MAXIMIZING SLUDGE AND BIOGAS PRODUCTION FOR COUNTERACTING GLOBAL WARMING

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Abstract Can wastewater treatment contribute to counteract global warming? Increased biogas production for substituting fossil fuel is one possibility. However, using maximum amount of the carbon source for biogas production there will be no carbon source for biological nutrient removal. This will need development of new methods for nutrient removal without carbon source, for which struvite precipitation and can anammox be used. Ozone treatment of digested sludge after degassing of CO_2 with recycling back to the digestion is a promising method to increase biogas production from sludge digestion.

At anaerobic digestion half of the energy is utilized as biogas and half remains as organic material in the digested sludge. To eliminate emission of greenhouse gases from digested sludge, all organic content in the sludge should be oxidized. At Super Critical Water Oxidation SCWO all organic content is oxidized and the energy can be utilized.

The possibility to use sewage sludge to counteract global warming by recycling carbon to deep see sediments should be studied.

Keywords Anammox, Anaerobic digestion, Biogas, Energy recovery, Experimental plant Hammarby Sjöstadsverk, Global warming, Nutrient removal, Phosporus recovery, Struvite, Sewage sludge,

INTRODUCTION

Global warming can be counteracted by substituting fossil fuel with biogas from digesting sewage sludge, thus reducing climate impact from carbon dioxide emissions. Biogas is more easily produced from primary sludge than from excess sludge from activated sludge process with biological nutrient removal. Primary sludge is easily bio-degradable since it consist of more easily digestible carbohydrates and fats, compared to excess sludge which consists of complex carbohydrates, proteins and long chain hydrocarbons (Gary et al., 2007). Biological nutrient removal also requires carbon source which decrease the amount of organic material which can be separated as primary sludge and thus decrease the possibilities to produce biogas. Maximum biogas production will give best opportunities to counteract global warming.

Organic waste exist both as sewage sludge from wastewater treatment and as municipal organic waste from for instance households. Sustainable handling of municipal organic waste and sewage sludge has as an important goal to recycle resources without supply of harmful substances to humans or the environment (Levlin 1999, Hultman and Levlin, 1997). Another important goal is to avoid to deposit waste and sludge on landfill. Degradation of the organic material deposited on the landfill produces CO_2 and methane which recirculates carbon back to the atmosphere and cause global warming. In Sweden a tax of 250 SEK/ton on all deposited solid waste was introduced year

2000 (SFS 1999:673). First deposition of incinerable waste was prohibited and in year 2005 there was a ban on deposition of all organic material on landfill (SFS 2001:512).

Substituting fossil fuel with energy from biogas produced from wastewater treatment and reducing energy consumption is a ways to use wastewater treatment to counteract global warming. Another method to counteract global warming is by returning carbon back to the lithosphere, from which fossil fuels is taken. In natural the global geochemical cycle for carbon the carbon balance with the lithosphere contains of a flux to the lithosphere (0.2 Gton/year) by sedimentation of organic carbon on the deep sea bed and a flux from the lithosphere (0.1 Gton/year) by volcanism (Butcher et al, 1994). The anthropogenic emission of carbon by burning fossil fuels is 5 Gton/year.

CASE STUDY OF CLIMATE IMPACT FROM SEWAGE HANDLING

A case study with calculations on amount of sewage, sludge, produced biogas, greenhouse gas emissions, energy gain etc. has been made in a study of emissions of greenhouse gases and other air pollutants for year 2001 made at the government of the islands of Åland (Levlin, 2004, 2003). The main part of the emissions (56 %) is from the sea traffic, which are the ferries going between Sweden and Finland. Emission of greenhouse gases from sewage and waste handling in Åland is estimated to 0.8 tonne CO_2–equivalents per capita, which is 4 % of the total emissions of greenhouse gases. Table 1 shows **e**missions from incineration of biogas from sludge digestion, and emissions from deposition of digested sludge (tonne/year) year 2001 calculated on a total amount of 1400 tones DS sludge before digestion. Emission of gases from stored or deposited sludge has calculated with emission factors by RVF Utveckling (2002), which are a methane emission of 3.13 kg/Mg DS and nitrous oxide emission of 5 kg/Mg DS. However, composting the sludge will probably reduce the methane and nitrous oxide emission from the digested sludge. The amount of produced biogas from totally 1400 tonne DS sewage sludge was 219 000 m^3. Using the biogas, witch gives 1.3 GWh energy, to replace fossil fuel would save 178 tonne oil and reduce the global warming impact from wastewater treatment on Åland from estimated 5200 to 4200 tonne CO_2-equivalents.

