INCINERATION VS. THERMAL HYDROLYSIS

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Abstract

Yorkshire Water Services (YWS) is seeking to move away from the use of incineration for sludge disposal in favour of Advanced Anaerobic Digestion (AAD) which comprises pre-treatment of the sludge using thermal hydrolysis, followed by mesophilic anaerobic digestion. The first plant in this programme is to be built at Esholt STW, Bradford, using the Biothelys thermal hydrolysis process as supplied by Veolia Water Solutions & Technologies (VWS).

This paper discusses the rationale behind YWS's decision to move to AAD together with the procedures which culminated in the choice of thermal hydrolysis process for Esholt, and also describes the Biothelys process in detail.

Key words

Thermal hydrolysis, incineration, anaerobic digestion, Biothelys, Enhanced Treated Sludge, Bio-Energy Strategy

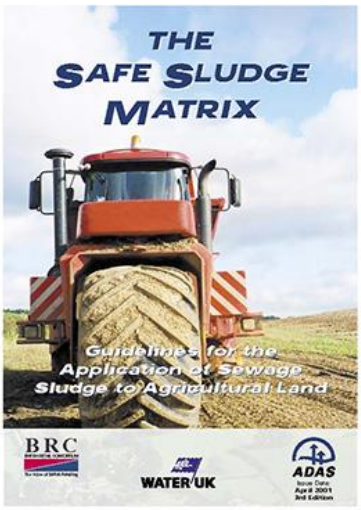
What is Thermal Hydrolysis?

Thermal hydrolysis (subsequently abbreviated in this document to TH) is a process which is used to treat sewage sludge, either raw primary or secondary (e.g. surplus activated), or a mixture of both by the application of high temperature and pressure (i.e. approximately 140-170 ^{o}C and 6-8 bar) for a period of 20-30 minutes.

Its effect is to disintegrate the cellular structure of the sludge and break down high molecular weight organic materials into smaller molecules. It also dissolves naturally occurring cell polymers (a form of protein) into an easily digestible feed for anaerobic digestion, resulting in a considerable increase in biogas yield.

The sludge produced by the TH process is also much less viscous than raw sludge, allowing the mass loading of sludge fed to an anaerobic digestion plant to be considerably increased (in some cases even doubling digester throughput). After digestion, the resulting biosolids material is also easier to dewater, with up to 40% dry solids being possible.

Biosolids material treated by the TH process is classified by the ADAS "Safe Sludge Matrix" as an "Enhanced Treated Sludge" which is free from *Salmonella* and where 99.9999% of the pathogens have been destroyed (i.e. a 6 log reduction). The material is, therefore, approved for use as a fertiliser/soil conditioner for all crops including cereals, vegetables and salads as well as for horticultural applications.



Background to the Implementation of Thermal Hydrolysis in Yorkshire Water

Yorkshire Water Services (YWS) currently relies on the use of incineration for the disposal of approx. 39% of its wastewater sludge production (as at December 2010). Although expensive, the incineration of sewage sludge is regarded as a reliable method of disposal when compared to restrictions to agricultural recycling.

However, YWS's incineration plants are becoming more and more expensive to operate due to the requirement for increased maintenance together with the rising costs of fuel and landfill disposal.

In addition to this, YWS recognises that the sewage sludge which it produces is a potential source of "green energy" and its use for energy production will contribute to YWS attaining its targets of carbon footprint reduction and sustainability.

YWS has developed a Bio-Energy Strategy which focuses on delivering environmental sustainability, eliminating waste, generating energy and ensuring its recycling routes are safe. This means plotting an exit strategy from the use of incineration at its major sewage treatment works and, instead, utilising the process of Advanced Anaerobic Digestion (AAD) which comprises TH prior to anaerobic digestion (AD) together with combined heat and power (CHP) units operating on the biogas produced.

This will have the following benefits:

- Elimination of the running costs associated with the existing incineration plants, including the costs of fuel and the disposal of ash to landfill.
- Production of an Enhanced Treated Sludge which is suitable for land spreading for agricultural and horticultural use and has the potential to be marketed as a saleable product.

