THERMAL HYDROLYSIS OF SEWAGE SLUDGE AND THE RECOVERY OF PHOSPHATE AND AMMONIUM FROM CENTRATE WATER

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Abstract

Recovery of phosphorous and ammonium from concentrated wastewater streams is getting more and more important nowadays. Phosphorous is a raw material, which is disappearing in ashes of sewage sludge, etc. Several studies predict a scarcity of phosphorous in the near future. Ammonium is produced out of nitrogen gas by fertilizer companies using natural gas (Haber Bosch process). Finally this ammonium ends up in WWTP where it is oxidized to nitrogen gas, using energy (aeration) again.

In anaerobic digestion processes ammonium and phosphorous are produced as soluble compounds, reaching high concentrations in the centrate water. When prior to the digestion of sewage sludge thermal hydrolysis is applied, very high concentrations of ammonium and phosphate will be reached in the centrate water.

Sustec applies its own continuous thermal hydrolysis system, TurboTec® process, before digestion of sewage sludge. In these cases the centrate water contains 2000 – 3000 mg NH_4-N/l and up to 500 mg P/l. For the treatment of this centrate water Sustec investigated the combination of struvite formation for phosphate recovery in combination with the recovery of ammonium. This so called NutriTec® concept is a new step for recovery of ammonium, resulting in a compact, sustainable and energy efficient method compared to classical methods like biological processes as anammox.

Keywords

thermal hydrolysis, digestion, dewatering, centrate water treatment, ammonia recovery, phosphate recovery, struvite

Introduction

Treatment of domestic wastewater is an energy consuming process. On a wwtp the net energy consumption is approximately 20 – 30 kWh per year per person equivalent treated wastewater, although wastewater contains approximately 130 kWh of potential chemical energy. In the Netherlands this potential energy content is equivalent with 2 billion kWh per year (about 2% of the Dutch electricity production). The nitrogen in the wastewater is mainly oxidized to N_2 gas. With this process another 37 kWh per person per year of potential energy is destroyed (to produce 1 kg of ammonia for fertilizers from N_2 about 2 Nm^3 of natural gas is needed). A lot of phosphorous ends up in the sludge. Due to higher concentration of nutrients in side streams ammonia as well as phosphorous can be recovered from these side streams.

In the Netherlands the wastewater treatment plants should become more energy efficient by 2% every year up to 30% in the next 12 years. At this moment many initiatives started to make the wwtp more energy efficient and even energy producing. By adding step by step several processes to the current wwtp, the plant can be made more energy efficient and valuable components like nutrients can be recovered (see figure 1).

One of the first steps, which can be introduced in this sustainable wwtp concept, is thermal hydrolysis of the surplus sludge and recovery of ammonium en phosphorous from the centrate water. Sustec has erected a continuous thermal hydrolysis of surplus sludge by the TurboTec® process at the WWTP Venlo and is constructing a TurboTec process in combination with nutrients recovery at the WWTP Apeldoorn (see step 2 and 5 in figure 1).

Concept for a sustainable wwtp

In figure 1 the several steps to add to an existing wwtp are shown towards a sustainable and energy neutral wwtp. This concept is mainly focused on using as much of the valuable components from wastewater as possible. This process consists of:
Pre-separation of raw wastewater: by effective pre-separation of raw wastewater more COD, nitrogen and phosphorous can be send to the sludge line. This pre-separation can be a high rate aerated step (A/B process), but also flotation or even membrane filtration. In this way more biogas can be produced and more nitrogen and phosphorous can be recovered.
Thermal hydrolysis of sludge by the TurboTec® for more biogas and an improved dewaterability of the sludge.
Return of a COD-rich side stream from the TurboTec® thermal hydrolysis for denitrification in the main wwtp. The liquid phase thermal hydrolyzed sludge contains a very high COD concentration, which can be used for denitrification (by pre-separation of raw wastewater the COD/N ratio can be too low for denitrification.
Digestion with addition of organic co-substrates (more room in digester is created by thermal hydrolysis).
Recovery of nitrogen and phosphorous by the NutriTec® process. In this process struvite formation and N-stripping are combined in a one-reactor system.
Local indirect drying with the use of produced biogas in order to produce energy rich sludge granules, with an energy content close to brown coal.

