Anaerobic digestion of sludge and optimal energy recovery

In a nutshell

SUMMARY
It is best practice to stabilise primary and excess sludge in anaerobic digesters and to employ the produced biogas, using efficient pumps and screw lifters, for on-site efficient electricity generation and for sludge drying.
Target group
Public administrations responsible for waste water management and urban drainage.
Applicability
This best practice is applicable to public administrations responsible for waste water management, in large new and existing waste water treatment plants, with a capacity of more than 100 000 population equivalents or of a daily inflow BOD5 load of more than 6 000 kg.
Environmental performance indicators
• Percentage of electricity and heat needs of the waste water treatment plant met by own-generated electricity and heat from biogas on an annual basis (%) • Electrical efficiency of the generator fuelled with biogas (%) • Specific biogas production (N?/kg organic dry matter input)
Benchmarks of excellence
• Own-generated electricity and heat from biogas cover 100 % of the energy use for municipal waste water treatment plants with a size of more than 100 000 population equivalents without on-site thermal sludge drying, and 50 % in the case of plants with on-site thermal sludge drying

Description

Generally, municipal waste water treatment plants contribute to about 20 % of the overall electricity consumption of the public services of a municipality or city, more than the consumption of hospitals, street lighting, water supply etc. (Haberkern et al., 2008). There is a significant potential to save energy and to increase the energy efficiency of the treatment plants (see also best practice on “Energy efficient waste water treatment achieving full nitrifying conditions”). Concerning energy recovery, the anaerobic digestion of sludge is of significant importance.

Sludge derives from primary treatment (sedimentation), called primary sludge, and from biological treatment (activated sludge system or trickling filter), called excess sludge. In addition, sludge or suspended solids results from tertiary treatment (if applied), such as precipitation of phosphorus, solids from backwashing of sand filters, powdered activated carbon or lignite coke from the removal of micropollutants (see best practice on “Minimisation of wastewater emissions with special consideration of micropollutants”); often these sludges/solids are removed from the system together with the excess sludge. Furthermore, residues originate from the bar screen and the aerated grease and grid chamber but they have to be disposed of separately.

From the carbon balances of the aerobic and anaerobic biodegradation, it can be seen that under aerobic conditions, about half of the organic compounds are transferred to biomass whereas under anaerobic conditions, this percentage is only 1-5 % as most of the organic carbon is metabolised to biogas (Figure 1). This is due to the different metabolism of aerobic and anaerobic microorganisms. The biogas consists to about 60 % of methane which can be used in gas motors for electricity and heat generation.