- Increase in biogas production compared with the use of AD alone, resulting in a net surplus of "green" electrical energy and the gain of additional Renewal Obligations Certificates (ROCs)

Estimates show that YWS's Opex costs for sludge disposal will fall from c. £150/tonne of dry solids using incineration to less than £30 using AAD, which will be reduced even further if markets can be developed for the sale of the treated biosolids material (e.g. as a horticultural soil conditioner) rather than simply distributing it free-of-charge to local farmers.

YWS requires that its AAD plants will be of a "world class" standard in terms of efficiency, operability, maintainability, whole life cost in terms of the following criteria:

- Provide an excellent asset with a long asset life
- Easily maintainable
- Provide high level of operability and plant availability
- Fit for purpose
- Have critical redundancy built in
- Optimised capex/opex cost profile

YWS began by appointing specialist consultants and in-house technical experts to study the TH market. Following an extensive programme of detailed discussions and visits to reference plants, Veolia Water Solutions & Technologies (VWS), together with another recognised provider of TH plants (i.e. Cambi), were invited to independently participate in the production of a "Thermal Hydrolysis Asset Standard".

This asset standard was intended to interface with YWS's existing asset standards relating to sludge treatment, for example:

- Sludge Thickening & Dewatering
- Polyelectrolyte Handling, Preparation & Dosing
- Anaerobic Digestion

VWS worked in close collaboration with both YWS in-house personnel and its external technical advisers for several months in order to produce the Thermal Hydrolysis Asset Standard which has subsequently been approved and included as a controlled document in YWS's suite of asset standards.

The Thermal Hydrolysis Asset Standard was then used to compare and evaluate the alternative TH technologies at the subsequent tendering stage of YWS's procurement process.

Esholt Sewage Treatment Works was designated by YWS as the first of its works to incorporate TH for sludge treatment using AAD. This works serves Bradford and the surrounding areas and the thermal hydrolysis plant would be designed to treat a nominal throughput of 30,000 tonnes dry solids per annum made up of both indigenous sludge, together with imports from surrounding works.

Morgan Sindall/Grontmij Joint Venture (MGJV), one of YWS's AMP 5 Capital Delivery Partners, was selected to deliver the scheme which, in addition to the provision of TH, also included the building of an additional anaerobic digester and new CHP plant, together with extensive modifications to the existing sludge handling facilities at the works.

MGJV invited VWS and Cambi to tender for the TH process for the Esholt scheme.

Following the submission of detailed tender proposals together with a programme of extensive discussions and presentations, VWS was nominated as "preferred bidder" for TH for Esholt scheme using its "Biothelys" TH process.

In addition to whole life cost, the selection process also took into account factors such as the alignment of the cultures of the competing companies with those of YWS and MGJV as well as their willingness to offer a plant which totally complied with the constraints of the Esholt site, rather than simply providing an "off-the-shelf" solution.

The Esholt scheme is currently (November 2011) at the detailed design stage and the plant is scheduled to be operational by mid-2013.

Description of the Biothelys® Thermal Hydrolysis Process

Biothelys® is a thermal hydrolysis process that is used to pre-treat thickened or dewatered sludge before biological treatment. The process was originally developed independently by VWS in the late 1990's for the treatment of surplus activated sludge, with the objective of producing a "zero sludge" sewage treatment works. The Biothely® process has since undergone further development and can be used to treat any kind of product that has a methanogenic potential such as: municipal or industrial wastewater sludges, fats and greases etc. in order to:

- Increase volatile matter destruction giving a higher biogas yield when the hydrolysed sludge is anaerobically digested. This results in increased electricity production.
- Produce an enhanced biosolids product which is classed as an "Enhanced Treated Sludge" under the terms of the "Safe Sludge Matrix", published by the British Retail Consortium, Water UK and ADAS, and is suitable for land spreading for the cultivation of all types of crop.

The table below shows the timeline for the development and implementation of VWS's thermal hydrolysis process.

Table 1: Timeline of Development & Implementation of VWS Thermal Hydrolysis Process

1997	1999	2004	2006	2007	2008	2009	2010		2011
First Bench Tests	**Witry** (France) 2500 p.e. Pilot	**Saumur** (France) 1,600 TDS/yr	**Chateau Gontier** (France) 1,000 TDS/yr	**Le Pertuiset** (France) 2,000 TDS/yr	**Tergnier** (France) 1,600 TDS/yr	**Monza** (Italy) 10,200 TDS/yr	**Versailles*** (France) 6,200 TDS/yr	**Lille*** (France) 15,600 TDS/yr	**Esholt*** (UK) 30,000 TDS/yr

*Currently under construction

Comparison of Biothelys® with Other TH Processes

In all TH processes, the actual "cooking" of the sludge at 165^{0}C and 6-8 bar pressure for 20-30 minutes is identical; although the way in which it is achieved is different for each process.

