Next Generation Thermal Hydrolysis Process - High Solids THP

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Abstract: A circular economy should benefit the consumer without producing waste or pollutants. In the wastewater industry, it is imperative we identify opportunities and develop solutions to harvest materials that appear to have little value and turn them into a valuable resource in order to realize the benefits of a circular economy. Thermal Hydrolysis is a proven cell lysing application for resource recovery in a sustainable and profitable manner from wastewater treatment plant. Two distinct thermal hydrolysis solutions have evolved, one a batch process and the other a continuous process. The two solutions are applicable in various configurations and each with unique features that will readily improve performance of existing anaerobic digesters or add considerably value to new digestion facilities. Often, the right solution for a wastewater treatment facility is not obvious. With energy cost on the rise and increase in population stressing the available natural resources, it is imperative that thermal hydrolysis efficiencies are improved to lower environmental impact. Numerous facilities across the globe have benefited from thermal hydrolysis, information from these facilities can be used to determine the ideal solution for most wastewater treatment plants. The design evolution, performance improvements, and lessons learnt over the past decade can also be used to assist wastewater treatment plants to fully realize the benefits of the circular economy.

Keywords: Biosolids; Thermal Hydrolysis, Sustainability, Anaerobic Digestion

Introduction

It is well known that anaerobic digestion (AD), with the right design and additional organic feedstock, integrated with a combined heat and power (CHP) can provide a vehicle to deliver cost-effective and energy net neutral solutions for wastewater treatment plants. The feasibility and sustainability of AD/CHP can be improved considerably with pre-treatment, such as cell lysing, which will enhance digester performance, improve energy recovery in the form of increased biogas production and achieve Class A quality biosolids.

Thermal Hydrolysis Process (THP) was first applied to improve sludge dewaterability (Haug et al.,1978), but has since grown into a pre-treatment for anaerobic digestion. THP is the engineered application of temperature (320 to 330°F) and pressure (87 to 130 PSI) to more effectively break down sludge. The lysing process decreases the viscosity of the material and increases available volatile solids for anaerobic digestion. Decreased viscosity alters the rheological properties to improve the digested sludge's dewaterability. Increased volatile content entering the digester increases methane production and reduces the amount of biosolids for disposal. The secondary benefits of lysis include lowering downstream process equipment requirements, reducing process chemical costs and production of Class A biosolids for ease of disposal and beneficial use as bio-fertilizer.

In short, thermal hydrolysis solves numerous challenges at a wastewater facility including increasing treatment capacity, reducing biosolids handling, increasing biogas production to reduce energy utilization, reduce operation cost for biosolids processing, produce renewable bio-fertilizer.

The typical process flow for THP includes a pre-dewatering step upstream (Figure 1) of the TH process. Unlike conventional process flow schemes that include thickening upstream of the AD, pre-dewatering for THP achieves solids content as high as 20% prior to digestion. This allows for processing a larger volume of solids within a small THP footprint. Post THP sludge may require dilution to maintain homogenous solids dispersion, uniform heating and sub-toxic ammonia levels.

The typical, or standard, process flow for THP has been successful with close to 70 installations worldwide. When compared to traditional mesophilic digestion without THP pre-treatment, the typical process flow generally achieves the following improvements:

- 10 to 25% higher volatile solids reduction in the digesters
- 10 to 20% higher methane generation
- 5 to 15% greater cake solids from dewatering.

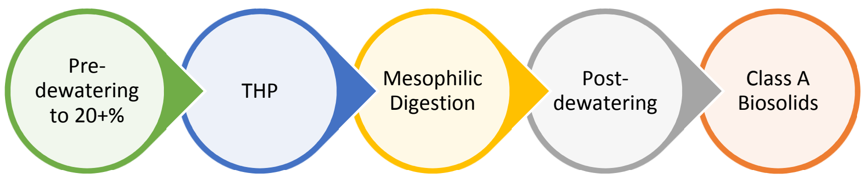

Figure 1: Typical Process Flow for the Thermal Hydrolysis Process

The success of THP, as evidenced by the increasing rate of installations and the treatment capacity in recent years (Figure 2), has been attributed to two methods for achieving thermal hydrolysis: one a batch process and the other a continuous process. The two solutions are applicable in various configurations and each with unique features that will readily improve performance of existing anaerobic digesters or add value to new digestion facilities.

