Benefits and drawbacks of thermal pre-hydrolysis for operational performance of wastewater treatment plants

P. Phothilangka, M. A. Schoen and B. Wett

ABSTRACT

This paper presents benefits and potential drawbacks of thermal pre-hydrolysis of sewage sludge from an operator's prospective. The innovative continuous Thermo-Pressure-Hydrolysis Process (TDH) has been tested in full-scale at Zirl wastewater treatment plant (WWTP), Austria, and its influence on sludge digestion and dewatering has been evaluated. A mathematical plant-wide model with application of the IWA Activated Sludge Model No.1 (ASM1) and the Anaerobic Digestion Model No.1 (ADM1) has been used for a systematic comparison of both scenarios—operational plant performance with and without thermal pre-hydrolysis. The impacts of TDH pre-hydrolysis on biogas potential, dewatering performance and return load in terms of ammonia and inert organic compounds (Si) have been simulated by the calibrated model and are displayed by Sankey mass flow figures. Implementation of full scale TDH process provided higher anaerobic degradation efficiency with subsequent increased biogas production (+75–80%) from waste activated sludge (WAS). Both effects—enhanced degradation of organic matter and improved cake's solids content from 25.2 to 32.7% TSS—promise a reduction in sludge disposal costs of about 25%. However, increased ammonia release and generation of soluble inerts Si was observed when TDH process was introduced.

Key words | biogas, plant-wide modelling, reject water, sludge disintegration, TDH, thermal hydrolysis

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INTRODUCTION

In general sludge disintegration technologies aim on two primary effects–both a more rapid and a more complete degradation of organic matter. Faster anaerobic degradation rates save additional digester volume and higher bioavailability of organics results in higher biogas potential and less residual solids production. Additionally there are some secondary side-effects which need to be considered. More efficient stabilization improves dewaterability of digested sludge but also leads to the generation of unwanted by products like ammonia and soluble inert organic matter. In this paper all these impacts will be evaluated by means of full-scale experiments and model based data analysis and simulation.

There are several methods for pre-treating solid particles in sludge: mechanical disintegration methods, chemical treatment, ultrasonic technique; thermal pre-treatment and enzymatic pre-treatment. Thermal hydrolysis is a well proven method to remarkably increase the dewaterability of sewage sludge. It involves heating of the sludge, usually to a temperature in the range of 150°C to 200°C. The pressures adjoining these temperatures are in the range of 6 bar to 25 bar (Barlindhaug & Ødegaard 1996). The process produces a sludge which is partially solubilized and the biological cells are disintegrated. The organic material in this form is much more available for anaerobic digestion. The Porteous process and the Cambi process are examples of thermal hydrolysis concepts which were previously implemented on many sites worldwide (Kepp *et al.* 2000; Neyens & Baeyens 2003). For example, the

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Cambi pilot system at HIAS plant, Hamar, Norway, performed a 30% hydrolysis rate at 180°C for 30 minutes of pre-treatment (Weemaes & Verstraete 1998). However, impacts of thermal hydrolyses depend on sludge characteristics and site conditions and systematic tools–e.g. mathematical model approaches–need to be developed for a more generic process description.

The Thermo-Pressure-Hydrolysis process TDH is a thermal pre-hydrolysis where sludge is treated under pressure (19–21 bar) at a temperature of 180°C. In contrast to other established technologies TDH represents a continuously operated system involving high pressure pump, controlled pressure release valve and heat exchangers. Even though differences in system configuration the pilot scale experiments have demonstrated expected benefits in particularly in energy recovery from enhanced digestion performance. Both, advantages and drawbacks of the TDH process are reviewed in the following.

ASM1 (Henze *et al.* 1987) and ADM1 (Batstone *et al.* 2002) are mathematical models for the simulation of activated sludge processes and anaerobic treatment processes, respectively. Application of ASM1 and ADM1 in a plant-wide framework helps to describe interactions between individual unit processes and also to optimize overall operational performance. The calibrated model tracks changing composition of sludge compounds during different treatment processes and can predict the impacts of implementing the TDH process in a WWTP.

The full scale TDH pilot system is in operation at Zirl WWTP since 2006 (Figure 1). In order to examine the impacts of TDH pre-hydrolysis, pilot scale and full scale digestion experiments were carried out and resulting data sets have been fed to calibration procedures of applied models.