The Biothelys® TH system uses only two types of vessel, in series, namely:

- Pairs of Batch Reactors
- Hydrolysed Sludge Buffer Tank.

The Biothelys® reactors work in parallel and out-of-phase with each other, with the thermal energy from the flash steam being recovered from one reactor vessel and introduced to its paired reactor. The process does not require a separate mixing stage.

The hydrolysed sludge buffer tank stores the TH-treated sludge , thereby allowing continuous operation of the biological treatment downstream of the TH stage. In the Biothelys® process the raw sludge is introduced at c. 16 % DS directly into the appropriate reactor, thus also eliminating a pumping stage.

A 3D image of a typical Biothelys plant is shown below.

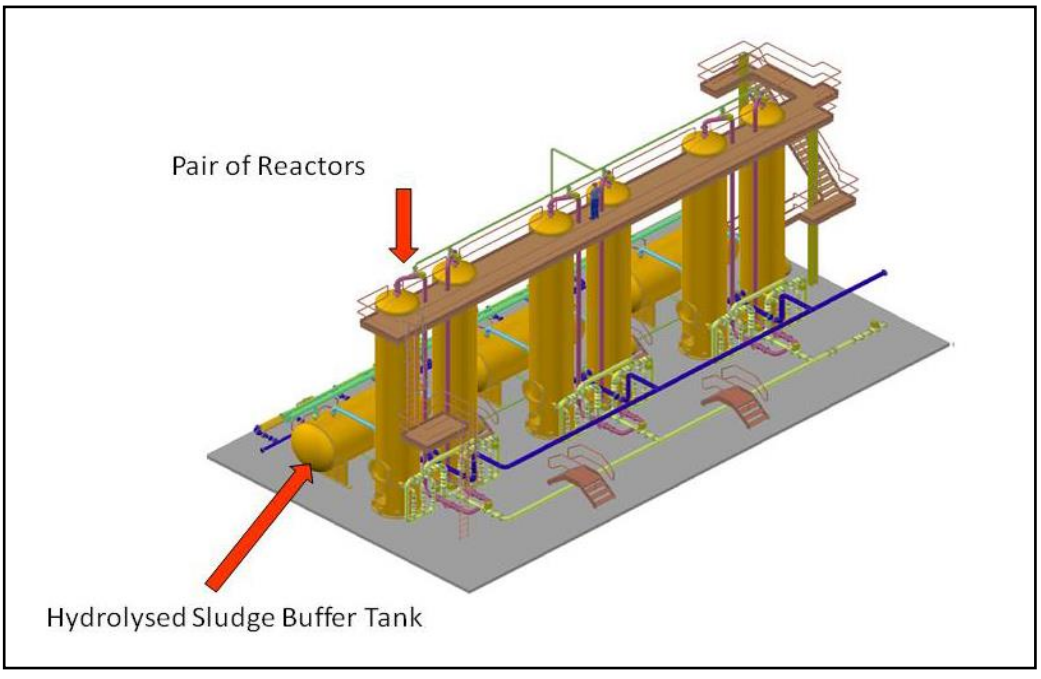


Figure 1: Simplicity of the design of the Biothelys TH Plant

Advantages of the Biothelys® Process

- Reactors operate in parallel pairs and the thermal energy from the flash steam is recovered from one reactor to its paired unit.
- There is no requirement for a separate mixing stage, compared with other TH designs, thus eliminating the need for a recirculation pumping system.
- In the Biothelys® design raw sludge is introduced directly into the appropriate reactor which eliminates a pumping stage
- Biothelys® uses the positive transfer of hydrolysed sludge by differential driving head and gravity (i.e. does not require a further pumping stage).
- Some other TH processes use a radioactive method of measuring the sludge level in the reactor vessel. Biothelys®, however, uses a different (i.e. non-radioactive) method of level measurement, thus eliminating the precautions and procedures which are associated with the use of radioactive isotopes.