The above processes are in different stadia of development and can be implemented on an existing wwtp step by step.

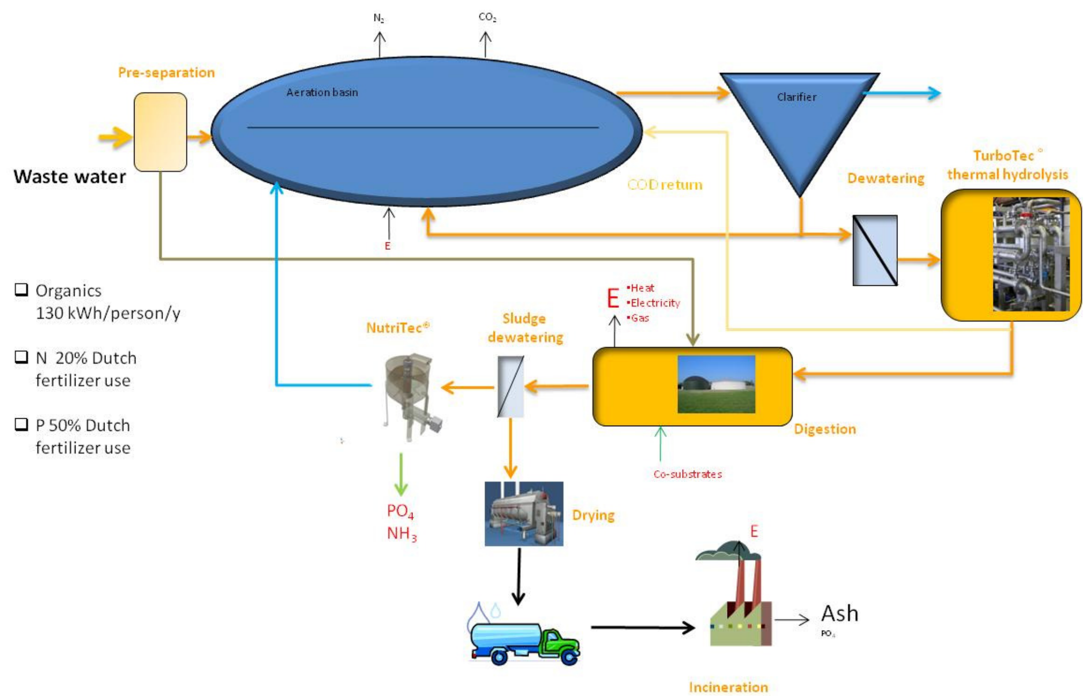


Figure 1: The sustainable wwtp

TurboTec®: continuous thermal sludge hydrolysis

Thermal hydrolysis of sludge prior to digestion is one of the first steps towards a sustainable WWTP, which can be easily implemented on existing WWTP. When sludge is treated under high temperature and pressure for a certain amount of time the sludge is hydrolyzed. Due to this treatment the cell structure of the bacteria in the sludge is destroyed as well as the extra cellular poly-saccharides (EPS) structures surrounding the cells. The content of the cells are released to the liquid phase. Due to this process the viscosity of the sludge decreases strongly. In figure 2 the thermal hydrolysis process is presented schematically.

