THE ENERGY AUTONOMOUS SEWAGE TREATMENT PLANT – ONCE A DREAM, NOW A REALITY

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Abstract
The dream of energy self-sufficient WWTPs is now becoming a reality through the optimisation of available technologies reducing energy consumption and maximising energy generation. Implementation of the deammonification process is an important opportunity for energy savings at a WWTP, requiring significantly less aeration than conventional nitrification/denitrification.

Sludge is the main energy source which is available on a municipal waste water treatment plant. Energy recovery measures are therefore basically related to sludge treatment and sludge treatment technologies. Lysotherm® is the thermal hydrolysis system developed by the SH+E Group. The process leads not only to higher gas yields during digestion, but also the more efficient dehydration of sludge. Recovery of phosphate and nitrogen in a treatment plant with biological phosphate removal is also possible if a suitable process is used. The sludge can be further utilised for energy recovery through incineration or pyrolysis.

Keywords
Energy autonomy, sludge treatment, deammonification.

Introduction
Primarily a sewage treatment plant is required to meet effluent consents according to the local legal requirements. In addition, the total costs of treatment are under strict control and in general there is an aim to reduce costs as much as possible. In particular operational costs such as those from electrical power consumption and sewage sludge disposal are very significant. Looking further, the recovery of fertilizers, mainly phosphorus and nitrogen, from sewage or from sewage sludge is a target for the near future.

Over the last few years, energy supply and energy efficiency are important political issues in many countries all over the world. Particularly because of the increasing costs for energy and the dependence on a few suppliers of fossil fuel is of importance. In Germany, waste water treatment plants are usually the biggest energy consumers for municipalities (approx. 20% of the total). In the Netherlands, the Water Boards are working on the implementation of energy efficiency measures on their wastewater treatment plants. Also in UK water companies there is a growing awareness of the importance of energy efficiency. Energy saving and energy recovery are recognized as basic requirements to minimise both operating costs and environmental impact, and the implementation of measures to achieve this is increasing.

Reasonably priced sludge disposal options such as agricultural disposal, landfill or landscaping are more and more restricted or forbidden by many countries with the consequence of increasing sludge disposal costs. Future EU regulations are expected to limit these outlets even more therefore techniques are required which reduce the amount of sewage sludge for disposal as much as possible.
Any energy self-sufficient sewage treatment plant must produce sufficient electrical and thermal power to at least cover its own needs. Consequently, measures have to be taken to achieve this goal (or at least to improve the energy efficiency of the plant) while also keeping in mind the need to minimise waste disposal costs.

**Energy saving**

Measures to reduce the power consumption of a waste water treatment plant may for example include the installation or the replacement of drives by those of high efficiency, the use of effective aeration systems (like plate aeration) as well as the use of turbo compressors with magnetic field bearings for compressed air generation in larger treatment plants.

The improvement of sludge dewatering/dehydration, for example by optimisation of the sludge conditioning or the digestion process, as will be outlined below, is a further possibility to reduce the electrical power consumption. It also minimises sludge disposal costs and decreases the thermal power demand for drying the dewatered sludge.

A major step towards the energy self-sufficient waste water treatment plant is to implement nitrogen removal by deammonification. With this technology, nitrogen removal is decoupled from the usage of carbon. As a consequence carbon is available for the generation of energy carriers (like methane). In many countries total nitrogen removal is part of the effluent consent.

The deammonification process is based on the partial (approx. 50 %) aerobic nitrification of the nitrogen load. The produced nitrite serves as basis for the subsequent further anaerobic ammonium oxidation.

![Reaction route: Conventional N-removal (standard process) vs. deammonification process](image)

**Figure 1:** Reaction route: Conventional N-removal (standard process) vs. deammonification process

Compared to the conventionally used N-removal process (nitrification/denitrification), deammonification requires approx. 60 % less oxygen, i.e. approx. 60 % less electrical power for aeration (reduction of the average specific energy consumption from 2.9 kWh/kg eliminated nitrogen to approx. 1.1 kWh/kg). In addition, no carbon source is needed. This opens up the possibility to use as much as possible of the carbon which is entering the
treatment plant for the generation of energy, instead of using it for nitrogen removal.

Deammonification systems are already used in an increasing number of sewage plants to treat the sludge liquor. Deammonification by DEMON® (patented system, Cyklar-Stulz GmbH, Switzerland, > 40 references) is not only applicable for sludge liquor treatment but may also be used for the treatment of the main stream of the waste water treatment plant. The highest efficiency can be achieved in waste water treatment plants which are run based on the so called A/B process (adsorption-activated sludge process).