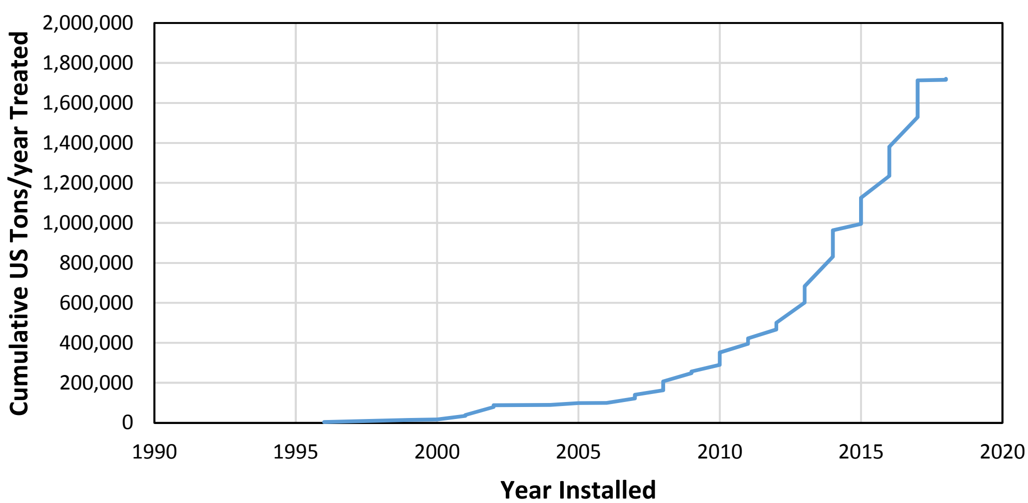

Figure 2: Growing Treatment Capacity of THP Installations Worldwide

Various factors such as flow rate, strength of waste, existing infrastructure, disposal method, operation experience and federal, state and local funds available for the facility dictate the direction of the solution. The process has also evolved over the years, adding new features and development that has resulted in compact, efficient process solutions for converting sewage sludge to a source of renewable energy and a usable biosolids end product.

Objectives

Although batch and continuous thermal hydrolysis processes have been successful, advances in both approaches may further enhance the established benefits of THP. In this paper, various types of thermal hydrolysis solutions along with their specific design features, system configurations, and operational variations are discussed, which aims to achieve the following:

1. Introducing adaptive application of THP technologies;
2. Providing the most feasible and economical THP configuration per specific sludge characteristics and unique field conditions;
3. Finally providing experts' insights about THP design and operation as a reference for municipalities and/or industries considering adopting advanced pre-treatment technologies for their organic wastes

Comparison

Thermal hydrolysis evolution over the last three decades is summarized in the schematic below. Two distinct thermal hydrolysis solutions have evolved, one a batch process and the other a continuous process. The former is well established technology but it requires minimum thickened sludge volume due to its steam delivery method using lances and its application is limited to the Lysis - Digestion (LD) using THP followed by AD mode only. The latter is relatively new and its applications are versatile due to the steam delivery method using dynamic mixers and can be configured in the LD mode, the Digestion - Lysis - Digestion (DLD) mode, and the Digestion - Lysis (DL) mode. Industry consensus is that the continuous THP system is relatively more adaptive to unique field conditions (Abu-Orf, et al, 2012).