The simpler design of the Biothelys® process provides a system with both reduced capital and operating cost, for example:

- **Capex** reduced by:
  - Fewer vessels
  - Fewer pumps, valves and instrumentation
- **Opex** reduced by:
  - Lower pumping costs
  - Lower steam usage because steam is flashed between vessels
  - Lower maintenance costs on the reduced scope
  - Lower operational manpower requirement for the simpler and more robust design

Esholt Biothelys TH Plant - Design and Performance

The table below shows the main design parameters for the Esholt Biothelys TH Plant

Table 2: Esholt Biothelys TH Plant – Main Design Parameters

Design/Average Throughput	82.2 tDS/day (i.e. 30,000 tDS/annum)
TH Maximum Throughput (Based upon the treatment of daily throughput in 22 hours)	89.7 tDS/day, (i.e. 32,727 tDS/annum)
Plant Configuration	3 Pairs of Reactors and 1No. Hydrolysed Sludge Buffer Tank
Raw Sludge Buffer Silos	2
Thermal Hydrolysis Reactors	6
Hydrolysed Sludge Buffer Tank	1
Reactor Feed Pumps	2 No. (1 duty/1 standby),
Digester Feed Pumps	2 No. (1 duty/1 standby) ,
Sludge Cooling Heat Exchangers	4 No. (1 No. per Digester)
Heat Recovery Steam Condenser	1
Vapour Condensing Heat Exchanger & Odour Control	1 Duty Exchanger & Separator with duty/standby Pumps

The table below shows the anticipated performance figures of the Esholt Biothelys TH Plant

Table 3: Esholt Biothelys TH Plant – Anticipated Performance Parameters

	Average
Inlet Design Load	82.2 tDS/d
% SAS	27.4 %
Raw Sludge Volatile Solids Content	69.1 %
Sludge DS at Digester Inlet	10 %
Digestion Time at Design Load	15 Days
Anticipated VS Destruction in Digester	59 %
Anticipated Biogas Production	28,499 Nm^3/d
Anticipated Biogas CH_4 Content	63.0 %
Dewatered Sludge %DS	30 - 35 %

The use of 6 No. reactors (i.e. three pairs) has the advantage that steam demand is constant, as steam is diverted from one reactor to another when operating temperature is reached.

This is shown in the diagram below which illustrates the operating cycle of the Biothelys TH plant.

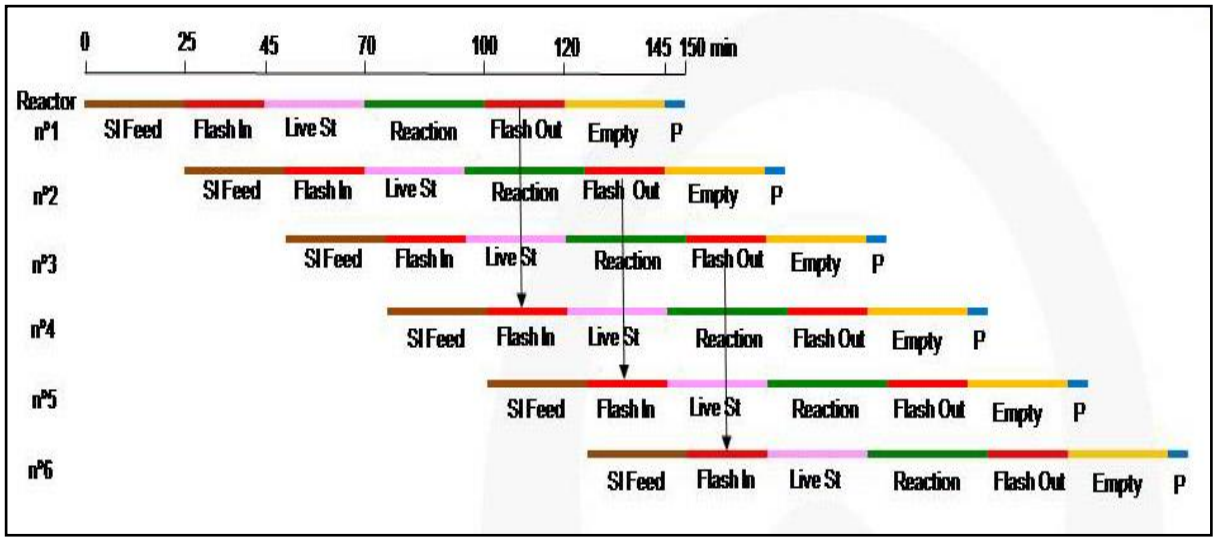


Figure 2: Operating cycle of the Biothelys TH Plant showing constant steam demand