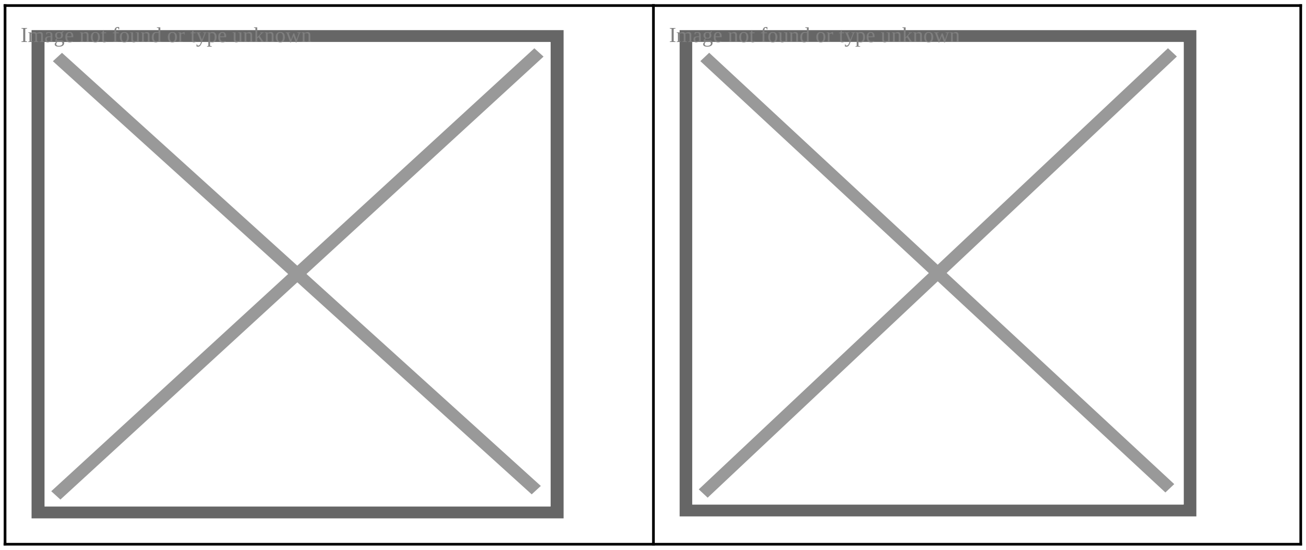

Figure 1: Carbon balance of the aerobic and anaerobic biodegradation process (Aivasidis/Wandrey, 1985)

The sludge is anaerobically digested in airtight tanks(see e.g. Figure 1 of the best practice on “Energy efficient waste water treatment achieving full nitrifying conditions”) and the biogas formed is collected and stored to be used for on-site generation of electricity and heat in biogas motors. The usual retention time in the digestors is about 20 days. The biogas can contain elevated concentrations of hydrogen sulphide (H_2S) which can lead to sulphuric acid corrosion in the biogas motor. As a consequence, measures to reduce the H_2S content, such as addition of iron(III)salts are applied in order to precipitate H_2S as iron(III)sulphide which remains in the digested sludge.

In case of spare capacity of the anaerobic digestor(s), waste or wastewater with high organic load (> 5,000 or better > 10,000 mg COD/l), for instance from food processing industries or from distilleries (but also from other types of industries), can be co-fermented resulting in higher gas production as most of the organic compounds are converted to biogas (methane and carbon dioxide) as well as in lower sludge formation and lower electricity consumption for activated sludge aeration as the concentrates have not be aerobically treated (see Figure 1). Thus, the co-fermentation of biodegradable concentrates, instead of their aerobic treatment, represents a win-win-situation.

Further, the disintegration of the sludge (comminution by physical, chemical or biological processes whereby, to date, ultrasonic techniques are mostly applied) can improve the anaerobic digestion and thus increase the biogas production (Bischofsberger et al, 2005). Favourable conditions for the application of disintegration techniques are:

- short retention times in the anaerobic digestor (< 20 d),
- a content of organic solids in the sludge of higher than 55 %,
- low specific biogas yields (< 350 NL/ kg organic dry matter input),
- separate processing of primary and excess sludge,
- excess sludge thickened to about 3-6 % dry matter, and
- a low percentage of coarse and fibre matters.

The biogas is usually used in biogas motors. Figure 2 shows the electrical efficiency which is between 30 and 40 %. This is low compared to other techniques which cannot be applied to biogas so far. However, the heat of the gas motors is also used for preheating the raw sludge as the temperature in the anaerobic digestors has to be maintained at around 37°C.

