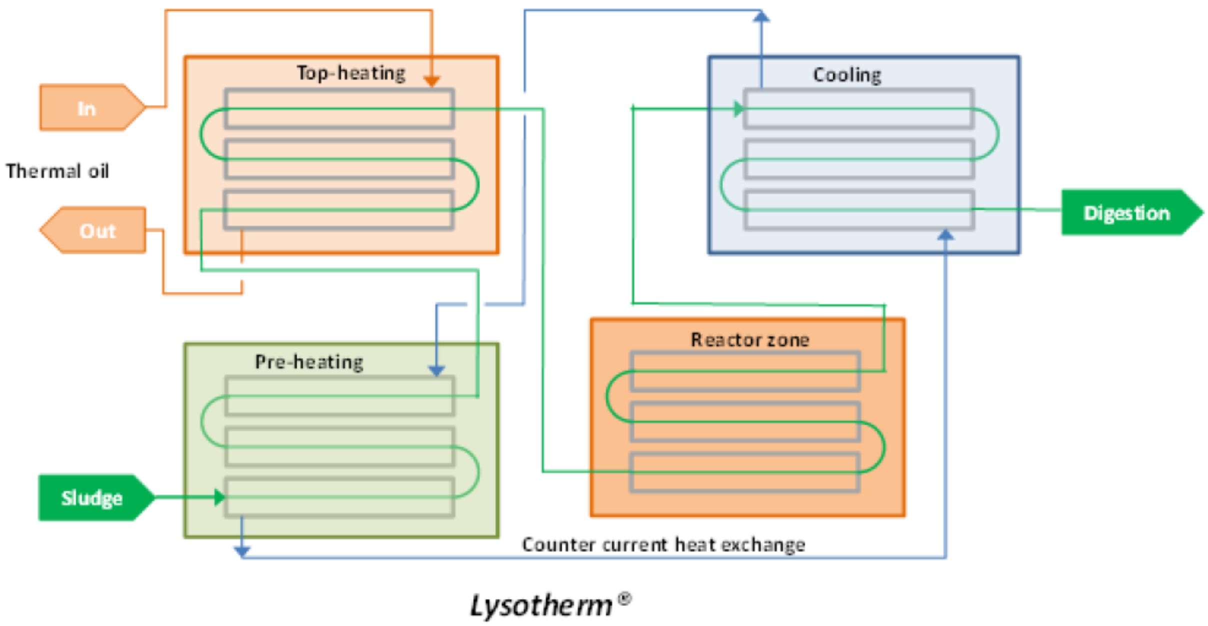

Figure 7 - Lysotherm® Process Flow Diagram

Full Scale THP/Mesophilic Anaerobic Digestion Performance Results

As mentioned previously, there are several drivers for the interest in THP processes in North America and other locations. One driver is the desire to obtain Class A exceptional quality biosolids. By processing both primary and secondary solids through THP processes and demonstrating that solids are exposed to an adequate time (>20 minutes) and temperature (>50°C) within the process, Class A process to further reduce pathogens as defined by the US EPA is achieved.

Maximising VSR and enhancing biogas production from AD for use in combined heat and power systems is another main goal of THP. Documented improvements of VSR after the addition of THP can be significant. At the Davyhulme, UK Cambi THP plant, digestion VSR reportedly increased from 43% to over 58% after the THP system was placed on line (Belshaw et al 2013). Other THP installations have yielded similar improvements in VSR (Fjorside, 2002).

Improvement in dewaterability of the digested biosolids is also reported at a number of THP facility installations. At the Venlo, Netherlands facility, dewatered cake solids increased from an average of 22 percent solids to an average of 29 percent solids after installation of the TurboTec THP system (Pereboom, 2014). Similarly, at the Hillerod WWTP, installation of the demonstration Exelys™ intermediate THP system improved dewatering after digestion from 24 percent solids to between 28 and 30 percent solids

(Gurieff et al, 2012). Recently, the Crawley, UK facility near the Gatwick airport reports dewatering improved from 25.8%TS to 33.6%TS on average since the Cambi B6 system was installed in 2014 (Panter et al, 2016).

Perhaps the most well documented performance improvement is the fact that due to decreased viscosity of THP sludge, virtually every system installation allows feeding the digesters with a much higher solids content material, typically between 9 and 11 percent solids (Merry et al, 2014, Edgington et al 2014, Chauzy et al, 2014, Hilstrom, 2015 and Panter et al, 2016). This one improvement alone reduces needed digester capacity by half or more over conventional mesophilic digestion.