In this process, the majority of the influent carbon is fixed by adsorption in a first high-loaded step (A-step) and used for methanogenic digestion. Most of the COD can thus directly be converted into biogas. The major disadvantage of the A/B system is that in the low-loaded B-stage, there may not be sufficient carbon left for denitrification. Implementation of DEMON® in the side stream as well as the main stream (B-stage) of this system, a concept which is called EssDe®, solves this problem. This results in a maximum energy surplus, thanks to minimal oxygen consumption and maximised biogas production, efficient nitrogen removal and less total excess sludge.  

In 2011, the German Federal Environmental Ministry together with KfW announced funding for a large-scale demonstration project at the municipal WWTP Eisenhüttenstadt, Germany. This project will demonstrate how a sewage treatment plant, previously operated with conventional nitrification/denitrification and with a high influent ammonium load (> 10 g NH₄-N/PE*d) can be converted to an energy autonomous waste water treatment plant by implementation of EssDe®. The project is scheduled to be completed in April 2014.

Energy recovery

Sludge is the main energy source which is available on a municipal waste water treatment plant. An energy balance of an average treatment plant, shows that a significant amount of energy is stored in sludge. Energy recovery measures are therefore basically related to sludge treatment and sludge treatment technologies. The most important one and the prerequisite for the energy self-sufficiency of a waste water treatment plant is sludge digestion which, beyond that, reduces the amount of sludge for disposal and/or improves dewatering quality thus reducing sludge disposal costs.

Common sludge treatment methods that use sludge as the energy source, such as sludge incineration primarily produce thermal power. The amount of electrical power which can be recovered if only these kind of measures are considered at a waste water treatment plant will usually not be sufficient to cover its total electrical power consumption. In addition, due to the relatively high investment costs and the operating requirements, these technologies are still mainly restricted to large sewage plants. Interesting alternatives such as sludge gasification and pyrolysis are still not regarded as “proven” techniques.

However, these methods, at present especially sludge incineration, are important options for the 100 % use of the sludge inherent energy and may be a perfect supplement to sewage sludge digestion.

For the total (electrical and thermal) energy balance of a waste water treatment plant and
in view of its sludge disposal costs it is, due to the reasons mentioned above, of prime importance:

- to select and implement the appropriate digestion process and/or the appropriate digester type;
- to use a digestion process which is optimised as far as possible;
- to select the appropriate power generation units for the conversion of the biogas to electrical current and heat;
- In addition, attention should be given to a proper heat management (heat recovery from the digested sludge etc.).

**Digestion process / Digester type**

In 2011, in Eisenhüttenstadt, Germany, a completely new waste water treatment plant, installed on a greenfield site, was started up, mainly for the treatment of the waste water from an industrial area (pulp and paper industry). The influent waste water (COD load 77 t/d) has a high calcium content (approx. 1000 mg/l). During anaerobic digestion, calcium tends to form calcium carbonate. This may lead to calcium carbonate generation, heavy sludge granules with reduced biological activity accumulating on the bottom of the digester. The specific design of the digesters used in Eisenhüttenstadt (ANAFIT R2S reactors) allows for removing the calcium carbonate from the digester, thus ensuring the required high biological activity of the sludge granules.

Currently, this plant generates 3,000 kWh el./h. Consumption is 1,200 kWh el./h, the surplus of 1,800 kWh el./h is exported to the grid. In addition, approx. 3,000 kWh/h thermal energy is recovered, most of which is supplied to the main producer of the treated waste water, the pulp and paper production unit.

**Optimisation of the digestion process**

Application of Thermal Pressure Hydrolysis (TPH, mostly named THP = Thermal Hydrolysis Process) prior to digestion is regarded as being an effective means for the disintegration of excess sludge with, substantially, the following effects:

- to improve the biological availability of the excess sludge and, consequently
- to increase the biogas production and
- to reduce the total dry solids amount of the digested sludge
- to increase the dry solids content of the dewatered sludge and, consequently,
- to minimise the amount of sludge for disposal

So far, the CAMBI THP system is probably the best-known THP system for the disintegration of excess sludge on the market and is successfully operated in a number of waste water treatment plants all over the world. However, in this system, thermal sludge disintegration is effected in a quasi-continuously operated batch procedure, using steam as the heat source. The steam has to be generated on the plant, treatment of the water supply to the steam boiler feed is also required. For some operators of waste water treatment plants, steam based systems are not a preferred option, mainly for operating and safety reasons. One further observed disadvantage of this steam based heating system is the initial capital cost,
which has been regarded by some as very high for small to medium sized waste water treatment plants.

