

CHALLENGES OF DEVELOPING SMALL SCALE THERMAL HYDROLYSIS AND DIGESTION PROJECTS

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Abstract

The Thermal Hydrolysis Process (THP) as a pre-treatment for anaerobic digestion (AD) was first explained at the European Biosolids conference in 1997. Since then THP has become a standard process in UK and Ireland with over 20% of all sludge being treated this way. These projects are in the 300,000 to 3 million PE range. The challenge has been to make economical systems for smaller digestion projects without losing system efficiency or reliability.

In designing smaller systems for the 100,000 to 300,000 p.e. range, the following factors were considered as essential to retain system efficiency: maintaining batch action in the continuous process; using steam injection not heat exchangers; maintaining heat recovery using a pre-heat tank for energy efficiency; optimum dry solids feed; ability for flash steam explosion; smooth steam profile for waste heat use; maintain high availability.

In designing smaller systems the following factors were considered important in keeping installed cost down: standardising design for assembly line production; fitting the systems in a standard ISO container footprint; rapid installation for minimum project and site costs.

The new systems are based on 6m³ and 2m³ reactors rather than 12 m³, but the operating method is identical to larger systems but at a much reduced cycle time. The batch can still be up to 30 minutes and has the benefit of being self cleaning compared to continuous systems at the same high dry solids.

The new system is to be installed in a number of projects in the UK and elsewhere. Examples of size and scope are given.

Keywords

Anaerobic Digestion, Dewatering, Thermal Hydrolysis, CHP, steam explosion

Introduction

THP has become a standard and worldwide process since its introduction in the HIAS Norway plant in 1995. There are now about 50 operating THP projects worldwide. The capacity of the 40 Cambi projects is about 1 million dry tonnes that gives an average capacity of about 25,000 tdsa (dry tonnes sludge per year) - with the largest projects being Davyhulme in UK (121,000 tdsa) and Washington DC in US 9146,000 tdsa). The average size of these THP plants to date is equivalent to a population of 850,000. This is mainly due to the building of sludge centres in the UK where sludge is treated for a wider region. However the potential for sludge centres is nearly complete in the UK and there is a growing demand for more small, stand alone THP plants in the range of 100-350k p.e. equivalent to 3,000 to 10,000 tdsa approximately

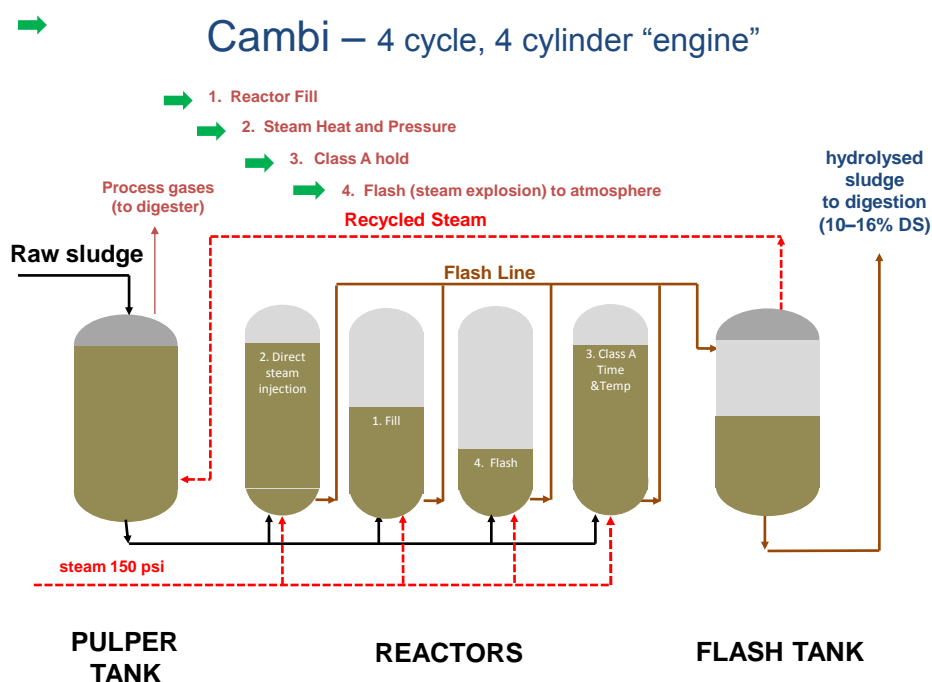
In other countries where there is not such regionalisation as the UK this demand is even bigger. A review of 1400 waste water plants in the USA that are stated as having anaerobic digestion shows that only about 110 of these have over digestion plants treating 10,000 tdsa of sludge or more. There are about 250 plants in the 3,000 to 10,000 tdsa range whilst the remainder are below the 3,000 tdsa range (considered in UK not to be viable for standalone AD)