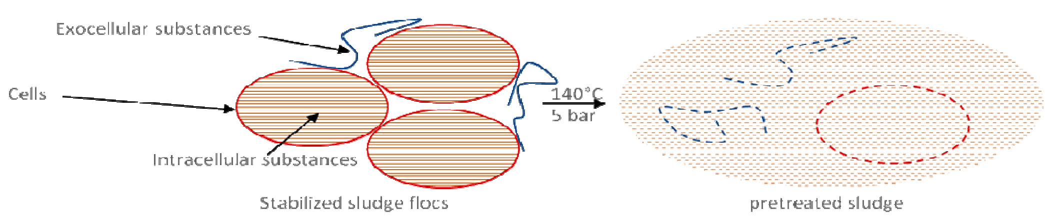


Figure 2: Principle of thermal hydrolysis of sludge

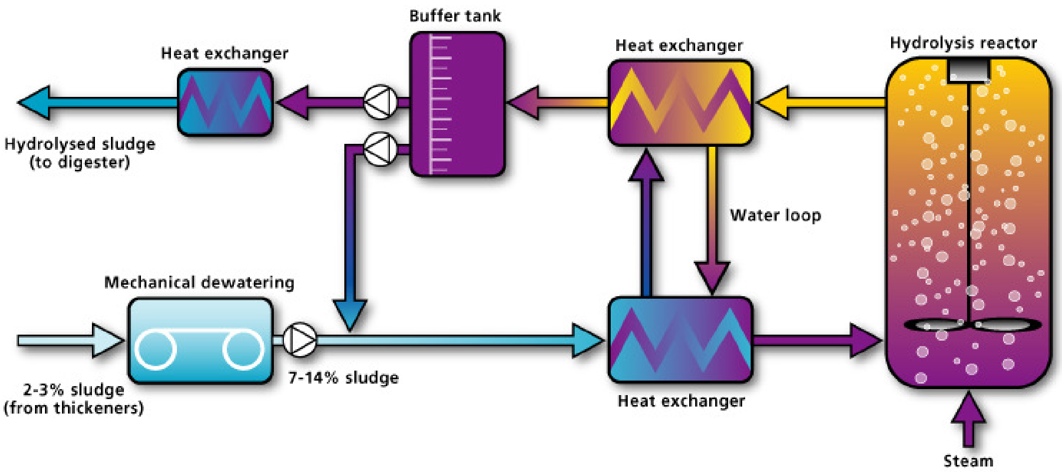
The TurboTec® thermal hydrolysis process developed by Sustec is a continuous process. After thickening or mechanical dewatering the sludge is fed to the hydrolysis reactor. Due to optimal heat recovery a minimum amount of external heat needs to be supplied to the reactor. This external heat can be supplied completely from the waste heat of the gas engine for electricity production. The waste heat from the gas engine is converted into steam. This “life steam” is directly fed to the hydrolysis reactor (see figure 3). The big advantage of a continuous system compared to existing batch systems is the simple process, resulting is easy operation and process control and low investment costs.

Thermal hydrolysis has several effects on the chain of subsequent sludge treatment steps, like sludge digestion, reject water treatment en sludge incineration.

Thermal hydrolysis has the following effects on sludge digestion:

- Increase of biogas production by 30% to 50%.
- Decrease of digestion time from 20 days to 15 days.
- Due to lower viscosity of the hydrolyzed sludge the digester can be fed with sludge with high TS (up to 12% TS) without causing mixing problems in the digester.
- Due to increased TS removal and higher TS loading the ammonia concentration in the digestion fluid will increase.

By running the digester with a higher TS concentration and run the digestion at shorter retention times will result in much compacter digester volumes (up to 3x times smaller) or having more digestion capacity in existing digesters. The TS loading of the digesters increase from 3 kg TS/m^3.d up



to 9 kg TS/m^3.d.

Figure 3: TurboTec® thermal hydrolysis system

Due to thermal hydrolysis a lot of sludge COD solubilizes, resulting in higher biogas productions. Typically biogas production and ODS degradation of secondary sludge increases by 30% - 40%.

The viscosity of the sludge after thermal hydrolyses strongly decreases. During the pilot research (see below) tests have been performed with a feed sludge of 7% TS till 12% TS. After thermal hydrolysis the sludge is completely fluidized, where the sludge of 12% TS after thermal hydrolyses has the viscosity of "raw" sludge of 6% TS.

The dewatering of the sludge directly after thermal hydrolysis (also before digestion) strongly improves. Dewatering tests show an improvement of dewatering of 40% - 50%, where the TS of the sludge after dewatering of secondary sludge improved from 21% TS to > 31 % TS.

Measurements of the sludge directly after thermal hydrolysis show that the COD in the liquid phase increases by 10 to 15 times to 20.000 mg/l till 50.000 mg/l. This COD contains for a big part organic acids. Due to this solubilization of sludge in the subsequent digestion process more biogas is produced. Also ammonia and phosphorous levels strongly increases in the liquid phase directly after thermal hydrolysis. Typically ammonia level rises up to 3000 mg N/l and phosphate up to 300 mg/l.