METHODS

A plant-wide model of Zirl WWTP has been set up by coupling IWA's biokinetic models ASM1 and ADM1 implemented in the MatLab/SIMBA simulation environment. During a monitoring campaign composite samples in 6 hours intervals have been collected for the characterisation of influent composition and variation. Additionally primary data such as soluble and particulate COD, TN, NH_4-N, TP, TSS, VSS and Q of all relevant internal streams were used to calibrate the model. Plant-wide modelling served for a complete picture of sludge generation and resulting sludge characterisation provided the input for ADM1 at the interface for the simulation of separate digestion experiments. The ADM1 calibration procedure based on a mass balance concept is described in Wett *et al.* (2006). Then the final model approach and parameter set for TDH and digestion was implemented in plant-wide configuration in order to evaluate overall impacts.

A prior study (Phothilangka *et al.* 2007, 2008) revealed only a minor impact of thermal pre-treatment on primary sludge and even on high loaded sludge from a 2 stages treatment (A/B process) compared to WAS. Hence only WAS–waste activated sludge from the secondary clarifier–was fed to the TDH unit before digestion. Therefore, simulation of digestion process in the plant-wide model needed to be divided: one lane for primary sludge and another for WAS (Figure 2). For the WAS digester, the calibrated parameter set of ADM1 represents both, pre-hydrolysis and digestion.

Figure 1 | Zirl WWTP (left) and installed TDH unit (centre and right).

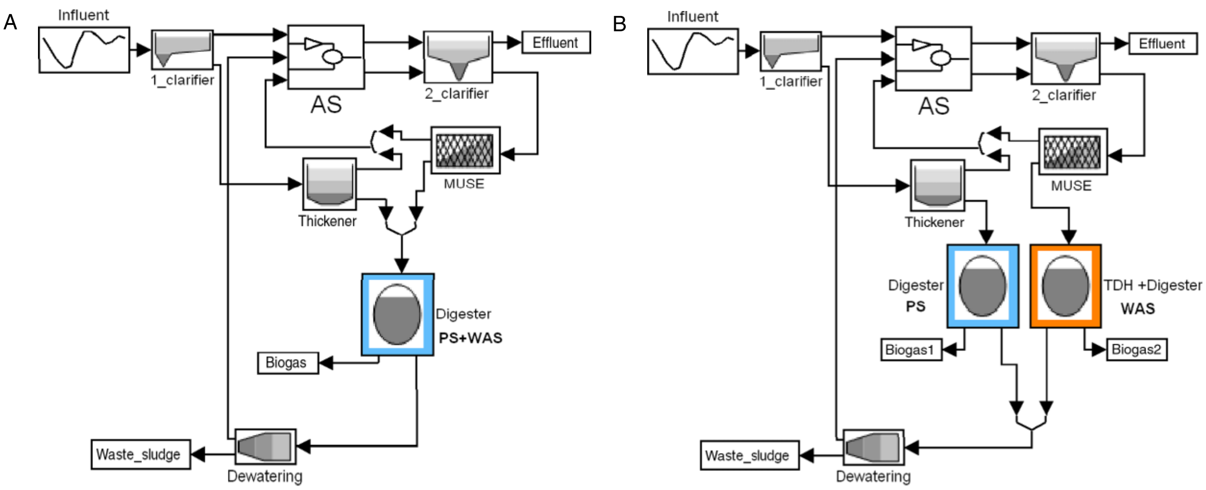

Figure 2 | Plant-wide model configurations for the simulation of both scenarios without (A) and with (B) TDH implementation at Zirl WWTP.

RESULTS AND DISCUSSION

Benefits of TDH

Biogas production

The thermal pre-hydrolysis process is expected to accelerate and anticipates the first step of the anaerobic process chain–the rate-limiting solubilisation and hydrolyses process. This effect can be reliably described by an increase of the ADM1 parameter value for the *disintegration rate*. The second effect–increased bioavailability of organic matter–is considered by a shift inert decay products towards degradable compounds (*disintegration coefficients* responsible for sludge characterisation). Enhanced anaerobic degradation results in improved biogas generation. Experimental investigation revealed a 75–80% increase of biogas production for pre-treated WAS. Using the experimental data, the modified ADM1 model including pre-hydrolysis was calibrated and validated on two different data sets (Figure 3).