Given this demand the main issue has to been to reduce cost without reducing performance. A number of new small THP systems have been introduced to operators and engineers in the last few years. However in the drive to reduce costs a number of these systems have not taken into account the necessary learning needed to make a successful THP plant and have failed. This paper reviews that learning and how this has been incorporated into smaller packaged systems.

Batch vs Continuous

Sewage plant operators are used to continuous systems. Continuous systems that thermally hydrolyse sludge would appear to be preferable in terms of throughput and operation. However set against is the need for some of critical control point (HACCP) or regulatory driver for batch treatment (time/temperature requirement of USEPA 503 alternate 1).

The ideal system is a continuous batch system – the analogy is a 4 cylinder car engine – each cylinder operation is batch combustion but fuel supply and output is continuous. By having a pulper tank that is fed continuously and a flash tank that is emptied continuously the Cambi system operates as a continuous system but allows a batch hydrolysis that meets all regulatory drivers for pathogen destruction.



The continuous batch system is self cleaning and emptied every cycle so reactor cleaning is required once a year only. Some continuous systems state a requirement of

up to 15% downtime for cleaning of sludge build up due to laminar flow in pipes and pipe reactors. This equates to 55 days down time per year and the possibility of odour release on each cleaning – this is a reminder of the old heat treatment systems and a non-starter for most operators

Steam injection vs heat exchange systems

The early heat treatment systems such as Zimpro or Porteus suffered from using heat exchangers for transferring heat into sludge and pumping against pressure.

UK experience of using heat exchangers has been poor also, particularly in pre-pasteurisation systems where sludge heated above 55C precipitates rock like vivianite onto heat exchangers walls – this is due to widespread use of iron salts in UK sewage treatment that leads to formation of ferrous phosphate that appears as hard green/blue crystalline deposit that is extremely hard to shift chemically. This has led to the closure of several heat exchange based systems in the UK. The same problem can occur with struvite.



With steam injection struvite and vivianite form in the sludge matrix and are not deposited in downstream sludge coolers that follow THP.

Heat exchangers also limit the dry solids that can be heated – claims that non Newtonian sludge can be successfully heated to high temperature and at high DS% are not credible considering that laminar flow will greatly increase the scaling problem. So systems relying on heat exchangers will of necessity be at low DS% and therefore have a high heat demand and taxing heat recovery systems. This necessitates large digester volumes and low loading rate.

Requirement for a pre-heat tank.

The pre- heat tank (or pulper as it is called) allows the system to be continuous – but more importantly it allows the recovery of used steam from the system so that steam consumption is reduced.

The consumption of steam is often the biggest cost in THP operations as the THP can be parasitic on the use of biogas as for CHP or fuel production.

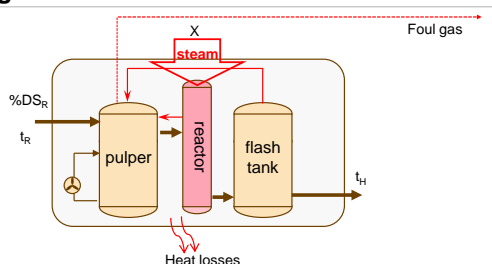
Steam consumption – general model

Black box model:

- X : steam fraction (ton steam/ton wet sludge)
- $\%DS_R$: raw sludge dry solids (%) (0.12 – 0.18)
- t_R : raw sludge temperature (°C) (5-50)
- t_H : Hydrolysed sludge temperature (°C) (107)
- $C_{P,S}$: specific heat of solids (kJ/kg°C) (1.5)
- $C_{P,W}$: specific heat of water (kJ/kg°C) (4.186)
- H_{steam} : enthalpy of steam (kJ/kg.°C) (2785)

Black box model assumes:

- no heat losses
- no losses with foul gasses
- all steam from flash tank condensed in pulper



$$X = (t_H - t_R) \cdot \frac{C_{P,W} - \%DS_R \cdot (C_{P,W} - C_{P,S})}{H_{steam} - t_H \cdot C_{P,W}}$$

Steam consumption only depends on sludge temperature, hydrolysed sludge temperature and feed dry solids. The hydrolysis temperature does not impact the steam demand of the Cambi system

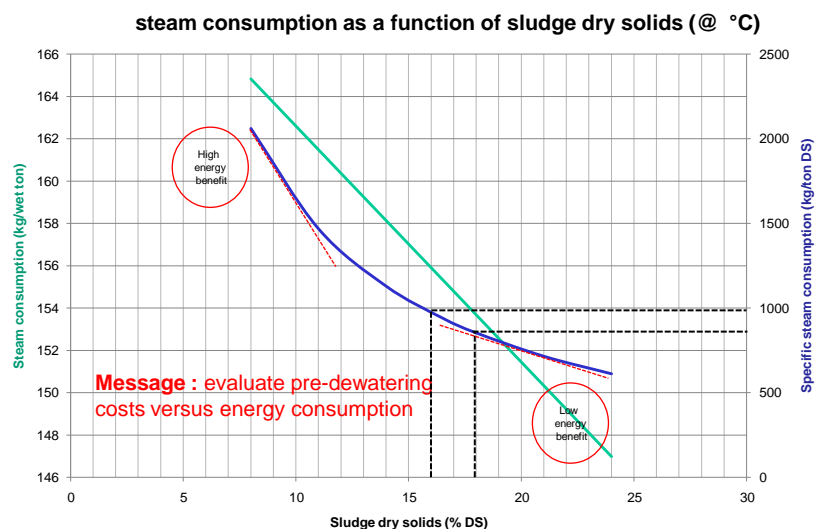


The general model shown before shows that this a black box model where the delta T across the system controls the steam consumption. Having the minimum exit temperature by steam recycling has two benefits: 1 reduces steam consumption, 2 reduces cooling requirements. The Holy Grail is to have a system that can hydrolyse all the sludge but that can operate on waste heat from CHP. This is expected in the near future.

Optimum dry solids feed.

The graph below shows the effect of DS% on steam consumption. Systems that use liquid sludge have a very high specific need for steam consumption – up to 2000kgs per dry tonnes. At the other extreme experience shows that hydrolysing sludge at above 20% can lead to “stiction” problems. In designing smaller Cambi systems the minimum diameter pipework must be retained if laminar flow problems are to be avoided. Both the B6 and B2 systems have the same pipework diameter that is designed based on DS% feed up to 20% DS so that there are no restriction to flow or rate of flow. Current Cambi systems operate at about 900 kg/tds at optimum dry solids feed of 16.5% DS>

Energy consumption – effect of sludge dry solids



Flash steam explosion

The steam explosion pressure was changed at the end of 2010 at Chertsey sewage works from 3 bar to 6 bar – corresponding to data point ~1000 in the graph below (axis is days of operation since 2008).

