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Achieving energy self-sufficiency and reducing GHG emissions by optimizing sludge treatment in Lingen, Germany.

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Abstract: The goal of the project was to convert the wastewater treatment plant of the city of Lingen (Ems), Germany not only to an energy autonomous wastewater treatment plan (i.e. to a so-called „Zero-Energy Wastewater Treatment Plant), but to a wastewater treatment plant with an energy surplus (i.e. to a so-called "Plus-Energy Wastewater Treatment Plant"). Measures to increase biogas production during sludge digestion and to optimize the energy recovery from biogas were implemented. The sludge digestion process was upgraded with mechanical primary sludge thickening, thermal sludge disintegration (LysoTherm®), phosphate precipitation and recovery from digested sludge (EloPhos®) and vacuum degassing (EloVac®), a centrifuge for the dewatering of digested sludge and new CHPs with higher electrical efficiency. In 2018 at the project's conclusion, the electrical power self-supply increased from 61% to 83% and total carbon footprint of the sludge treatment was reduced by a total of 400 tons/year, or by 17% prior to the implementation. This paper discusses the implications for becoming a 'Plus-Energy Waste Water Treatment Plant' over the six-years of the project.

Keywords: Thermal Pressure Hydrolysis; vaccum degassing, GHG emissions

Introduction

The German Federal Ministry for Environment, Nature Conservation, Building and Nuclear Safety setup an innovation program "energy efficient wastewater treatment plants" in 2011 [1], which funded initiatives related to energy efficiency and efficient resource recovery in sewage sludge treatment. The Lingen (Ems) wastewater treatment plant, located in northwest Germany, is designed to serve approximately 195,000 PE, see picture 1. The actual COD load in 2011 was approx. 150,000 PE and was divided into approx. 60,000 PE connected inhabitants and discharges from industrial enterprises of approximately 90,000 PE. The majority of the industrial discharges came from a manufacturer of synthetic fibers. With conventional plant practices, the COD of Lingen was only 50% degradable, which had consequences for the dewatering and polymer consumption. The objective of this project was to convert the WWTP to a "Plus Energy Treatment Plant" and to reduce the carbon footprint of the sludge treatment process. The project started in autumn 2011 and the last evaluation period ended in summer 2018.

An excerpt of the original state data and the funding criteria of the innovation program shown in Table 1 [1], [2].

Material and Methods

The innovation program required the implementation of new technologies. LysoTherm® (picture 2), installed for the enhancement of the digestion process, is Eliquo's proprietary technology for Thermal Hydrolysis Process (THP). LysoTherm® does not require steam and/or chemicals for its operation. A thermal oil system, which uses the heat from the exhaust of the CHPs, provides the required heat energy to achieve a process temperature of ca. 160 °C. Due to the high grade of heat recovery, only a portion of the available heat is required for the operation of LysoTherm®.

EloVac® (picture 3) withdraws methane from the digested sludge by vacuum degassing and hence prevents methane emissions. The vacuum pump extracts both methane and carbon dioxide, which increases the pH and creates the ideal conditions for the subsequent P precipitation in the EloPhos® reactors. EloVac® not only prevents the emissions of the vacuumed gases, but allows for the subsequent utilization in the gas system. Methane is a strong greenhouse gas with a mass-related greenhouse factor of 28. This means, that 1 kg of methane emitted into the atmosphere has the same impact in terms global warming of 28 kg of carbon dioxide. Since all contained methane in the digested sludge ends up released to the atmosphere, either in an intermediate sludge storage tank, centrifuge, drying, or during land application, EloVac® substantially contributes to the mitigation of diffuse greenhouse gas (GHG) emissions in the course of the sludge treatment.

The magnesium chloride dosing to the digested sludge in the downstream EloPhos® reactors creates the P precipitation. The process conditions in the EloPhos® allows for the growth of the precipitated micro crystals, which at a certain size can then be harvested from the system.

In the course of this project, the following phases were necessary to assess the success of the measures:

a) R0: Reference state: the operational data of the year 2010 selected as "reference state".

b) R1b: Thermal disintegration of waste activated sludge with separated digestion and with struvite precipitation: in this phase, the THP process treated the waste activated sludge only. Furthermore, the separated digestion of primary sludge + co-substrate in one digester and the THP treated waste activated sludge in the second digester were tested. A downstream struvite precipitation process supplemented the digestion of the hydrolyzed waste activated sludge to achieve better dewatering and phosphate recovery.

c) R2b: Thermal disintegration of digested sludge (in loop configuration) with mixed digestion and struvite precipitation.