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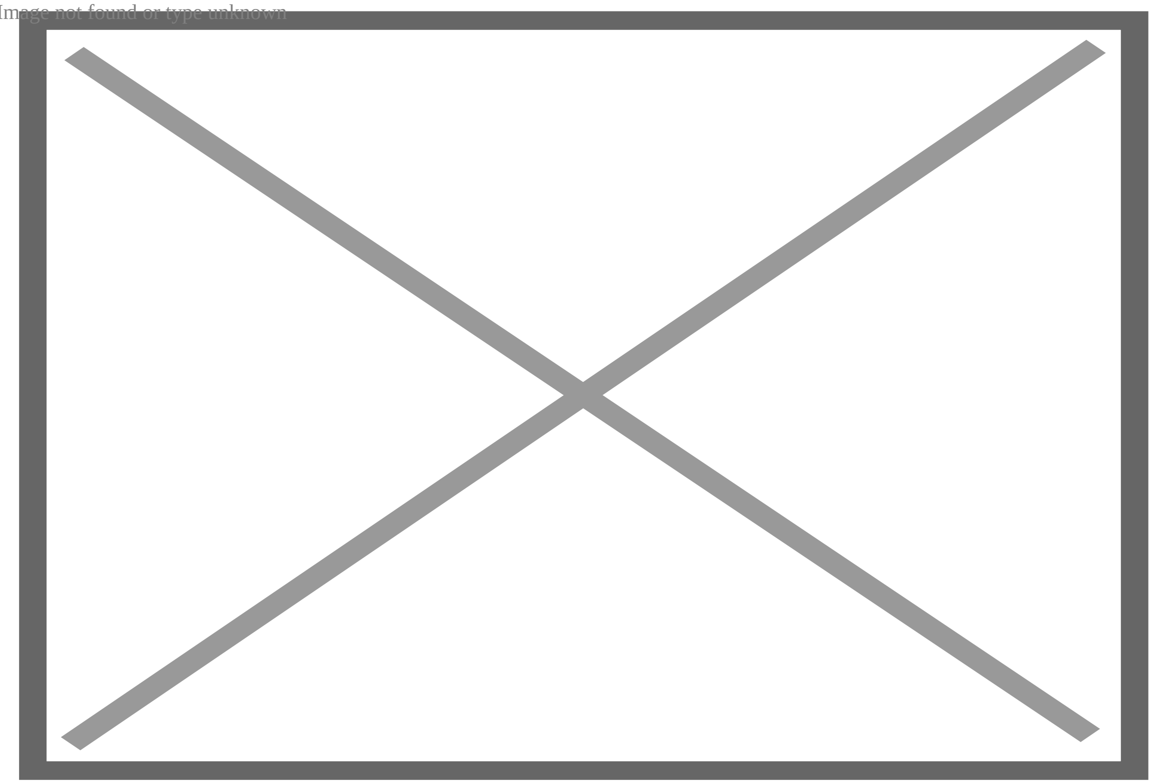

Legend: PEFC: Proton Exchange Membrane Fuel Cell; PAFC: Phosphoric Acid Fuel Cell;

SOFC: Solid Oxide Fuel Cell; MCFC: Molten Carbonate Fuel Cell

Figure 2: Overview of electrical efficiencies of available power generation techniques, according to (Haberkern, 2013)

Environmental benefits

Due to the high content of microorganisms and organic compounds, raw sludge is biochemically highly active. The anaerobic digestion stabilises the sludge, i.e. it significantly reduces its microbial activity.

The whole biogas produced can be used for electricity and heat generation to cover 100 % of the electricity and heat consumption of the wastewater treatment plant. This leads to reduced consumption of fossil fuel for generating electricity and consequently fewer emissions to air (CO_2, NO_x, etc.). However, in case of thermal sludge drying, a substantial part of the biogas generated is used for this process (as heat). Consequently, the percentage of electricity and heat demand of the waste water treatment plant covered by biogas produced on-site is significantly less. For instance, Figure 3 shows respectively the electricity consumed, generated on-site, and purchased (from the grid) of a plant with thermal sludge drying downstream of anaerobic digestion. In this case, about half of the biogas is directly used to thermally dry the sludge. Otherwise, the biogas would cover the whole electricity demand.

In Figure 3, the energy use sharply decreased in 1992 due to the replacement of the aeration of the activated sludge system with pure oxygen, produced on-site, by a conventional fine-bubble air aeration system. However, the consumption increased again due to additionally introduced treatment steps such as denitrification and sand filtration. The on-site generation of electricity started in 1998 and was steadily increased and optimised since then. Consequently, the percentage of generated electricity increased whereas the purchase of electricity from the grid decreased accordingly.