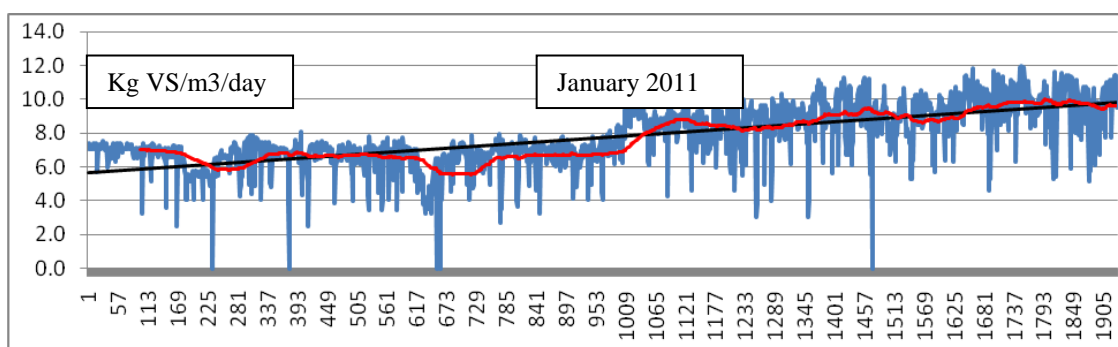
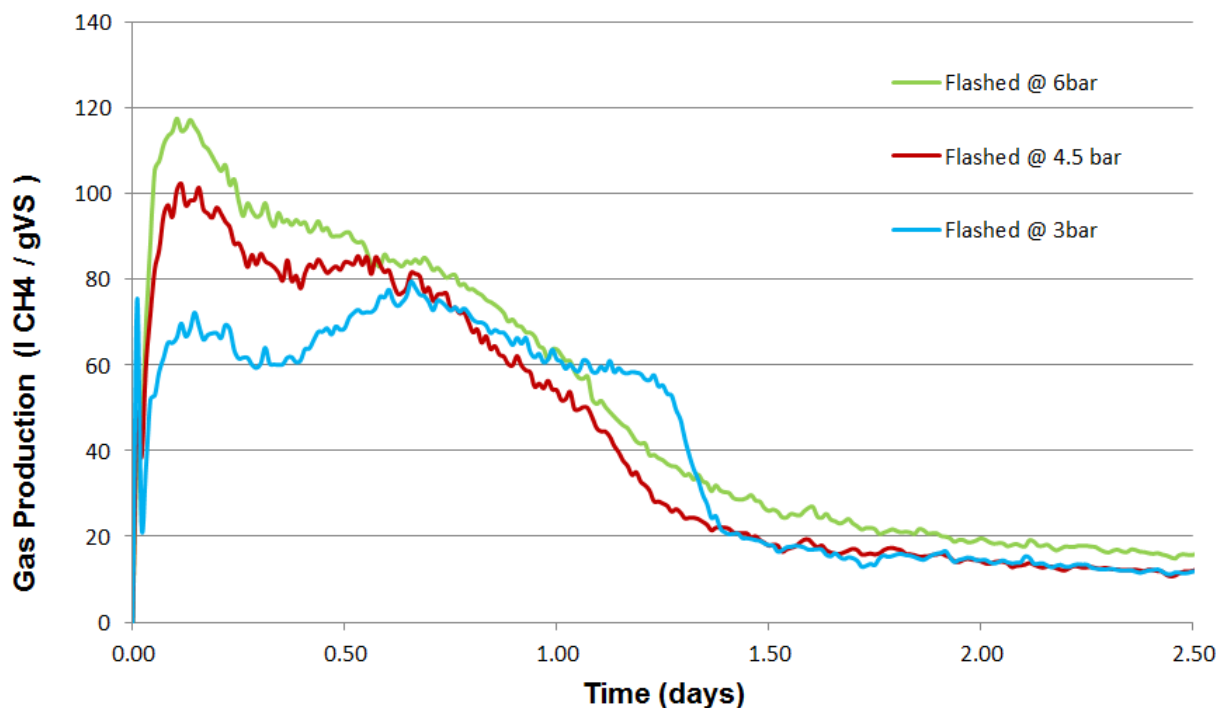


Figure 1: Data for Chertsey STW Feb 2008 too Aug 2013

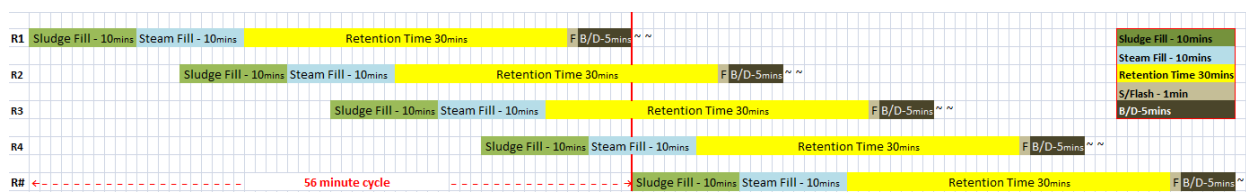
This enabled a much faster feed rate and higher VS loading that has been reported earlier. The change at Chertsey enabled the digesters to be loaded by about 2kgVS.m³/day more than had been done previously. Other work not published yet shows that steam explosion has a very positive effect on digestion effectiveness and rate – see graph below. Over the full term of the digestion chemostats the 6 bar steam explosion digester produced 30% more biogas per dry solids than the 3 bar system.



The newer smaller systems include mechanical changes that allow this higher pressure steam disintegration to occur without undue abrasion or wear in the system.