In order to provide Yorkshire Water with optimum whole life cost the scope of supply for the Esholt TH plant was agreed as follows:

Table 4: Esholt Biothelys TH Plant – Scopes of Supply

VWS	MGJV
Reactor and Digester Feed Pumps	Civil Engineering & Building Works
Reactor Vessels	CHP and Boiler System
Hydrolysed Sludge Buffer Tank	Sludge Thickening Centrifuges
Heat Recovery System	Sludge Feed Silos
Hydrolysed Sludge Heat Exchangers	Steam and Hot Water Supply Pipework
Interconnecting Pipework & Cabling	Digester Feed Pipework
Process Control Software	MCC

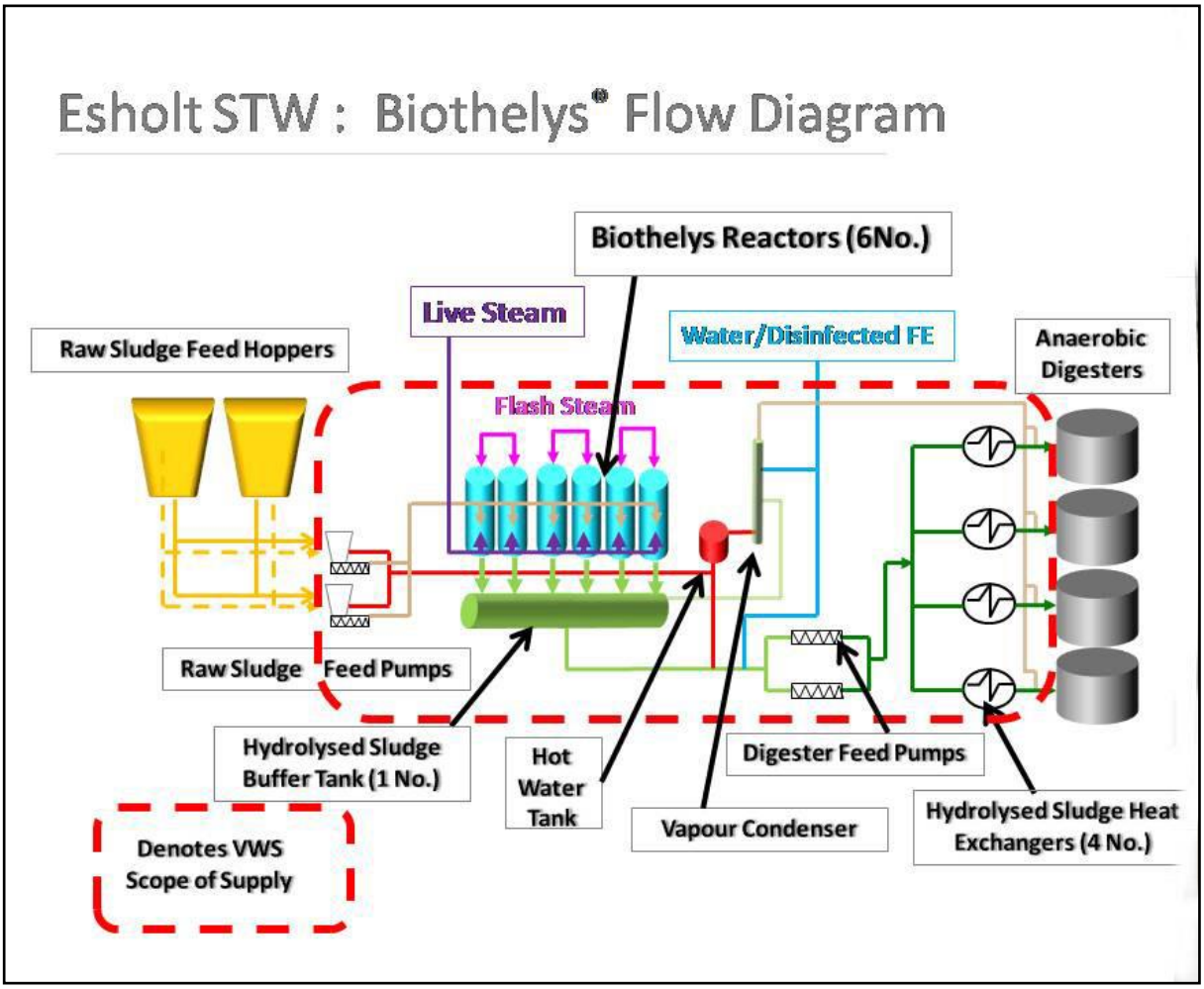


Figure 3: Biothelys Flow Diagram for Esholt (Simplified)

Below are shown views of a typical Biothelys TH installation.

Figure 4: Views of a typical Biothelys TH plant

Veolia's Overall Process Expertise

VWS's expertise is not simply confined to the design and installation of thermal hydrolysis plants.

Rather, they are a provider of specialist technologies in all areas of water, wastewater and biosolids treatment.

VWS was, therefore, able to tailor the design of its Biothelys® TH process in the context of its place within the overall flowsheet of Esholt STW and taking into account wider considerations, such as:

- The potential effect of the return liquors on the performance of the treatment works
- The effect of ammonia concentration on the performance of the anaerobic digestion plant

VWS is also experienced in the commissioning and long term operation of water, wastewater and biosolids treatment plants and they were, therefore, able to incorporate input into the design of the Biothelys plant from their operating "arm" to recognise any potential areas of difficulty in terms of issues such as: availability, reliability and maintainability in order to produce a plant with minimum whole life cost.

VWS is familiar with the intricate workings of all stages of a wastewater treatment plant, including the potential effects of the addition of a thermal hydrolysis and/or anaerobic digestion plant to an existing works. Their knowledge and experience enables them to provide answers to questions on areas of the plant in addition to the actual TH plant itself. As an example of this, shown below are some of the questions which they answered during the selection process:

- ***"Provide the energy requirement in MW per m³ for digestion mixing including an explanation of the basis of the calculation and viscosity assumptions".***
- ***"Provide process information of expected conditions of the digestion process, VFA, Alkalinity, etc."***
- ***"Provide details of the expected hard COD in the return liquors from the dewatering process after Thermal Hydrolysis. Concentration and flow"***
- ***"What is the struvite potential for TH sludge passing through the digesters based on assumptions of the form PO4, Mg and NH3-N"***

They were, thus, able to adapt the design of the Biothelys® process to take account of the particular requirements of the Esholt site, rather than simply providing a standard design solution to treat a particular plant throughput

Energy Production

The Biothelys® process is more energy efficient than other TH designs in the following ways:

- Biothelys® uses fewer pumping stages
- Biothelys® does not require the provision of an external mixing system within any of its vessels

- Biothelys® is more steam recovery efficient

In the Biothelys® process the reactor vessels operate in pairs and, following initial start-up, the residual steam which has been used to raise the temperature of the raw sludge in Reactor A up to 165^0C is transferred, after the 30 minute "hold" period, to Reactor B where it initially pre-heats the sludge from ambient temperature to over 90^0C, prior to the injection of fresh live steam to raise the temperature to 165^0C in Reactor B.

Following completion of the hydrolysis reaction, Reactor A is discharged to the Hydrolysed Sludge Buffer Tank and a new charge of raw sludge is fed to Reactor A and the above process is repeated in reverse (i.e. residual steam from Reactor B being fed to Reactor A). The above cycle is then continuously repeated.

The above sequence ensures that maximum benefit is taken from the energy value of the steam for heating as it is transferred directly from one reactor to another, rather than being recirculated via an additional tank as is the case with other TH designs.

Further energy is saved in the Biothely®s process by pre-heating the dewatered sludge upstream of the reactor. This is achieved by diluting the sludge from 22 % DS to 16 % DS using the hot water from the waste heat recovery system used to condense the vented vapour from the hydrolysed sludge buffer tank.