In the current paper the focus is put on the impacts of TDH treatment on the whole WWTP. By plant wide simulation a 44% COD removal (from 63.1 kgCOD/m^3 to 35.3 kgCOD/m^3) after digestion of disintegrated sludge was calculated. The corresponding increase production yielded 75% as shown on Figure 4. These results are in line with the outcome of prior studies on the thermal hydrolysis impact under similar operating conditions at 180°C (Panter 1998;

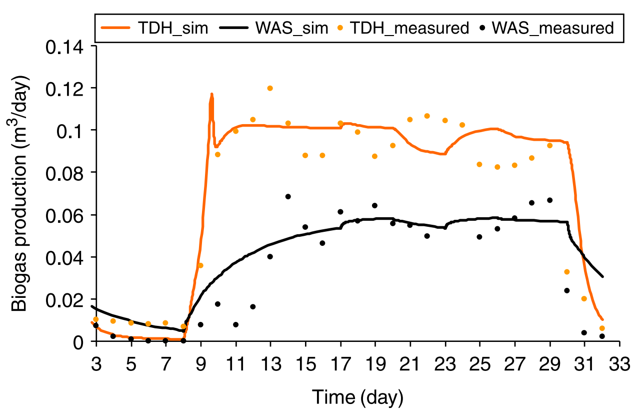

Figure 3 | Measured and simulated biogas generation from untreated WAS and TDH-treated sludge (Phothilangka *et al.* submitted).

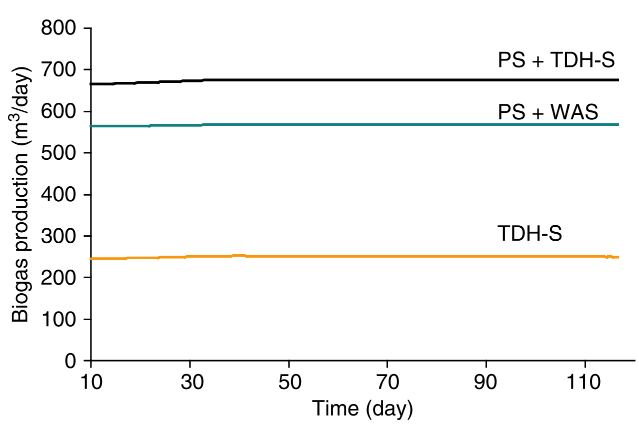

Figure 4 | Simulated biogas production of TDH-S and WAS according to plant-wide model of Zirl WWTP.

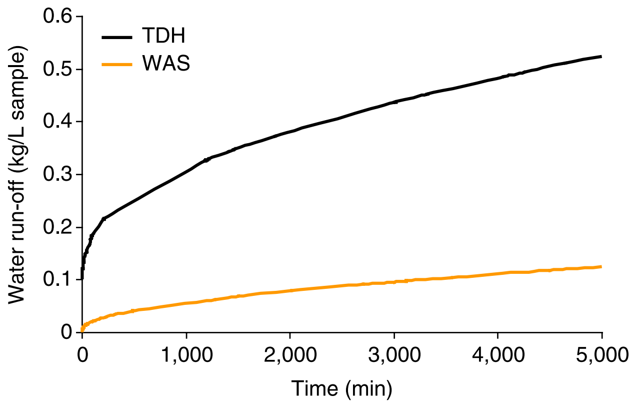

Figure 5 | Measured water release from a lab-scale dewaterability test comparing digested sludge with and without TDH pre-treatment.

Kepp *et al.* 2000). However, total biogas yield increased only by 20% in case both streams the untreated primary sludge and TDH-treated WAS are mixed.

Moreover, the comparison of dynamic gas production after a stabilisation period without feeding indicates process acceleration (compare slopes in gas production profiles in Figure 3): Gas production rate from digestion of TDH-treated sludge achieved maximum values within 2 days while for untreated WAS it took about 7 days. Results from experiments exposed that required retention time HRT drops significantly: lab experiments with parallel digesters showed that digestion of both, TDH-treated WAS at 14 days and at 20 days of HRT had an equal increase in biogas production. Therefore, a volume reduction of the digester can be expected in case of TDH-S digestion.

Dewaterability

Thermal sludge treatment was originally used to improve sludge dewatering. Heat treatment induces a higher breakdown of the cell structure of sludge and the release of intracellular bound water (Weemaes & Verstraete 1998). The results for WAS taken from two WWTPs showed the same impact of TDH pre-hydrolysis regarding dewatering. In labscale experiments sludge samples were passed under additional pressure (1 bar, 37°C) through a geo-textile. Digested TDH-S showed an improved dewaterability as shown in Figure 5.