A ramp-up period preceded each phase until an operational steady state was achieved. An independent consultant conducted the evaluation and data measurements.

Results

In Table 2 the sludge characteristics before and after implementation of the measures are shown. In phase R1b, where LysoTherm® was installed upstream digestion and waste activated sludge (WAS) was disintegrated prior digestion, the specific biogas production raised from 534 m^3/Mg VDS_{feed} to 643 m^3/Mg VDS_{feed}. The increase was caused by the better availability of the organic compounds in the WAS due to the thermal disintegration with LysoTherm®. In phase R2b, LysoTherm® was working in loop. This means, digested sludge was extracted from the digesters, thermally treated in LysoTherm® and fed back to the digesters again. With this unique configuration a specific biogas production of 613 m^3/Mg VDS_{feed} was achieved, which is slightly below the value achieved with the pre-configuration in phase R1b. But here it has to be taken into account, that – based on the volatile solids - the portion of the primary sludge in the total raw sludge fed to the digesters decreased from 46% to 40%. Hence, the portion originating from the waste activated sludge raised from 54% to 60%. Since the ratio of PS to WAS heavily influences the behavior of sludge in digestion and dewatering, also the achieved results in R2b are remarkable. The same can be said for the volatile solids removal (VSR), which raised from 48% to 62% in phase R1b and to 59% in phase R2b.

Dewatering increased from 23.1% to 29.0% in phase R1b and even 29.2% in phase R2b. Due to the much better volatile solids removal and better dewatering in both phases, the specific sludge cake mass decreased from 160 g OS/PE/a to 131 g OS/PE/a (R1b) and 135 g OS/PE/a (R2b).

In conjunction with the new CHPs, the electrical power self-supply increased from 61% to 83%. The plant did not achieve the project goal of 100% self- supply because the PE load in the influent of the WWTP dropped from 150,000 PE to less than 85,000 PE due to the shutdown of an industrial site. While the wastewater flow remained at the same level, the COD in the influent dropped significantly. Despite the energy-optimized operation of the whole WWTP, the specific electrical energy consumption increased from 26 kWh/PE/a to 32 kWh/PE/a. Furthermore, the lower COD concentrations in the co-substrate resulted in lower gas production. Hence, it remains as a goal for the future to take easily degradable co-substrates, as far as it is technically and legally possible, and thus further increase the biogas production. The plant had already achieved energy self-sufficiency in terms of heat prior the project. Increased gas production offers the possibility for the WWTP to sell excess heat to a public swimming pool and neighboring estates via a new local heat network. Hence, the amount of excess heat, released into the atmosphere via emergency coolers, dropped to negligible values even during summer.

By means of the energy analysis, savings at the individual process steps were identified. Table 3 shows a comparison of the key ratios of the energy check according to DWA-A 216 [3].

Specific electrical energy consumption

The specific electrical energy consumption of the Lingen WWTP was calculated to 32 kWh/PE/a. Thus, this value is 5 kWh/PE/a higher than the ideal value. The annual savings potential can be calculated to about 478,000 kWh/a.

Specific energy consumption for aeration

The specific energy consumption for aeration corresponds to nearly the ideal value of 10 kWh/E/a. Thus, no potential for optimization can be identified.

Specific biogas production

The specific biogas production from primary sludge (PS) and waste activated sludge (WAS) without the co-substrate is ca. 35% higher than the ideal value (614 vs. 457 L_N/kg VS_{feed}). This is due to an enhanced digestion process with the LysoTherm® THP.

Conversion grade from gas to electrical energy

During the assessment phase, the plant did not flare off or used direct generation of heat energy with the existing gas burner. Hence, the conversion grade from gas to electrical energy corresponds to the operational electrical efficiency of the CHP. The electrical efficiency according to the CHP's datasheet is > 38%. Therefore, the lower efficiency was caused by operating the CHPs with reduced power (ca. 60% of max. power).

Electrical energy self-sufficiency

The grade of electrical energy self-sufficiency was 83% and thus, lower than the 100% target. This can be explained by the reduced COD load in the influent of the WWTP, whereas the volumetric load remained. A lower COD load in the influent reduces the sludge amount for digestion. The energy requirements for the whole infrastructure and in particular for the wastewater pumps remains almost constant. Picture 4 shows the rating of the Lingen WWTP in terms of electrical energy self-sufficiency compared to 175 WWTPs in Germany – only approximately 8% of the investigated WWTPs achieve a higher value.