An example of the performance of various THP configurations coupled with AD as reported in the literature is shown in Table 2 (Rus et.al. 2015), based on field scale pilot testing performance. These results show the impact of THP and AD on VSR, biogas yields and expected improvements on dewaterability of various THP configurations.

Table 2 - Performance of Various Thermal Hydrolysis Configurations as Reported by Rus et al 2015.

Parameter	Units	Conv AD	Conv THP	SAS only THP	Int-THP	High DS THP (Post)
# of systems in service		>1,000	>30	6	Pilot	1
VS Reduction	%	44%	59%	55%	65%	55%
Gas Yield	% Increase	N/A	134%	125%	149%	130%
Digester volume	%	100%	31%	57%	63%	100%
THP Size (approx.)	%	-	100%	40%	60%	60%
Dewaterability (BFP/Piston)	% DS	21 / 30	32 / 45	28 / 35	34 / 48	42 / 60

A review of published literature on full scale system performance was conducted in an effort to determine data trends that have been observed. Table 3 shows a summary of this performance data for 18 full scale plants (9 Cambi, 2 TurboTec, 2 Haarslev, 3 Veolia and 2 Lysotherm). Because of the different authors and the different data collection emphasis each paper presented, a complete summary of all data parameters was not feasible to ascertain for more than a handful of installations on many parameters. One of the key aspects of performance is the amount of volatile solids reduction achieved during digestion after THP is applied, which directly correlates to gas production and reduction of solids requiring final disposition. Nine plants with reported data were compared to see if any correlation exists between digestion residence time and volatile solids reduction achieved. Eight of the plants operated in conventional THP of both primary and secondary sludge followed by AD. Seven are Cambi installations and one is Haarslev. One plant operated in a DLD configuration using Kruger/Veolia Exelys™ and the overall digestion residence time (76 days in that case) was used. Figure 8 below shows this data. Analysis was performed to determine if any correlation appeared to exist. The variation of the data does not support any strong correlation with this limited data set. The amount of primary vs. secondary sludge does not appear to have significant impact on this relationship. All plants are achieving very good volatile solids reduction except the one plant where the digestion residence time was less than 15 days and the VS reduction was reported to be only 51%.