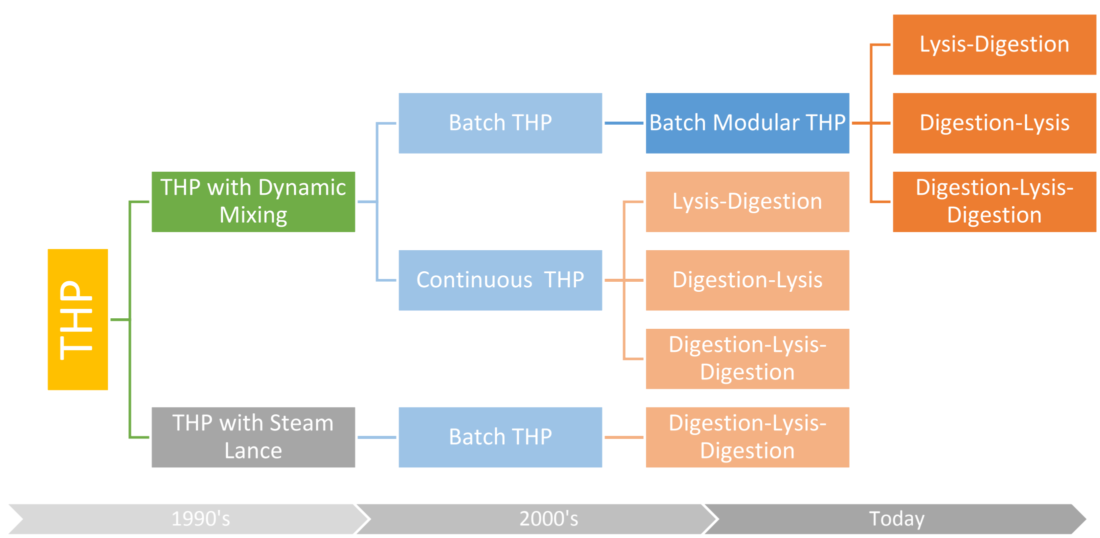

Figure 3: Evolution of THP

The ability to apply high pressure steam directly on to dewater sludge is a measurable efficiency of the TH process. The efficiency of thermal hydrolysis process to lyse the cells, which in effect is responsible for both the change of fluid rheology and the subsequent benefits described earlier is directly proportional to the efficiency of heat transfer from high pressure steam to directly on to the sludge.

The principal difference between thermal hydrolysis designs is the mode of operation. While the majority of the installations worldwide are operating in a batch mode, the continuous mode process is fast becoming an acceptable alternate to the design with various added value and advantages over the batch system.

The batch process has been in use for over thirty years, however the process has evolved over time. The process represented below is the next generation thermal hydrolysis. This new design of the process operates at a temperature range of 310-330 °F and at 100 psi. The process requires energy, but the majority of this energy is created by the process in the form of biogas combustion in combined heat and power systems and the subsequent heat captured from the exhaust of the CHP. Furthermore, the system is insulated and cladded resulting in minimal heat loss and also allows the flexibility to place the system outdoors.

In the process shown in Figure 4, the actual pressure heating of the sludge cake is taking place at 310 – 330 °F and 100 psi pressure for 20 minutes or more inside one of the four reactors.

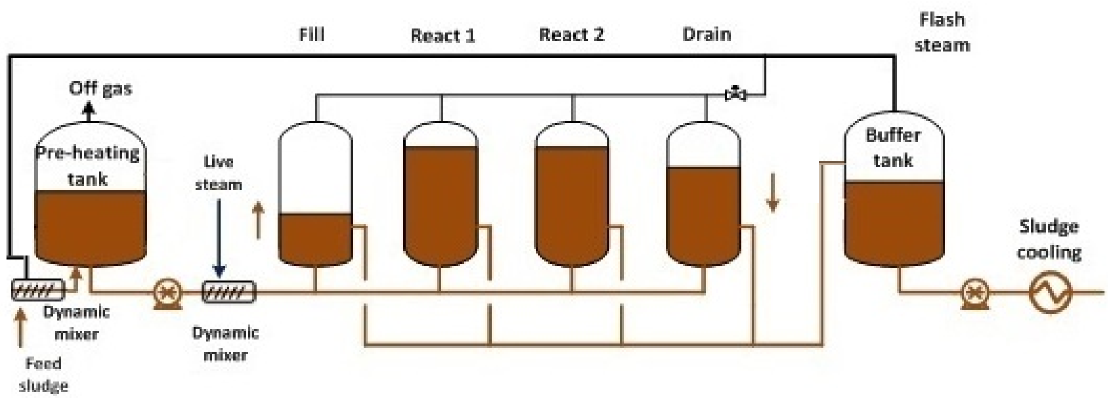

Figure 4: Batch System – Typical Scheme

The process, while by definition considered a batch operation, is a continuous flow batch THP system that utilizes three separate stages. They are typically (i) a Pre-Heating Tank, (ii) n number of batch TH Reactors (usually four, as shown in figure 4), and (iii) a Buffer Tank.

The sludge cake is pre-heated to 80 to 100°C in the Pre-Heat Tank. Here it is continuously receiving ambient temperature sludge cake and flash steam (from the Buffer Tank). This pre-heated sludge is then conveyed via progressive cavity pumps through a dynamic mixer where live steam is introduced and mixing and full condensation takes place.

The sludge structure and rheology is modified by two effects:

- Mechanical shear
- Temperature and pressure impacts

As a result, the viscosity of the sludge is significantly decreased. The dynamic mixers are a commonly used technology in the food, cosmetics, paint and dairy industries.