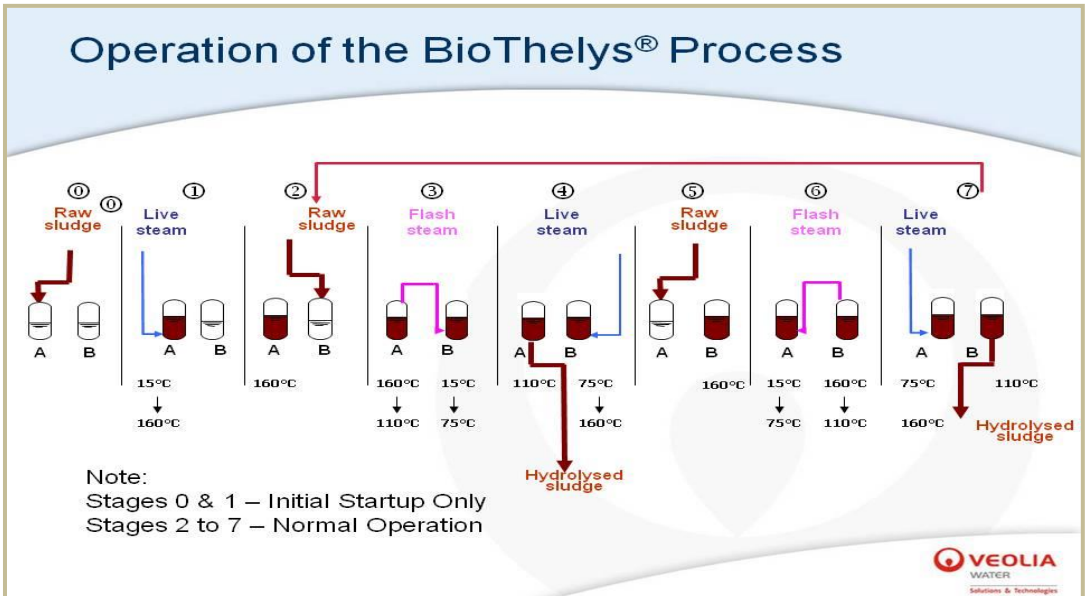


Figure 4: BioThelys®Process reduces the number of pumping stages and does not require a mechanical mixing system in any vessel

Operational Support

As part of their tender proposals for Esholt, VWS will provide a Commissioning and Support team who will be responsible, in close liaison with YWS's Operations personnel, for overseeing the initial start-up of the plant to the point where it is consistently achieving its design output and has passed its acceptance tests.

VWS recognises that thermal hydrolysis is new to YWS and may, therefore, require an enhanced level of operational and process support until YWS's operations staff is familiar with the new asset.

VWS will tailor this level of support to suit YWS's requirements but it could range from periodic site visits to recommend any minor adjustment which might be required, right up to the provision of full time residential process support staff.

A 24/7 "hotline" contact number will also be provided in the event of a rapid response being required.

VWS will also provide the facility of remote monitoring of the Esholt Biothelys® TH plant at one of their Operational Control Centres at which authorised personnel will have the facility (password controlled) to monitor the performance of the plant and respond to any problems.

Plant Optimisation

VWS will also provide a specific optimisation service as an integral part of the Esholt Biothelys® TH scheme comprising:

- Personnel (both on site and available on call) to fulfil the specified optimisation services
- Monitoring the plant performance and make recommendations to:
    - Improve operational efficiency and enhance performance
    - Optimise maintenance, life cycle cost and extend component part life
    - Reduce consumables and power consumption
- Revision and updating of the Operation & Maintenance manuals to incorporate optimisation recommendations developed at commissioning and testing phases.

The Future of Thermal Hydrolysis in Yorkshire Water

The implementation of AAD for the treatment of sludge by YWS is a key feature of their Bio-Energy Strategy. This strategy is funded within AMP5 to deal with the increase in sludge production from population growth and new environmental quality legislation. A significant benefit of this approach is the anticipated opex and efficiency savings which will result .

The success at Esholt will determine how YWS consider what to do with their remaining large sludge treatment centres. There are, for example, notional proposals to build AAD plants on YWS's major treatment works at Knostrop (Leeds), Huddersfield, Blackburn Meadows (Sheffield) and Hull (the latter to replace a sludge dryer). The timing for these schemes has yet to be finalised and will be dependent on the performance and the level of opex efficiency which are achieved at Esholt.