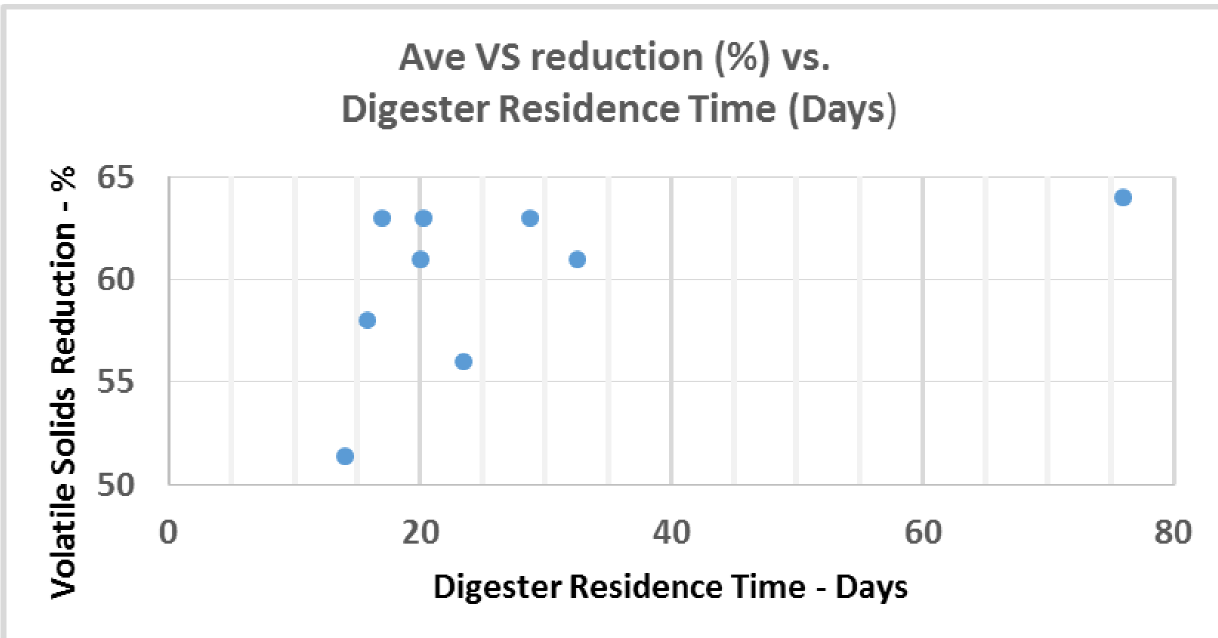

Figure 8 - VSR vs. Digestion Detention Time for 9 THP Plants

An interesting correlation was found when comparing the impact of the percentage of primary sludge in the THP feed vs. the dewatered cake solids achieved after digestion. Again, 9 THP plants reviewed had data to compare. It has been asserted that the amount of primary sludge vs. the amount of secondary sludge will impact the dewatered cake solids that can be achieved. Figure 9 shows that this impact becomes more pronounced after the amount of primary solids exceeds 50%. It is interesting to note that two installations actually achieved higher cake solids with 100% secondary sludge compared to plants with 12%, 20% and 26% primary sludge in their mixtures (Chauzy, 2014 and Pereboom, 2014). These data closely correlate with a second order polynomial function with a very high correlation coefficient of 0.872.

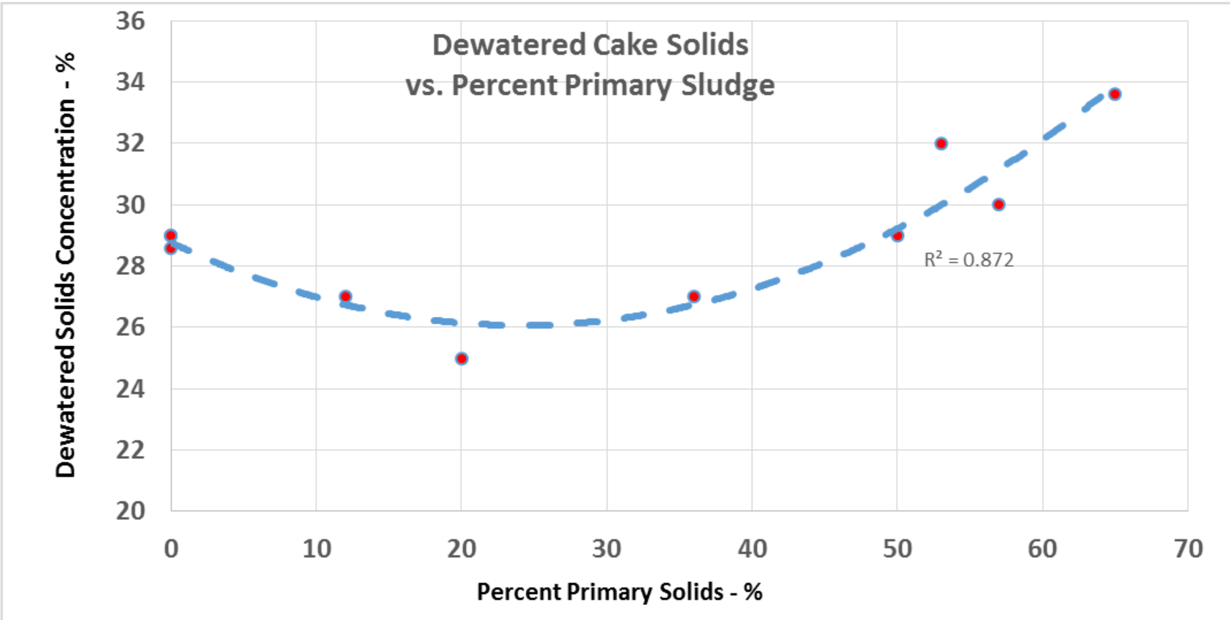

Figure 9 - Dewatered Cake Solids vs. % Primary Sludge in THP/MAD Feed

Eight plants had data for both digestion residence time and dewatered cake solids. As shown in Figure 10, when a first order logarithmic regression was performed on this data set, a very poor correlation was found (R^2 = 0.1493).