Effect on cycle time and batch retention

By keeping large pumps and valves in these systems cycle times are reduced whilst keeping the ability to batch sludge for up to 30 minutes is retained. So in the original Mk I, B12 Cambi system retention time is 90 minutes. At the other extreme the B2 system can operate with a cycle time of 56 minutes – see illustration below. This makes the smaller systems more productive in proportion to vessel size, so capital cost is better used or reduced cost per ton DS treated



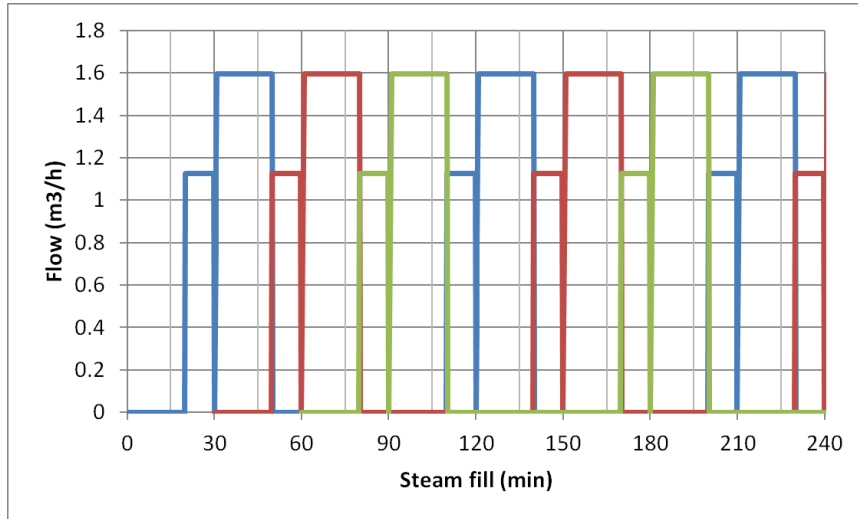
Duty standby pumps

B12 and B6 come with duty standby pumps as standard and all standard valves. In the B2 system there is only room for one pump for each duty, but each pump is set up for fast changeover using an EZstrip system and/or standby boxed up spare. All valves are standard so it's easy to keep minimum standby stock for quick replacement.

Steam profile

The other reason to operate continuous batch with multiple reactors is to get a smooth steam profile when operating of waste heat from CHP.

The graph below is from the Long Reach project that will hydrolyze only secondary sludge based on the waste heat output from two 1MW CHP engines based on a B6 x 3 system.



New designs

B6

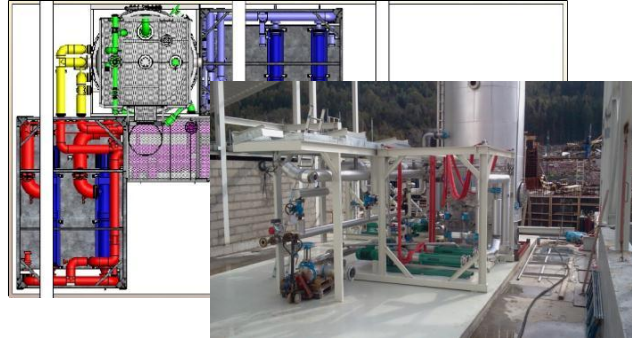
The B6 system is design to be delivered in a number of standard containerised units that are manufactured off site and delivered on standard flat bed trucks. The system is erected in 2-3 days.

The system below was built in 2011 in Drammen, Norway. The design has been further refined and is being delivered on a number of projects including Long Reach, Crawley and Seafield in the UK and in Vigo in Spain and Stavanger in Norway.

Installation philosophy for the modules

Day two

Module 5: Digester Feed Pump Skid



CAMBI
- recycling energy

B2

The B2 system was designed to be delivered completely erected on a standard shipping container footprint. The first systems are in construction and will be installed in Spain and the UK. The illustration below shows the comparative size of the B2 and B6 systems compared to the original B12 design of Cambi plants in the UK.



These new designs enable a quicker and simpler installation. The THP process is well established now and the design of these new standardized systems enables simpler and faster procurement and installation.

There is still “devil in the detail” when it comes to integration with other services that comprise a total THP installation. Experience of 40 plus projects ensures that this can be done successfully.