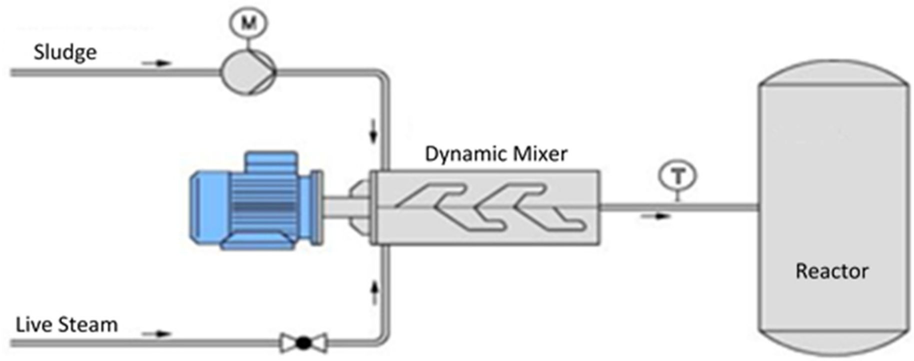

Figure 5: Dynamic Mixer used to condense live steam on incoming sludge

In the newer designs, live steam is directly injected in line upstream of the TH Reactors, allowing further optimization of the equipment designs such as tanks sizes, plant layout, and plant height. No heat transfer through steam lances is performed inside the TH Reactors; this reduces mechanical maintenance requirements and reduces system downtime. The process reactors operate in a sequence of Fill, React and Drain.

In the process the TH reactor vessels operate in a sequenced Fill, React, Drain configuration. The sludge feed is continuous, with each reactor fed in turn while the other reactor(s) are in React phase or being drained/transferred to the Buffer Tank. The depressurisation associated with the sludge transfer to the Buffer Tank produces flash steam which is recovered in the Pre-Heat Tank.

This sequence ensures that maximum benefit is realized from the energy value of the steam while reducing capital cost for tanks, structures, and equipment access platforms, and decreasing the overall foot print of the system.

In the older designs, live steam was injected into the TH reactors via steam lances. This limits the operational range of the TH in terms of solids concentration to about 17% dry solids. This requires water to be added to dewatered sludge to dilute the concentration down which creates an inefficiency within the process train as most modern dewatering units are capable of dewatering sludge to a much greater concentration with minimal effort and cost. This compels results in increased chemical and operating costs for the older THP design.

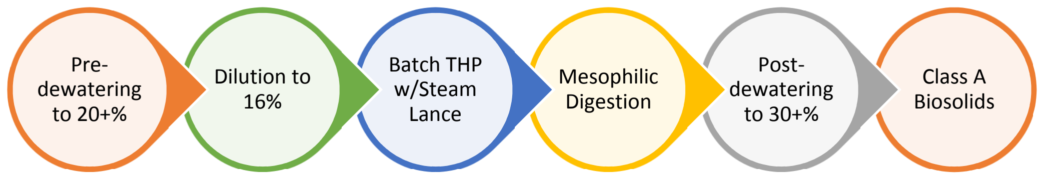

Figure 6: Old, process is limited by solids loading, requiring dilution of dewatered sludge

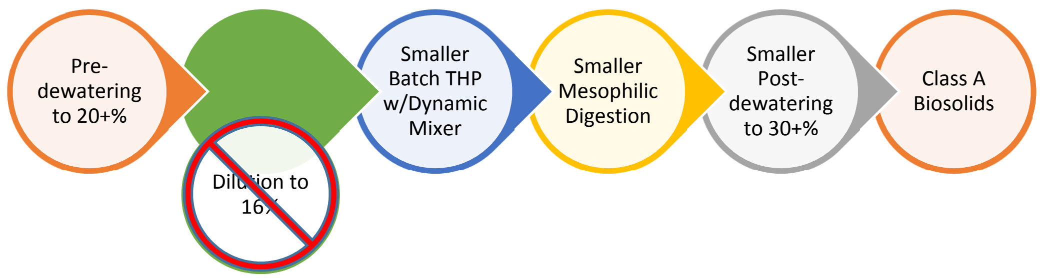

Figure 7: New, more efficient design allows for smaller footprint and higher solids load

Batch to continuous mode of operation is a normal evolution of a process giving a smaller footprint, simpler control and easier service and maintenance (Stedman, 2010). The continuous thermal hydrolysis process operates at a temperature range of 285°F - 330°F at pressures between 130 – 220 psi. Similar to the batch process, pre-dewatering is required.