Table 1. Emissions of greenhouse gases and some other air pollutants from incineration of biogas from sludge digestion, and emissions from deposition of digested sludge (tonne/year) year 2001 calculated on a total amount of 1000 tones DS sludge before digestion (Levlin, 2003).

	Greenhouse gases			
	CO_2	CH_4	N_2O	GWP
Biogas incineration	843	0.010	0.019	850
From digested sludge	1269	2.911	4.665	2777
Total	2112	2.921	4.684	3627

After producing biogas through sludge digestion there will be a digested sludge which has to be taken care of. Emission of gases from methane and nitrous oxide emissions from stored or deposited sludge, will give a larger global warming impact of 2,8 g CO_2-equivalents/g DS (RVF Utveckling, 2002), which is higher than from CO_2 from burning biogas, 0,85 g CO_2-equivalents/g DS. Oxidation of all organic material in the sludge would therefore be preferable. Sludge incineration is a method which oxidizes all sludge and produces an inorganic ash. However the sludge has to be dried to 40 % before incineration which is an energy consuming process and at many incineration plants the energy from incineration is required for the sludge dryer. Super Critical Water Oxidation SCWO, (occurs in water of a supercritical phase at a temperature above 374 °C, a pressure higher than 22 Mpa) of sludge will produce more energy (as heat at 600 °C) and produce an inorganic sludge product with no emissions of greenhouse gases. Table 2 shows a comparison of SCWO with other sludge oxidation methods. A sludge oxidation method as SCWO would therefore be most beneficial for counteracting global warming.

Table 2. Comparision of energy gain and rest products from some sludge oxidation methods.

Method	Composting	Anaerobic digestion	Sludge incineration	Super Critical Water Oxidation
Energy gain	No	Half, 2.5 kWh as biogas/kg DS	The energy is needed for sludge drying	Almost all 5 kWh as heat/kg DS
Rest product	Half of the organic content is oxidised		All organic content is oxidised	

EXPERIMENTAL PILOT PLANT HAMMARBY SJÖSTADSVERK

2008 Royal Institute of Technology KTH and IVL Swedish Environmental Institute have jointly taken over responsibility for Hammarby Sjöstadsverket, which has wastewater treatment lines for 150 p.e. (1.5 m^3/h) in pilot plant scale:

- Aerobic treatment with activated sludge process and sedimentation.
- Aerobic treatment with membrane bioreactor (MBR), an aerobic reactor with submerged micro filter, and drum filter for separation of primary sludge.
- Anaerobic treatment with UASB-reactors (Upstream Activated Sludge Blanket). With anaerobic treatment high biogas production can be achieved, however, without possibility for biological nutrient removal.
- The produced sludge can be thickened, digested and dewatered.

Figure 1. Pilot plant lines at Hammarby Sjöstadsverk; a) traditional activated sludge process with sedimentation, b) membrane bioreactor (MBR) and c) UASB-reactors and sludge digesters.

INCREASING BIOGAS PRODUCTION FROM SLUDGE DIGESTION WITH OZONATION

At Hammarby Sjöstadsverk a project for increased biogas production from digestion of sludge has started. The idea is to dewater digested sludge and recycle it back to the digestion and also to hydrolyze the sludge through ozonation. Ozonation of sludge is a method that mostly has been used for reducing sludge volume, but has also been studied for achieving increased biogas production. Ozone treatment has two counteracting effects:

- Degradation of molecules and cell structures that are undegradable for methanogenic bacteria will increase biogas production
- Oxidation of organic molecyles that are degradable for methanogenic bacteria will decrease biogas production