The TurboTec® thermal hydrolysis system can be used in two ways:

- Hydrolysis of sludge and direct dewatering of the sludge followed by anaerobic digestion of the fluid fraction. Preferably this can be done by FermaTec® aerobic MBR.
- Hydrolysis of sludge followed by anaerobic digestion and dewatering of the digested sludge after the digestion.

In both cases the liquid phase can be treated by NutriTec® ammonium and phosphate recovery.

Pilot tests on TurboTec thermal hydrolysis

For several waterboards Sustec has performed tests on continuous thermal hydrolysis of the surplus sludge of the wwtp's. First research is done on laboratory scale to select optimal circumstances for thermal hydrolysis of this sludge. The sludge is pretreated in several ways, after which digestion tests and dewatering tests are performed (see figure 4).

Figure 4: Laboratory tests on thermal hydrolysis, digestion and dewatering

After the laboratory tests pilot tests have been done on wwtp Venlo, Amersfoort and Leeuwarden in the Netherlands. In these pilot tests continuous thermal hydrolysis and subsequent digestion and dewatering have been tested for the surplus sludge's under different conditions. Main research goals were improvement of biogas production, improvement of TS reduction, improvement of dewaterability and reduction of the retention time during digestion. The pilot unit consiss of sludge sieving, mechanical thickening, TurboTec® continuous thermal hydrolysis and two identical digesters (see figure 5). One digester has been fed with the hydrolyzed sludge and the other with none hydrolyzed sludge.

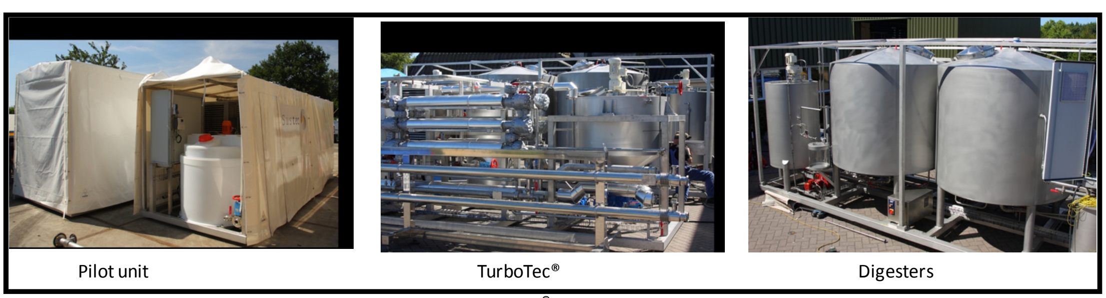


Figure 5: Pilot plant unit with TurboTec® thermal hydrolysis and digesters

Table 3: Results of thermal hydrolysis of secondary sludge on pilot scale

Increase in biogas production and VS degradation	+ 30 %
Improvement of dewater ability of digested sludge	+ 40%
Reduction of viscosity	7 times
Reduction of retention time in digester	- 40%
TS in feed to digester	12% TS

NutriTec® N&P recovery

Due to thermal hydrolysis the concentration of nitrogen and phosphorous increased in the centrate water after thermal hydrolysis and digestion. The effect of thermal hydrolysis on the amount and composition of centrate water is show in table 4.

Table 4: Effect of thermal hydrolysis on centrate water amount and composition

	Only digestion	**Digestion with Thermal hydrolysis**
TS feed to digestion	6%	11%
TS sludge cake after dewatering	24%	33%
Centrate water	7 m3/ton TS	14 m3/ton TS
NH4-N centrate water	1000 mg/l	2500 mg/l
P-centrate water	200 – 400 mg/l	200 – 400 mg/l

Due to the reduced centrate water flow (<50%) and increased concentration of nutrients, recovery of ammonium and phosphate from the centrate becomes more interesting. Sustec has investigated the recovery of ammonium and phosphate from centrate water by the combination of struvite formation and ammonia stripping. In this scheme the centrate water is fed into an airlift reactor with addition of caustic and $MgCl_2$, resulting in the formation of $MgNH_4PO_4$ crystals. These crystals are collected from the bottom of the reactor. In the subsequent step the water is heated up and the ammonium is removed by air stripping. Finally the ammonia is trapped in sulfuric acid, which can be sold as a fertilizer. This unique concept of struvite formation and ammonium recovery is the NutriTec® concept (see figure 6).