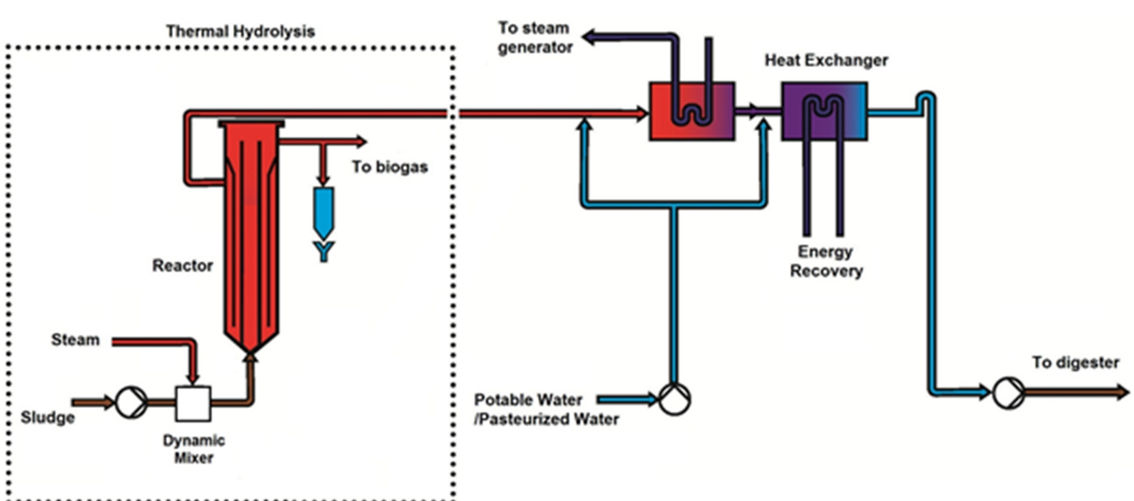

Figure 8: Continuous System – Typical Scheme

Dewatered sludge from a storage silo or hopper is continuously fed to the process via a -positive displacement pump. As the sludge enters the system, steam is continuously fed and mixed with the incoming sludge using a dynamic mixer, at the bottom of the reactor. This instantaneously blends live steam on to the sludge starting the condensation process.

As this mixture moves up and in to the reactor, the steam continues to condense onto the sludge, thereby transferring heat energy to the sludge and raising the temperature to that required for hydrolysis to occur. The sludge flow in the process combined condenser and reactor sections ensure a homogenous distribution of heat through the sludge and also capture any steam that has not condensed earlier. This ensures that all of the energy available from the steam injected is utilized effectively in the reactor, maximizing the energy efficiency of the process.

The reactor is typically a three pass tube in tube design, sludge at the required hydrolysis temperature and pressure at the top of the first concentric pipe flows to the middle pipe or first reactor section. In this section the sludge flows at a very low velocity, leading to plug flow conditions. This plug-type flow ensures there is no short-circuiting and all the sludge is under thermal hydrolysis conditions for the required amount of time. Subsequently, when sludge reaches the bottom of the first reactor section, it flows to the second reactor section or outer section. In the second reactor section, the sludge moves up completing the hydrolysis process. Once the sludge has been held for the required retention time of 20 minutes or more, it leaves at the top of the reactor.

Upon exiting the reactor, the sludge enters a heat exchanger system to cool the sludge to a suitable temperature for the downstream mesophilic digestion process without requiring supplemental heating in the digesters. The heat exchangers allow for easy cleaning and maintenance. The cooling water from the heat exchanger system can be used for pre-heating incoming cake, boiler water, building heat, or for other low temperature heat sources at the plant.

After the heat exchanger system, there are provisions to inject potable water into the sludge. The water injection can be used to dilute and cool the sludge as required by the downstream digestion process.

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

The continuous thermal hydrolysis process also allowed for new configurations that were previous not in use.

The three commonly used configuration are:

- LD – Thermal lysis (L) followed by digestion (D)
- DLD – Digestion (D) followed by thermal lysis (L), which is followed by digestion (D) is a patented process that was first demonstrated in 2009 and validated in Denmark (Gurieff et al., 2012)
- DL – digestion (D) followed by Thermal lysis (L)

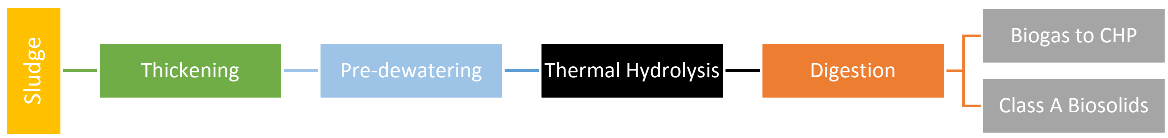

Figure 9: Sludge Lysing followed by Digestion Configuration

Lysis followed by digestion (LD) is the most traditional way to configure a thermal hydrolysis process. It has proven to be very effective in enhancing digestion performance while at the same time being cost effective. This configuration is typically used for larger facility with limitation of digestion capacity. Most batch thermal hydrolysis processes are utilized in this configuration. The most popular reference for this configuration is at a facility in Washington D.C, USA, using the CambiTHP^{TM} process.