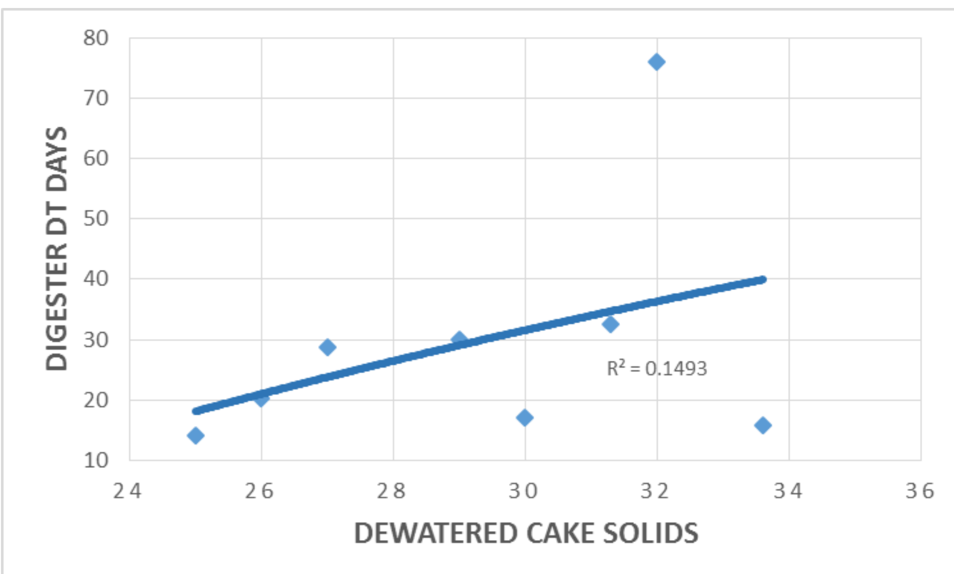

Figure 10 - Dewatered Cake Solids vs. Digester Detention Time in Days

Based on this literature review, it appears that the only significant correlation of performance of dewatered cake solids exists compared to the amount of primary solids in the mix. Other factors are suspected to overshadow any apparent correlation between digester residence time and volatile solids reduction or dewatered cake solids. However, it must be realised that this is a limited data set that was reviewed based on available literature references.

An area where much attention is being made in newer THP systems is energy use optimisation. Dampening of the steam demand by developing continuous or semi-continuous operating regimes as compared to batch only systems is being used more frequently in an effort to minimize the steam system capacity and the amount of biogas required for firing these systems. There are also operations that utilise jacket cooling water from combined heat and power systems to pre-heat the cake before THP thereby lowering the THP steam demand (Panter et. al., 2016). There is a wide range of specific steam consumption values reported in the literature and shown in Table 3 from a low of 0.745 tonnes steam/tonne dry solids at the Venlo, Netherlands plant to a high of 1.44 tonnes steam/tonne dry solids at the Bran Sands facility (Pereboom, 2015 and Merry et al., 2014). Methods of cooling the hydrolysed biosolids through use of primary solids or cooler effluent water are being used in process designs to reduce the cooling demand. There are trade-offs of this approach to process secondary sludge only in the THP system in cases where Class A product is not absolutely required. If a wastewater utility does not need to achieve Class A status for their biosolids through AD either because Class B is adequate for their program or subsequent processes such as thermal drying is used to meet Class A pathogen standards, THP of secondary sludge only could be a more economical choice than applying THP to the entire solids stream. Key benefits of secondary sludge only THP installations compared to full THP of secondary and primary solids are summarized below:

- Significantly less steam/heat energy is required, about 50% less because of the reduced mass being treated by THP
- Significantly smaller pre-dewatering system
- Less polymer use in pre-dewatering
- Smaller THP system components
- By using primary sludge to cool the THP solids prior to digestion, no or little supplemental cooling is required
- Digester throughput is increased due to the increased treated secondary solids content
- More biogas is available to fire a combined heat and power system
- More favorable overall energy balance results
- No need for sterile polymer dilution or wash water in post dewatering

There are other thermal hydrolysis suppliers in the marketplace but at the time of this writing, the authors could not obtain sufficient published documentation to present operating performance. Therefore, these offerings were not included in this paper but are mentioned here as published performance data will likely be available in the next year or two. PONDUS, a Chemical-Thermal hydrolysis system has two operating facilities in Gifhorn (2005) and Uelzen (2014) Germany and a new facility in Kenosha, Wisconsin, USA (2016).