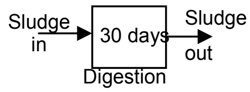
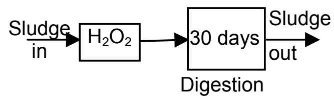
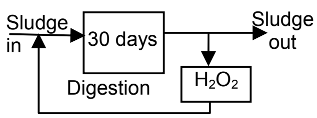
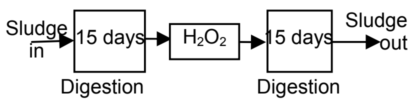
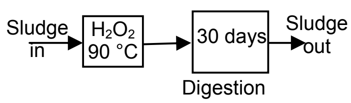
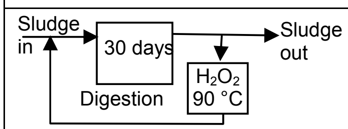
At experiments with digestion of ozonated sludge by Weemaes et al. (2000), the biogas production increased with 80 % at ozone treatment with 0.1 g O_3/g COD. At higher ozone concentration the increase of biogas production was smaller. Ozone treatment gives a partial destruction of the microbial sludge cells resulting in an increased amount of dissolved organics and higher biodegradability of the sludge. However, the amount of organic material was decreased.

Ozonation of digested sludge and recycling back to the digestion would therefore achieve largest biogas production. Digestion for 40 days of raw sludge mixed with 50 % ozonated digested sludge reduced biogas production to 80 % - 70 % of incoming organic material and 97 % - 89 % of removed VSS. (Bernal-Martinez et al., 2009). Then mixing digested sludge with raw sludge, half of the sludge has been digested before digestion for 40 days, and the real digestion time is therefore 60 days. If no further digestion occurs of the digested sludge the biogas production will be 50 % of digestion of raw sludge.

Biogas production at experiments with different configuration shown in table 3, with oxidative treatment of sludge with H_2O_2 has been studied by Cacho Rivero et al. (2006). Oxidative treatment reduced biogas production counted per amount of removed VSS (Volatile Suspended Solids) which shows an increase in the amount of organic material that has been oxidized without producing biogas. The result on the biogas production calculated on the amount of treated sewage was different depending on the configuration. Oxidation of digested sludge circulated back to the digestion gave no increase in biogas production but in combination with heat treatment this configuration achieved the highest biogas production (+ 40%).

At ozonation of sewage carbonate stifle the effect of ozone (Beltrán, 2004). The recommendation is that the ozonation is made at high pH-level which promotes the degradation effect of ozone. However, CO_2 produced at ozonation increases the carbonate concentration which stifle the effect of ozone. The carbonate can be removed as CO_2 by addition of acid, and after removal of CO_2 the pH-level can be raised again with addition of base.

Table 3. Biogas production at experiment with oxidation of sludge with H_2O_2 (Cacho Rivero et al., 2006).

Configuration	Biogas production	
	9.6 mL $CH_4/mL_{treated}$ ·day 650 mL $CH_4/gVSS_{removed}$	
	9,8 mL $CH_4/mL_{treated}$ ·day 502 mL $CH_4/gVSS_{removed}$	+21 % –23 %
	9,6 mL $CH_4/mL_{treated}$ ·day 593 mL $CH_4/gVSS_{removed}$	±0 % –9 %
	11,8 mL $CH_4/mL_{treated}$ ·day 633 mL $CH_4/gVSS_{removed}$	+23 % –3 %
	6,8 mL $CH_4/mL_{treated}$ ·day 293 mL $CH_4/gVSS_{removed}$	–29 % –55 %
	3,5 mL $CH_4/mL_{treated}$ ·day 571 mL $CH_4/gVSS_{removed}$	+40 % –12 %

To get higher biogas production by ozonating digested sludge and recycling it back to the digestion the carbonate produced in the digestion has to be removed before ozonation. At digestion both methane and CO_2 is produced which gives a high carbonate concentration in the digested sludge. One way to remove CO_2 is to use heat treatment as in the configuration by Cacho Rivero et al., (2006) which give the highest biogas production. Figure 2 shows a **p**roposal for a process with degasing and heat treatment of digested sludge. Degasing of CO_2 can by made addition of acid and base with electricity as shown by figure 3.