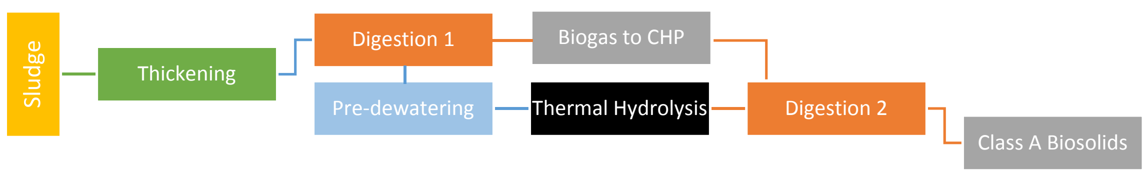

Figure 10: Digestion followed by Sludge Lysing and second stage Digestion Configuration

Digestion followed by lysis, followed by digestion (DLD) is a patented configuration and currently exclusively used with the continuous thermal hydrolysis process. It allows for the digestion process to degrade the simple, “easy to digest” organic compounds, followed by a small thermal hydrolysis process to break down the undigested organics, which is then sent back to a digester for degradation. This configuration works for both small and larger facility with excess digestion capacity. This configuration is especially advantageous if a continuous TH process is applied between two existing digesters. A well know reference for this configuration is a facility in Billund, Denmark using the Exelys^{TM} process.

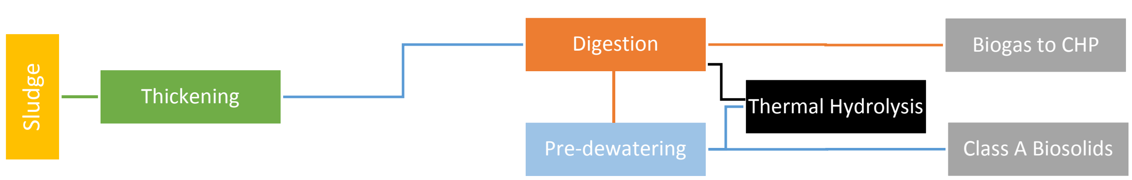

Figure 11: Digestion followed by Sludge Lysing Configuration

Digestion followed by lysis (DL) is a relatively new configuration and combines the benefits of the aforementioned configurations. It is a cost effective manner of achieving Class A biosolids and improve the energy profile of the treatment facility. This configuration is used in both small and larger facility with limitation of digestion capacity and limitations of room for expansion. The first known reference for this configuration is at a facility in Versailles, France, also using the Exelys^{TM} process.

A 2013 study that compared the various configurations of THP concluded that utilization of THP in any of the aforementioned configuration would result in smaller foot print of the anaerobic digestion facilities or increase of existing digestion capacity, high energy potential from biogas production and significant solids reduction across the process (Chauzy et al, 2013).

The central differentiating module that separates the older and newer design is in the mechanism of steam delivery. Older design relies on steam lances while the newer design utilizes dynamic mixers. This evolution extends the operational range to match the efficiencies of the dewatering unit, eliminating the need for dilution of dewatered sludge down to 16-17% DS. The new design is capable of operating at 28% DS, although typically designed at 23%, reducing footprint while improving energy utilization, production and management. The table 1 summarizes the major differences between the old and new design.

Table 1: Summary of Old vs. New TH Design

	Old	*New*
Mode	Batch	Continuous or Batch
Configuration	LD	LD, DLD, DL
DS%	16.5	Up to 28%
Operator Intensive	Yes	No
Dilution Required	Yes	No
Steam Injection	Lance	Dynamic Mixer
Lysing Efficiency	Medium	High

The graph in Figure 12is a plot of theoretical calculated biogas production over a range of input solids loading. The graph also shows the steam utilization on the secondary axis. In the new TH design, biogas potential is not impacted by concertation of solid, however there is a significant decline in biogas potential due to inefficient lysing of high concertation solids using steam lance. The steam requirement decreases with higher concertation solids input to the TH reactors. This is possible only if the steam delivery method is capable of handling high concentration waste. While dilution might be required post THP due to ammonia loading, higher solids TH allows the ability to reduce foot print, reduce energy usage in the form of steam, maintain the efficiency of upstream dewatering (pre-THP) process and improve overall efficiencies across the TH process.