Lysotherm® is a newly developed THP system which has especially been designed as an economic and safe to operate option for both small scale and large scale sewage treatment plants (≥ 30,000 PE). Lysotherm® is patented by SH+E. The technology is based on in-house knowledge and construction of heat-exchangers for the dairy industry.

The Lysotherm® design allows continuous operation. The system is based on the indirect heating of sludge with two heating circuits.

- A closed regenerative water circuit:
  The closed regenerative water circuit allows recovery of surplus heat from the hydrolysed sludge before this is fed into the digester and its reuse in the pre-heating of the excess sludge which is freshly pumped into the Lysotherm® system.

- A thermal oil circuit:
  The thermal oil circuit ensures the supply to the Lysotherm® system with the required process heat. This is recovered from the exhaust gas of the associated CHP units.

Hydrolysis is usually obtained at temperatures ranging between 140 - 160 °C and with a residence time of the sludge at the hydrolysis temperature of 30 - 60 min.

Table 1: Results obtained with Lysotherm® in a full scale demonstration at the WWTP Stockach, Germany

<table>
<thead>
<tr>
<th>Results of primary hydrolysis with Lysotherm®</th>
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<tr>
<td>Increase in gas production:</td>
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<tr>
<td>Approximately 20 % related to VDS feed total sludge</td>
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<tr>
<td>Hydrolysis ratio 35 – 48 %</td>
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<tr>
<td>COD-exposure degree A_{COD}: Approximately 40 – 50 %</td>
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<tr>
<td>Reduction in viscosity of the excess sludge: ≥ 65 %</td>
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<tr>
<td>Reduction of the viscosity in the digester: ≥ 50 %</td>
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<tr>
<td>Improvement of the dewatering: ≥ 5 %</td>
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The WWTP Stockach has two identical digesters. A long term full scale demonstration was carried out during which both digesters were fed with the same amount of primary and excess sludge per day. However, the excess sludge which was fed into digester no. 2 was hydrolysed by Lysotherm® prior to digestion (so-called "primary hydrolysis"). The demonstration was run for > 12 months. The results obtained are comparable to those reported for the Cambi THP system under comparable conditions.

In addition to an average 20 % increase in gas production, the improvement in dewatering of the digested sludge was remarkable. Depending upon the type of dewatering method used (belt filter press vs. centrifuge), an increase of the dry solids content in the digested and dewatered sludge of ≥ 5 % was observed.

The following example highlights the consequence of this result in terms of sludge disposal costs:
For a waste water treatment plant with approx. 4 metric ton DS/d of digested sludge (corresponds to approx. 100,000 PE), the increase in the dry solids content of the digested and dewatered sludge of “only” 5 % from 25 % to 30 % corresponds to 16.7 % less digested sludge for disposal and hence 16.7 % reduced sludge disposal costs.

Amongst other criteria, the digestion process has to ensure sufficient retention time of the sludge freshly fed into the biological system in order to maximise gas production and minimise the amount of digested sludge. For municipal sludge, 20 - 25 days of retention time in the digester system are usually claimed. Applying Lysotherm® reduces the required minimum residence time to 15-20 days.

At the 170,000 p.e. WWTP Lingen (Germany) a full scale Lysotherm® process has been running for 2 years at a capacity of 1750 metric ton DS/y. Two other full scale plants are in construction (9800 and 3500 ton DS/y). Lysotherm® is designed and constructed as a modular and containerised system, bringing standardisation, off-site fabrication minimising site time and increasing safety.

An anaerobic treatment process called LysoGest® (patented system, P.C.S, Germany) was developed where the primary sludge is digested in one digester and hydrolysed excess sludge in a second separate digester. Laboratory and pilot scale test results indicate that this should:

- reduce the required retention time during digestion (max. 15 days for excess sludge) and therefore reduce the required digester volume
- result in a further increase in gas production (+ 10 % related to the gas production resulting from the hydrolysed excess sludge) due to a better adaptation of the biology.
- allow recovery of phosphate and nitrogen in a treatment plant with biological phosphate removal if a suitable process is used. Examples of such a process is the AirPrex® system (patented by Berliner Wasserbetriebe, Germany) for phosphate recovery and improvement of dewatering.
Figure 2: LysoGest®, example of implementation

Figure 2 shows one possibility of how the LysoGest® process can be used in a waste water treatment plant. It reflects what is foreseen in a further demonstration project, funded by the German Federal Environment Ministry (BMU) together with KfW, in the context of a support programme with the focus on energy efficient sewage treatment plants. The project has already started and will finish by the end of September 2014. It is being undertaken at the WWTP in Lingen, Germany, and will demonstrate, for the first time on a large-scale, how a plant using thermal hydrolysis of the excess sludge (Lysotherm®), separate digestion of the primary sludge and hydrolysed excess sludge (LysoGest®) and by application of the AirPrex® phosphate recovery procedure and the Demon® rejectwater treatment can be transformed into a “Plus-Energy-WWTP with Phosphorus Recovery”.