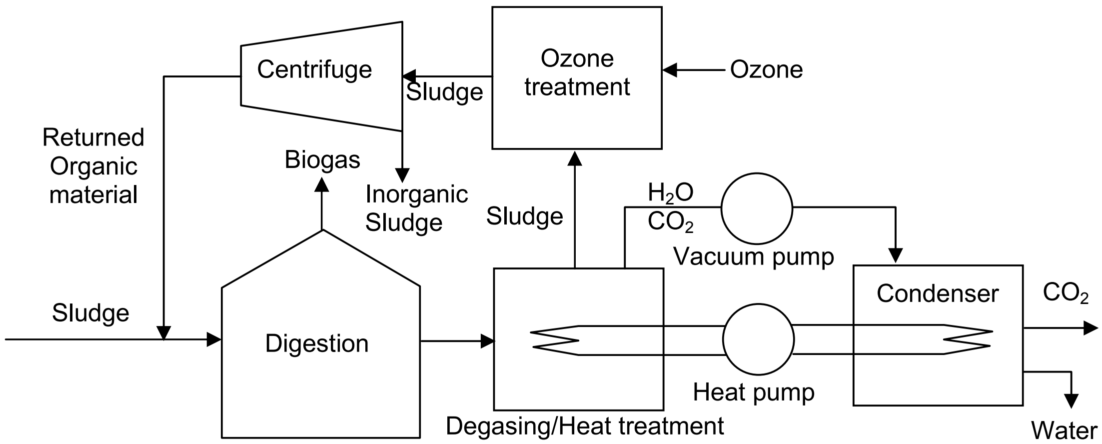
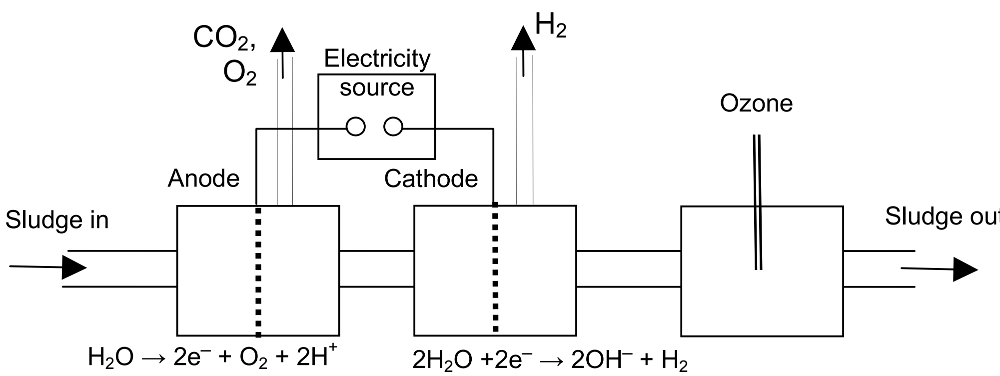


Figure 2. Proposal for process with degasing and heat treatment of digested sludge.



Figur 3. Proposal for a process with elektric degasing of sludge.

PROPOSAL FOR NUTRIEN REMOVAL WITH ANAEROBIC SEWAGE DIGESTION

With anaerobic treatment a very high biogas production can be achieved (Kepp and Solheim, 2000). Figure 4 shows a comparision of biogas production from activated sludge process with sludge digestion, there half of the organic content in the sludge is converted to biogas, and anaerobic digestion of all sewage, there most of the organic content is converted to biogas. The activated sludge process has also a large energy consumption for the air blowers, which makes anaerobic process more energy efficient, which can save fossil fuel and reduce global warming. However, anaerobic digestion of the sewage gives less possibility for achieving biological nutrient removal. In order to maximize biogas production and reduce energy consumption pilot plant lines for anaerobic wastewater treatment has been built at Hammarby Sjöstadsverk. The possibility to use reverse osmosis for nutrient removal has been studied at (Kieniewicz, 2006), but the energy consumption is very high.