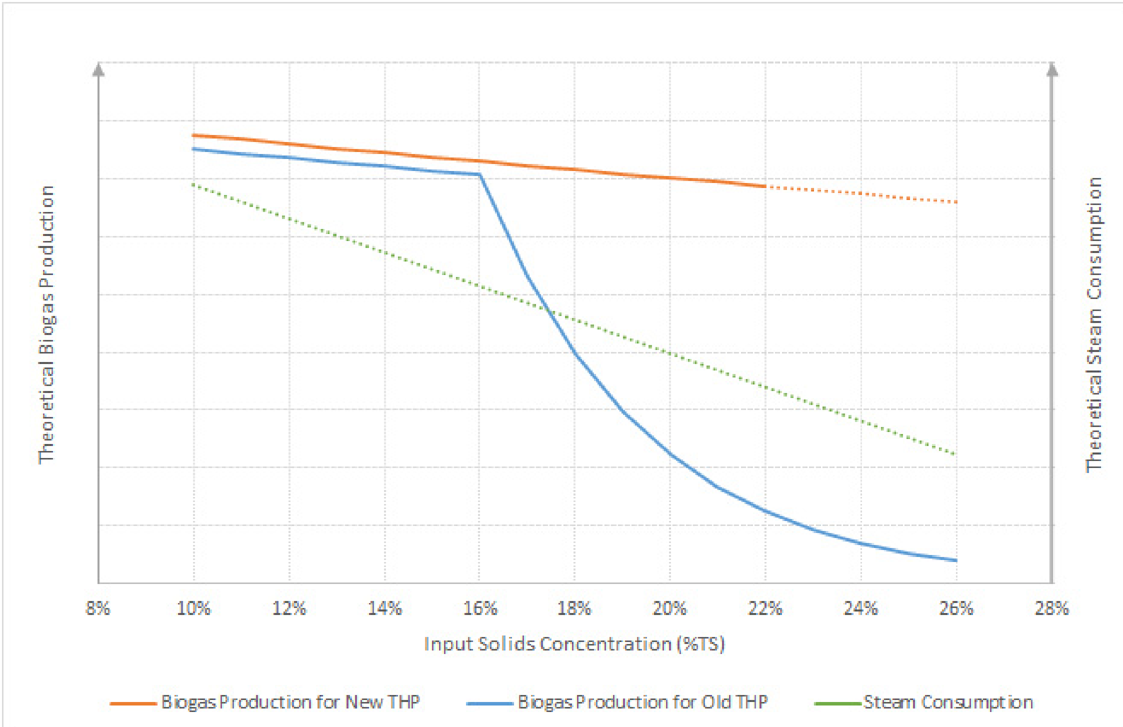

Figure 12: Improvements in design extends the operable solids loading concertation

Choosing the Right Technology

Careful consideration is required while selecting a thermal hydrolysis process. With information currently available and taking into account the evolution over the last three decades, it is now possible to evaluate feasibility and design application for any wastewater facility.

A high level evaluation of needs for any wastewater facilities should include study of:

- Current and future capacity of the plant
- Current and future energy needs and sources
- Current and future process efficiencies and available treatment options

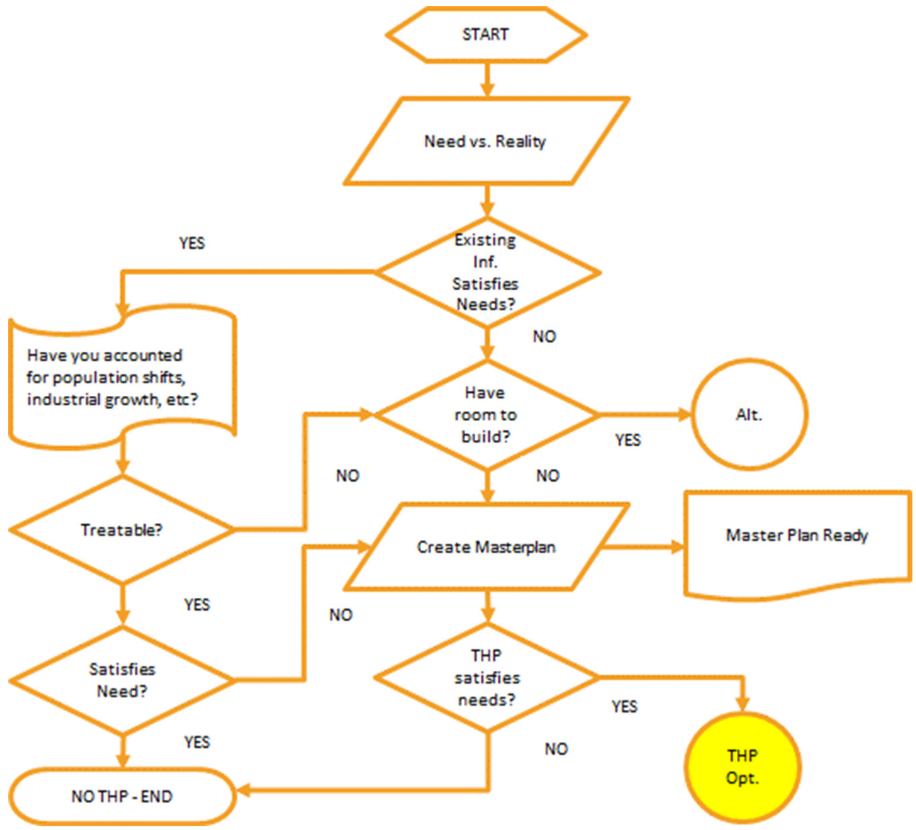

Figure 13: Example of Needs Analysis for THP

Other factors to consider during the needs analysis are sources and costs of energy, availability, conditions of existing infrastructure and capacities of:

- Mesophilic anaerobic digesters (MAD) - necessary for all THP
- Dewatering units - both pre-THP and post MAD
- Combined heat and power systems - to benefit from increased biogas production
- Biogas handling - especially to accommodate the increase in production
- Steam boilers - required for THP
- Heat exchanges - required to cool TH sludge

If it were determined that a THP is a feasible and economical solution for a wastewater facility, the analysis is shifted to determine the type of process to select. The following is an example of one such analysis.

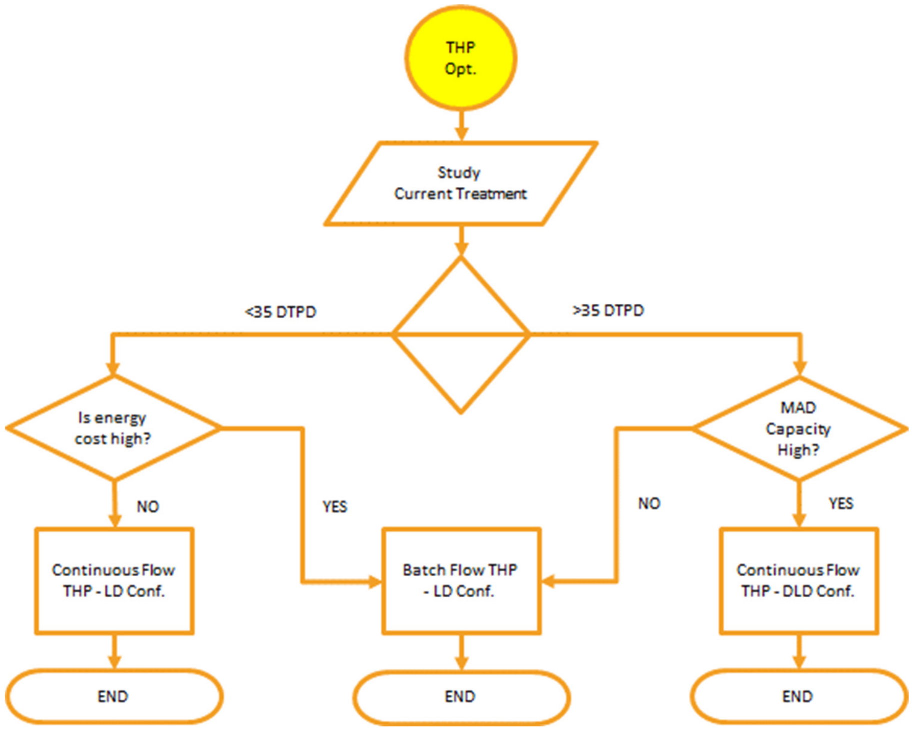

Figure 14: Example of Analysis to Determine THP Solution

An amalgamation of publically available data and proprietary information was used to determine the loading capacity that would benefit from a batch process as opposed to a continuous process. This study took into consideration

In the analysis to determine the right TH solution, it is evident that there is emphasis on economics based on loading capacity, this factor is not absolute and was determined based on publically bid THP projects worldwide and data correction to inflation, scope and currency. It is clear that there is a need and specific advantages to choosing the batch or the continuous process depending on the facility needs, status of current and future infrastructure and drivers such as capacity and regulation along with economic drivers like funding and available rebates.

Conclusions

With growing strain on resources due to population growth, thermal hydrolysis process is fast becoming the most versatile tool in biosolids management. The design evolution, performance improvements, and lessons leant over the past decade can also be used to determine the need and logically identify the solutions.

Thermal hydrolysis process solves not one but numerous challenges faced by wastewater treatment facilities including improvement in digester loading capacities by lowering viscosity, better destruction of organic waste by lysing, improve dewatering by eliminating extracellular polymeric substances, reduce volume of biosolids and reduce downstream equipment needs and chemical costs. The aim of this effort was to offer information and a tool demonstrating the differences, advantages and disadvantages of batch and continuous process and to determine the right THP solution for a given facility. Identifying and using the right solution will help wastewater treatment facility to fully realize the benefits of the circular economy.

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