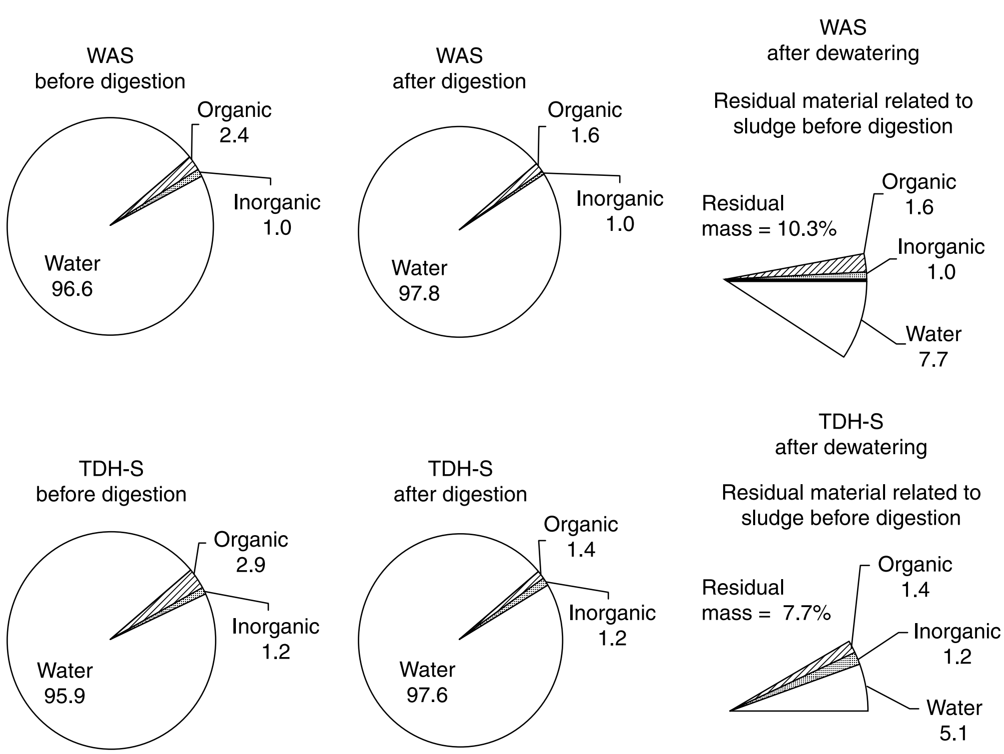

Figure 6 | Properties of sludge before, after digestion and after dewatering comparing between WAS and TDH-S.

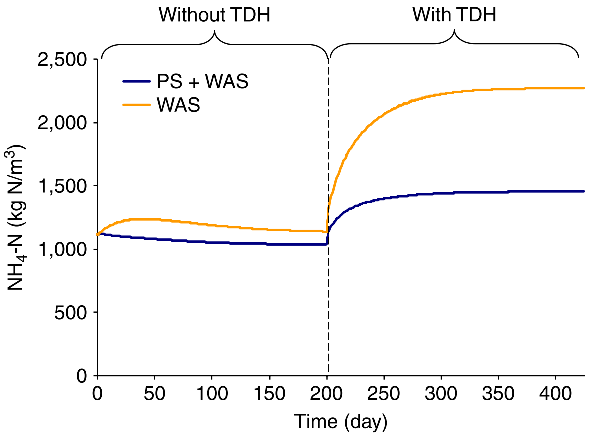

Figure 7 | Simulation of ammonia released from digestion of WAS and the mixture of untreated primary sludge PS and WAS before and after implementation of TDH.

In a full-scale experiment TDH-S was digested in a separate 50 m^3 digester and subsequently dewatered in the plant's dewatering unit (TSS 32.7%). Usually, digested sludge from treatment plant (mixture of PS and WAS without pre-hydrolysis) is dewatered by the same spiral press achieving a TSS content of 25.2%. This difference in dewatering result has been translated into the comparison of sludge cake reduction of WAS and TDH-S (Figure 6). Residual humid mass decreased from 10.3% to 7.7% related to the initial liquid sludge mass before digestion. Therefore, both effects–enhanced degradation of organic matter and improved cake's solids content–promise a reduction in sludge disposal costs of about 25%.