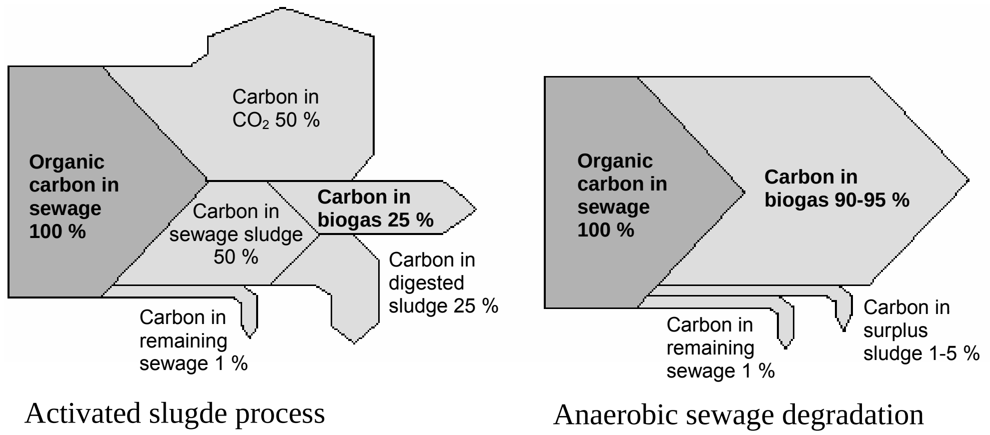


Figure 4. Comparision of biogas production from activated sludge process with sludge digestion and anaerobic sewage degestion (modified from Kepp and Solheim, 2000).

Struvite (magnesium ammonium phosphate, $MgNH_4PO_4$) precipitation with magnesium and the anammox reaction are processes that can be used for nutrient removal without need of carbon source. Struvite can not be directly precipitated from the effluent since the concentrations are to low. To precipitate struvite the concentrations can be increased by concentrating ammonia and phosphate with a ion exchange process such as REM NUT (Liberti et al, 2001), where ion exchanger is used to remove ammonia and phosphate from the treated water and struvite is precipitated from the regeneration solution. In a P-driven REM NUT the amount of magnesia needed to remove phosphate is used and remaining ammonia is removed through nitrifiction/denitrification, which requires carbon source for denitrification. Struvite can be precipitated by increasing the pH value by adding base (Mishina, 2001).

In the anammox process, which have been studied since many years at KTH (Szatkowska et al., 2007), half of the ammonia is oxidized to nitrite and reacts with the remaining ammonia to form nitrogen gas, without need of carbon source. The process requires a high ammonia concentration and can therefore not be made in the main wastewater stream. In the proposed process shown by figure 5, the amount of produced struvite and added magnesium, correspond to the phosphate content in the incoming wastewater. In the main wastewater stream is the concentrations to low to achive struvite precipitation. Therefore the pH-level has to be raised by addition of base, which has to be neutralized with acid after precipitation. This can be done by using magnesíum hydroxide. An alternative is, as shown by figure 6, to use electricity for addition of both base and acid. Half of the ammonia exceeding the phosphate content is extracted as ammonia and the rest as struvite. By oxidizing ammonia in struvite to nitrite, the amount of struvite larger than the phosphate content is redissolved. In experiments made at the department struvite was dissolved by oxidizing ammonia with nitrification bacteria (Levlin and Hultman, 2008). The nitrate of the dissolved struvite can with the extracted ammonia in an anammox process be converted to nitrogen and the magnesium and phosphate can be returned for struvite precipitation. This process can preferentially be used together with an anaerobic treatment process such as UASB, there all nitrogen is in form of ammonia.

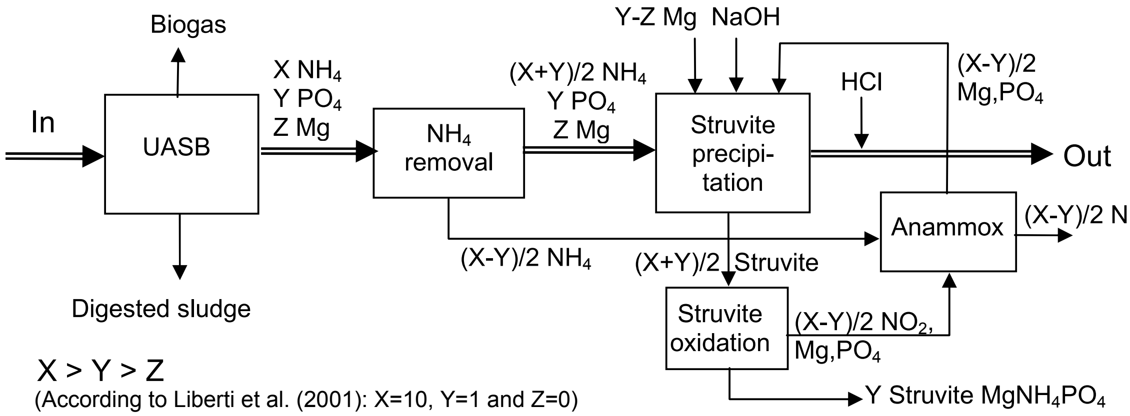


Figure 5. Proposed process for nutrient removal and phosphorus recovery based on struvite precipitation and anammox (Levlin, 2009).