Conclusions

With ever increasing attention to cost, biosolids quality, and resource recovery in biosolids management, the North American market has responded with the introduction of the thermal hydrolysis process (THP) as a pre-treatment or intermediate step in AD. Indeed, while the thermal hydrolysis process is somewhat new in North America, there are more than 50 operating THP installations globally, with several vendor/supplier options available. Now that the thermal hydrolysis process has its first installation in North America at DCWater with several other projects in the planning and design phase, wastewater utilities are frequently choosing to compare THP with AD as an alternative to include in biosolids planning analyses. What is common in the results of full scale installations is a much higher solids feed to the anaerobic digesters (9-11 percent solids typically), improved volatile solids reduction and biogas production, and significantly improved dewaterability of the digested solids, especially when there is a higher percentage of primary solids in the feed. For these reasons, the THP technology will continue expanding its reach in North American installations over the next decade.

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Table 3 Full Scale THP Systems Performance Data as Reported in the Literature

System Supplier		Cambi									TurboTec		HAARSLEV		Veolia BioTHELYS LD		Veolia Exelys DLD	Lysotherm	
Parameter	Units	Howdon, UK	Bran Sands, UK	Cardiff, UK	Afan, UK	Davyhulme, UK	Aberdeen, UK	Fredericia, DK	Naestved, DK	Crawley, UK	Venlo, NL	Apeldoorn, NL	Lancut, PL	Grevesmuhlen, DE	Esholt, UK	Oxford, UK	Lille, FR	Amersfoort, NL	Lingen, DE
Year on line		2012	2009	2010	2010	2013	2002		2000	2014	2014	2015	2014	2014	2013	2015	2014	2016	
Design Throughput	tDS/Yr	32,000	36,500	30,000	20,000	91,000	16,500	8,000	850		7,000	13,000	1,500	3,500	32,800	26,000	13,800	12,000	1,200
Design Throughput	tDS/Day	88	100	82	55	249	45	22	2	31	19	36	4.2	9.6	90	70	41.8	33	3.5
Average Throughput	tDS/Day	80.9	92.3	62.9	29.5	203	33	21		25.6	19.2	24.7	3.6				35		
Percent of Capacity	%	92%	92%	77%	54%	81%	73%	95%		83%	100%	69%	86%				84%		
PRI	%	61	50	12	36			57		65			50	20			53		
WAS	%	39	50	88	64			43	100	35	100	100	50	80	100	100	47		
Ave THP Feed	%TS	15	15	15.6	16.8	16.5		18	18	16.5	11		16	19.5	16		22		
THP Reactor Temperature	C	165	165	165	165	165		160			140		165	165			165		
Ave Digester Feed	%TS	9	9.3	8.5	10	11	9.5	9	8	10			9	5	10		11		
# Digesters	#	3	3	2	2	8		2		2	2		1	2			1	3	
Capacity/Digester	m^3	6,000	6,700	7,500	4,250	7,500		2,000		1,940	2,300		1,300	900			6100	2700	
Total Capacity	m^3	18000	20100	15000	8500	60000		4000		3880	4600		1300	1800			6100	8100	
Ave Nominal Detention Time	Days	20	20.3	20.3	28.8	32.5	23.5	17		15.8			30	14			76		
VS loading to digester	kg VS/m3/d					3.39				5									
Dewatering Equipment				centrifuge		centrifuge	BFP	centrifuge	BFP	BFP	centrifuge		centrifuge	centrifuge			centrifuge		
Ave Dewatered Cake	%TS			27	27	31.3	32	30	28.6	33.6	29		29	25	29		32		
Specific Steam Consumption	tonnes/tDS	1.17	1.44	1.01	1.04	0.861				0.88	0.745		1.1	0.92	1				
Specific biogas production	Nm^3/tDS	442	435	343	376	252		412		407	350		650	424	286		414		
Ave VS Reduction	%	61		63	63	61	56	63	57	58	41		53	51.4	48		64	57	
Reference		1,2	1	1,2	1,2	2	3	4	4,5	12	6,7	6,7	8	8	9	9	10	11	11

References Denoted in Table 3:

1 Merry et al, 2014

2 Edgington et al, 2014

3 Wilson et al, 2003

4 Evans, 2003

5 Fjordside, 2002

7 Pereboom, 2015

8 Hilstrom, 2015

9 Chauzy et al, 2014

10 Djafer et al, 2016

11 Geraats, 2015

6	*Pereboom, 2014*	*12*	*Panter, et al, 2016*