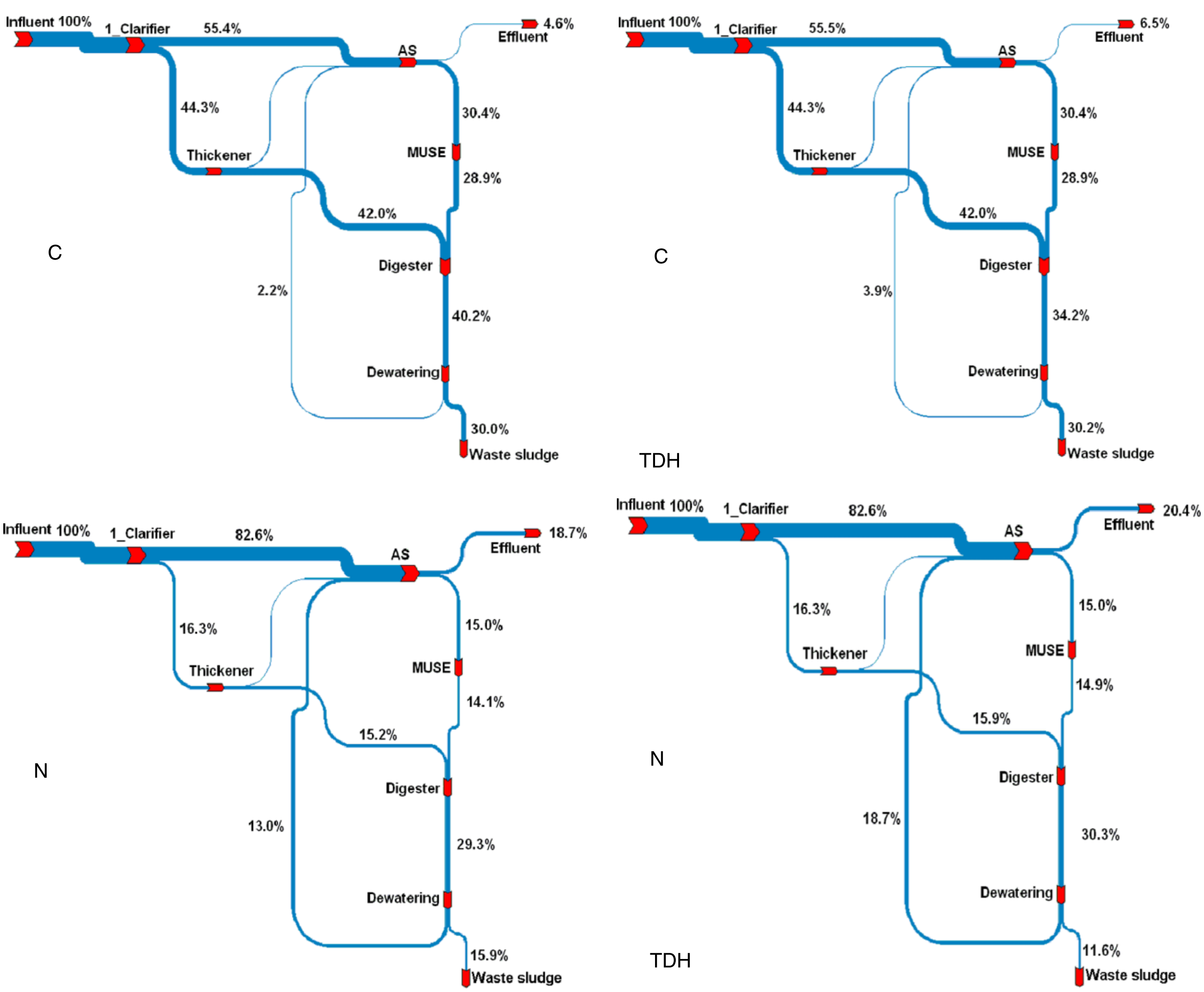

Figure 8 | Simulated nitrogen and carbon mass flow schemes for both scenarios before (left) and after implementation of the TDH process (right).

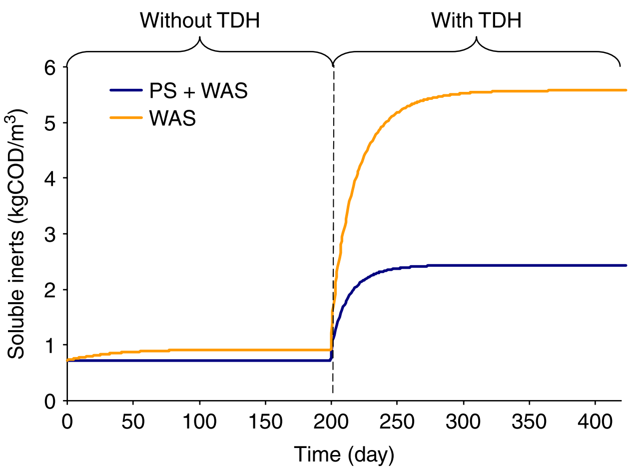

Figure 9 | Plant-wide simulation of soluble inerts Si after digestion generated from WAS and PS + WAS before and after implementation of pre-hydrolysis.