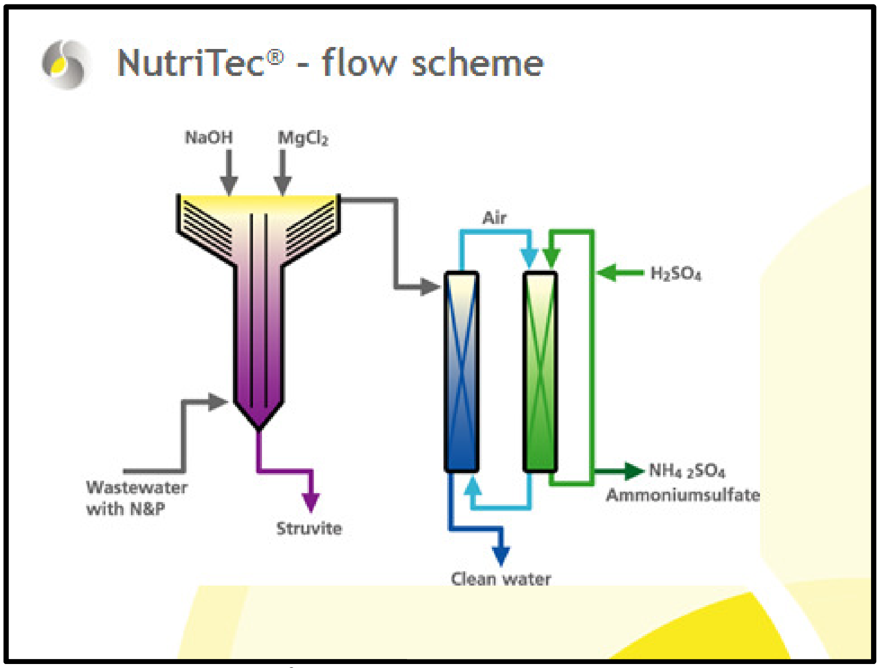


Figure 6: NutriTec® concept for N&P recovery

Several calculations have shown that the NutriTec® is an attractive alternative with respect to conventional centrate water treatment technologies, like anammox processes.

Full-scale plants

In 2011 Sustec has been awarded to realize a full-scale thermal hydrolysis plant at the WWTP Venlo. The basis for the project award was a calculated pay back time of the unit of less then 5 years.

The project consists sludge pretreatment (sieving, mechanical dewatering), TurboTec thermal hydrolysis, digestion, sludge dewatering and biogas treatment including electricity production and steam and heat production. The system is started up in the fall of 2012. In figure 7 the full scale

Figure 7: Full scale the TurboTec® thermal hydrolysis plant at WWTP Venlo

TurboTec® plant is shown.

The first NutriTec® concept is implemented in 2010 on semi-full scale for the recovery of ammonium and phosphate from human urine. In this unit 5000 ton of urine per year is treated (see figure 8).

Figure 8: Full scale NutriTec® concept for recovery of ammonia and phosphate from human urine

In 2012 Sustec/GMB has been awarded for the full scale TurboTec thermal hydrolysis together with NutriTec P-recovery at the WWTP Apeldoorn. This plant has a capacity of 9.000 ton/y of secondary sludge. In this plant more than 50 ton of P will be recovered per year as struvite. The plant will be in operation by the end of 2013.

Conclusions

Thermal hydrolysis can be an important step towards the direction of the energy neutral wwtp. The by Sustec developed continuous thermal hydrolysis process, the TurboTec® process, is relatively simple, which results in an economical feasible process with maximum energy recovery. Due to the fluidization of the sludge by the thermal hydrolysis the digestion process can by optimized and the sludge dewatering is strongly improved. This results in more renewable energy production due to higher biogas production and decreased sludge treatment costs. These features make the process economically attractive. Furthermore the thermal hydrolysis process is a first step towards a sustainable wwtp with nutrient recovery. The first full scale units with the NutriTec® nutrients recovery system are currently under construction.

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