The goals of the projects are to show that the WWTP Lingen will not only become energy self-sufficient for electrical and thermal energy. Due to the LysoGest® procedure, digestion is intensified and the retention time of excess sludge in the digester may be shortened, hence leaving capacity for additional co-substrate (biodiesel waste water) which may be added to the digestion procedure resulting in a surplus of electrical power (approx. 25 %) as well as thermal energy. Phosphorus recovery rate is targeted be at least 30 % of the phosphorus load in the influent of the waste water treatment plant.

Sludge treatment overview

In several countries, sludge incineration is the preferred or even the only accepted method for sewage sludge disposal. Depending on the method of incineration an energy surplus is possible.

If sewage sludge is to be incinerated without the addition of other (dry) materials, it requires a dry solid content of > 37 %, preferably approx. 45 % dry solids, to allow a safe and effective incineration. Usually, it is dewatered and dried before incineration. For economic reasons, to minimise thermal energy requirement, dewatering should be maximised.
Figure 3: Sludge treatment – options

The scheme shown in picture 3 summarises the discussed options for sludge treatment with two additional possibilities:

- Thermal hydrolysis may be used not only to treat excess sludge before digestion (so-called “primary hydrolysis”), but also for the treatment of digested sludge. This has no effect on the biogas production, but on sludge dewatering. Results obtained during testing with the Lysotherm® system at the WWTP Stockach show an increase of the dry solids content of the digested sludge after secondary hydrolysis of up to +10 % -points. This is approx. + 5 % -points compared to results obtained with hydrolysed and subsequently digested sludge. However, in both cases, proper sludge conditioning, which has to be adapted to the modified sludge quality, is a crucial factor and significantly influences the dewatering quality (and also the polymer consumption).

- Phosphate can be recovered as MAP (Magnesium - Ammonium – Phosphate, also called “Struvite”) from the centrate of the dewatered sludge or from the digested sludge (as at the WWTP Lingen) before dewatering. This will yield two additional potential benefits:
  - Effective prevention of undesired downstream crystallisation of MAP/Struvite in pipework and equipment.
  - A significant increase in the dry solids content of the dewatered sludge can be expected (up to +5 % -points based on results obtained on laboratory scale).

However, this still has to be further investigated and proven in large-scale applications.  

Conclusions

The idea of energy autonomous sewage treatment plants is not an illusion; it is a vision which has realistic chances to become reality. Waste water treatment plants may be converted to become energy self-sufficient or, at least, energy efficient waste water treatment plants by the intelligent choice and combination of different processes and techniques. There is not only one way to obtain an energy self-sufficient waste water treatment plant design,
different options are possible. Sludge treatment and sludge treatment technologies play a major role in converting a sewage plant to an energy autonomous plant. Sewage sludge digestion is an essential pre-requisite and, so far, the key to success. In this context, sewage sludge no longer has to be regarded as just an environmental problem and cost issue, but rather as an important source of energy.

Measures taken to optimise sludge digestion in order to improve the energy efficiency of a waste water treatment plant usually also reduce the amount of sludge to be disposed and hence sludge disposal costs. Additionally, phosphate recovery may be achieved at treatment plants with biological phosphate removal.

Abbreviations

DS: Dry Solids  
MAP: Magnesium-Ammonium-Phosphate (= Struvite)  
PE: People Equivalent  
THP: Thermal Hydrolysis Process (= TDH, ThermoDruckHydrolyse (German))  
VDS: Volatile Dry Solids  
WWTP: Waste Water Treatment Plant

Data sources:

1. Cyklar-Stulz GmbH, Rietwiesstrasse 39, 8737 Gommiswald, Switzerland  
2. P.C.S. Pollution Control Service GmbH, Merkurring 46, 22143 Hamburg, Germany  
3. CUTEC-Institut GmbH, Leibnizstrasse 21 + 23, 38678 Clausthal-Zellerfeld, Germany