Drawbacks of TDH

Ammonia release and nitrogen return load

Because thermal disintegration improves biological accessibility of compounds, more nitrogen gets released in form of ammonium nitrogen (NH_4-N) by degradation of N-containing organic matter. Influent characterisation and model calibration at Zirl WWTP pointed that soluble and particulate inerts of WAS contain about 2.5% nitrogen. Inactivated aerobic biomass and decay products show a content in nitrogen of about 6% from proteins contained in cell mass. High ammonia increase due to TDH-pretreatment can only be explained a complete degradation of decay products. On the other hand, the particulate inerts Xi already contained in raw sewage are hardly degraded.

Simulations of the plant-wide model show a 100% increase of NH_4-N (from 1,138 kgN/m^3 to 2,269 kgN/m^3 at 200 days running on simulation) when WAS is pre-hydrolysed by TDH process (Figure 7). Thus a substantial load of ammonia additionally released from organic matters contributes to the N return load from sludge dewatering. Figure 8 shows the increase of nitrogen return load when the TDH process was implemented in the plant wide model (from 13.0% to 18.7%).

Table 1 | Simulated WWTP key data with and without TDH treatment of waste activated sludge WAS (no pre-hydrolysis of primary sludge PS)

	Without TDH	With TDH	
Total biogas generation		+20%	(mixed digestion: PS + WAS)
Biogas from WAS		+75%	(separated digestion: WAS)
N return load	13.0%	18.7%	
COD removal	95%	93%	
N removal	81%	80%	
Aeration requirement		+ ca.3%	
Solids cake reduction		− ca.25%	

The increase of soluble inerts

Soluble inert compounds Si are produced when sludge is pre-treated at high temperatures such as TDH process. Usually during mesophilic digestion the fraction of soluble inerts yields a share of about 2% in particulate composites Xc. This share was increased to 9% when WAS was pre-hydrolysed at 180°C, a value that was confirmed from two different sludge sources (WAS from Zirl WWTP and Strass WWTP A/B process). As can be seen from Figure 9, 5.7 kgCOD/m^3 of Si was generated when the TDH process was applied compared to only 0.9 kgCOD/m^3 from untreated WAS. Generated soluble inert compounds are diluted in the mainstream wastewater lane and contribute about 10 mg/L to the effluent COD. Therefore simulated COD removal efficiency was decreased from 95% to 93%. N-removal efficiency was reduced insignificantly from 81% to 80% due to a poorer C/N ratio.

Results from the current work are in agreement with the study of Muller (2000) who denoted that hardly degradable organic compounds are generated when thermal disintegration is applied for sludge pre-treatment. For the same reason operating temperature should not exceed the optimum range of 170 to 180°C leading to an excessive production of these inert compounds.

A broad range of different aspects of implemented thermal hydrolysis has been discussed and exemplified by a systematic case study. The most important impacts of the TDH process on the operational performance of a WWTP are listed and summarized in Table 1.

CONCLUSIONS

Benefits

Utilities with digesters pushed to capacity limits are the first to consider the implementation of a sludge disintegration technology and savings in digester volume may pay-off investment costs. From economic standpoint improved sludge dewaterability and a potential 25% reduction in biosolids disposal costs are the major benefits of the Thermo-Pressure-Hydrolysis process. Smart cycling of thermal energy gained from increased biogas production back to the heat input for thermal hydrolysis is required for saving external resources and approaching CO_2 goals.

Drawbacks

Reduction in loads of soluble organic compounds and nutrients to receiving water bodies–the original intention of biological wastewater treatment–is not supported by any sludge disintegration technology, but internal return loads of COD and ammonia are generated. However, soluble organics produced by thermal hydrolysis are highly stabilised compounds which do not cause DO depletion in rivers. Additional ammonia return load released by enhanced solids degradation is well caught in high-strength sludge liquor ready for an efficient side-stream treatment.

ACKNOWLEDGEMENTS

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