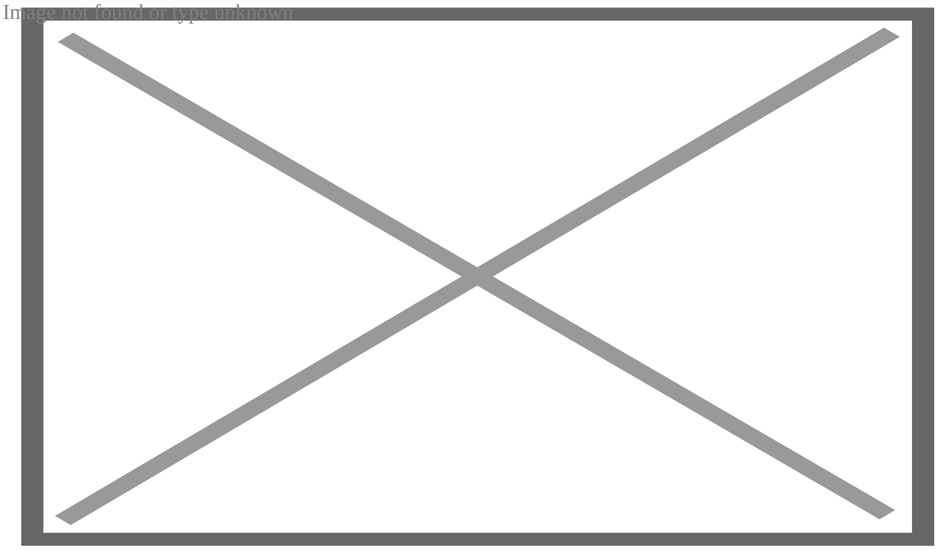

Figure 3: Development of the electricity consumption, the on-site generation and purchased electricity of the municipal waste water treatment plant "BreisgauerBucht" as shown in Figure 1 of the best practice "Energy efficient waste water treatment achieving full nitrifying conditions"

Side effects

There is no significant environmental cross-media effect known when implementing this best practice.

Applicability

The technique is applicable to new and existing plants. Modern biogas utilisation in motors with high electrical efficiency can be retrofitted to existing plants. An example can be seen from Figure 4 where a modern gas motor (as a container module) has been installed in an existing plant.

Figure 4: Retrofitted gas motor in a container for the use of biogas from anaerobic digestion of sludge to generate electricity and heat at the treatment plant "BreisgauerBucht"

Considering a whole region or country, such as Germany, most of the electricity consumption of all existing municipal wastewater treatment plants takes place in big plants; e.g. the German plants with a capacity of more than 10,000 population equivalents consume about 86% of the electricity consumed by all existing plants. Consequently, the described technique may concentrate on these large plants although they are usually more energy-efficient than smaller plants (when the similar processes are compared).

Economics

The sludge from municipal wastewater treatment has to be stabilised at any rate. Then, it is best to use the technique of anaerobic digestion as it can be combined with biogas generation and thus with energy recovery to an extent that the whole electricity and heat demand can be covered if the sludge is not thermally dried. However, the investment in anaerobic digestors is significant and there is a trade-off. For plants with a capacity of more than 5,000 – 10,000 population equivalents, the anaerobic digestion of the sludge with efficient energy recovery is the preferable technical approach which pays back; however, concrete numbers are not available and differ from case to case.

Driving forces for implementation

The steadily increasing energy prices are the major driving force to invest in anaerobic digestors and energy-efficient use of the biogas formed.

Reference organisations

Many municipal wastewater plants across Europe practice the anaerobic digestion of sludge from waste water treatment and do steadily invest in the improvement and optimisation of energy recovery measures (increase in the specific biogas yield) and in the energy-efficient use of the biogas formed, e.g. the plants in Freiburg, Balingen, Frankfurt, Waldshut, and Düsseldorf (all in Germany), Copenhagen/ Denmark.

Literature

Concerning the anaerobic digestion of sludge from waste water treatment, there are many textbooks available such as Metcalf & Eddy, Inc, "Wastewater Engineering – Treatment, Disposal and Reuse" issued by McGraw-Hill, Inc

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