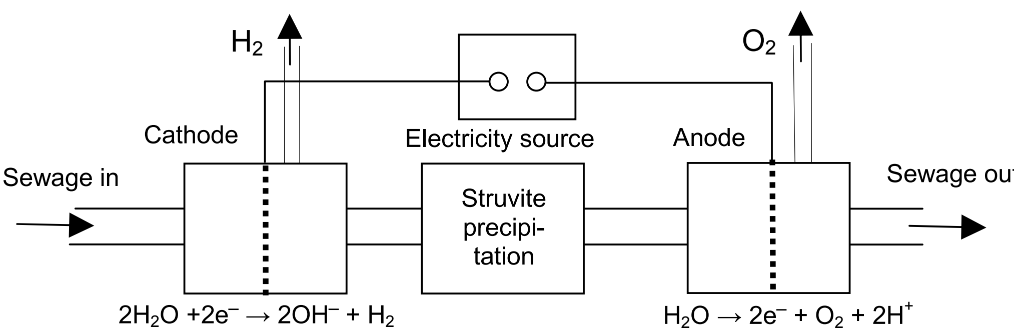


Figure 6. Use of electricity for increasing pH-level to achieve struvite precipitation.

USING SLUDGE FOR RECYCLING CARBON BACK TO THE LITHOSPHERE

An idéa to counteract global warming is thereby to increase the flux to the lithosphere by deposition of organic material on the sea bed. Fossil fuels originate from organic material deposited on the sea bed million years ago. Ocean sequestration of crop residue (Strand and Benford, 2009) returns about 90% of the carbon including reduction for use of fuel for collection and transport. Crop residue oceanic permanent sequestration, there crop residues is collected and transported to deep ocean sites, ballasted as needed with stone, and sunk to rest on ocean sediments at depths greater than 1000-1500 m, is a method that can potentially remove 15% of the current global CO_2 annual increase. The method takes advantage of the relative stability of terrestrially derived organic matter in the sediments compared to marine organic matter, due to the cold, limited oxygen availability, and apparent lack of a marine mechanism for the breakdown of lignocellulose equivalent to that of the terrestrial lignin peroxidase systems. Only one part per thousand of the CO_2 in the deep ocean layer below 1500 m is estimated to annually leak into the upper layer.

Sediments at the sea bottom are water saturated which reduced oxygen diffusion and makes the sediments anaerobic with very low degradation rate of the organic material. On depth below 500 m methane produced by anaerobic degradation of organic material will due to the high pressure together with water produce solid methane hydrates (Szamalek, 2004). Due to formation of methane hydrates methane produced in sediments deep in the ocean will be trapped in the sediments and will not contribute to global warming. A large problem for many wastewater treatment plants is to find methods to handle produced sewage sludge. Methods for sludge minimization are therefore used to reduce the problems of sludge handling. Energy consuming methods such as ozone or thermal heating are used for degradation of organic material in the sludge and thereby reduce the sludge volume. However, if the sludge is a useful resource that can be used for counteracting global warming by deposition on the sea bed at depth larger than 1000 m, sludge maximization will maximize the possibilities for counteracting global warming.

CONCLUSIONS

Using maximum amount of the carbon source for biogas production will give maximum possibilities to substitute fossil fuel and thereby counteract global warming.

However, using maximum amount of the carbon source for biogas production will need development of new methods for nutrient removal without carbon source, for which struvite precipitation and can anammox be used.

Ozone treatment of digested sludge after degassing of CO_2 with recycling back to the digestion is a promising method to increase biogas production from sludge digestion.

The possibility to use sewage sludge to counteract global warming by recycling carbon to deep see sediments should be studied.

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