Specific external heat purchase

The increased gas production leads to an increased production of electrical and thermal energy. Excess heat is also utilized in a local heat network,

With the implementation of all the projects, the total consumption of electrical energy decreased from 32 kWh/E/a to 31 kWh/E/a. Thus, the possible reduction of the total electrical energy consumption is in a range of less than 5%, which is a clear sign for an already optimized operation of the wastewater treatment plant.

The implemented measures led to net savings including the operational costs of the new technologies of ca. 360,000 €/a.

Conclusions

The technologies implemented at Lingen have demonstrated reliable performance in the six years of operation. The sludge hydrolysis technology (LysoTherm®) increased biogas production in conjunction with a significantly higher VSR resulting in lower GHG emissions of ca. 240 t/a. With upstream vacuum degassing (EloVac®), the EloPhos® system helps to prevent methane emissions into the atmosphere of further about 150 t CO_2/a. Reduced truck transports for the hauling of the dewatered sludge cake in a cement kiln resulted in another ca. 10 t CO_2/a of reduced GHG emissions. In total the measures resulted in ca. 400 t CO_2/a avoided GHG emissions. Two main sources contribute to the GHG emissions of municipal wastewater treatment plants: GHG from the production of the electrical energy for the operation of the plant and diffuse GHG emissions. According to [4] the CO_2 emissions for the production of electrical energy are 489 kg CO_2/MWh. With a degree on self-sufficiency of 61%, a specific consumption of electrical energy of 23.1 kWh/PE/a and 150,000 connected population equivalents the yearly emissions in the original state can be calculated to 661 t CO_2/a. Diffuse GHG emissions on wastewater treatment plants are estimated to ca. 1.3 g/h/PE [5]. The sludge treatment contributes to about 75% to this number. For Lingen the diffuse GHG emissons can be calculated to 1,708 t CO_2e/a. The total GHG emissons in the original state account to 2,369 t CO_2e/a. The ca. 400 t CO_2/a avoided emissions represent a reduction of 17%.

The necessary measures on the route to achieve energy self-sufficiency are on the one hand to minimize the energy consumption for the operation and on the other hand to maximize the energy production of the WWTP. The assessment of the WWTP Lingen showed, that there is nearly no further potential to minimize the energy consumption. The implementation of LysoTherm® resulted in a 35% higher gas production than for an “ideal sludge digestion” and hence, the digestion realizes its full potential now. External circumstances, like the reduction of the influent COD load at a non-changed wastewater flow to be treated and a lower COD concentration of the co-substrate prevented, that an electrical energy self-sufficiency in Lingen was achieved. Such external circumstances have to be accounted in the assessment of the project. Hence, from a technical point of view, the goals of the funding project were achieved.

Table 1: Original state and funding criteria/target values

Parameter	Unit	Original state	Funding criteria
El. energy consumption, total	kWh/PE/a	23.1	18
Specific biogas production	L/PE/a	20,9 (16,4*))	30
Degree on biogas utilization	%	97	100
El. efficiency of the CHP	%	30,8	38
Degree on self-supply of heat	%	100	100
Degree on self-supply of el. energy	%	61 (48x))	100

*) without co-substrate

Table 2: Characteristics before and after the implementation of the measures

Sludge digestion:			
	Spec. methane production	Spec. biogas production	VSR
Before:	ca. 13 Liter CH_4/PE/d	534 m³/Mg VDS_{feed}	48%
After:			
R1b - WAS[1)] disintegration	ca. 20 Liter CH_4/PE/d	643 m³/Mg VDS_{feed}	62%
R2b - DS[2)] disintegration	ca. 20 Liter CH_4/PE/d	613 m³/Mg VDS_{feed}	59%
Dewatering:			
	DS dewatering	Sludge cake mass	Spec. sludge cake mass
Before:	23.1% $DS_{dewatered}$	18.2 Mg OS/d	160 g OS/PE/d
After:			
R1b - WAS disintegration	29.0% $DS_{dewatered}$	12.1 Mg OS/d	131 g OS/PE/d
R2b - DS disintegration	29.2% $DS_{dewatered}$	11.2 Mg OS/d	135 g OS/PE/d

[1)] WAS = Waste Activated Sludge

[2)] DS = Digested Sludge

Table 3: Key ratio comparison

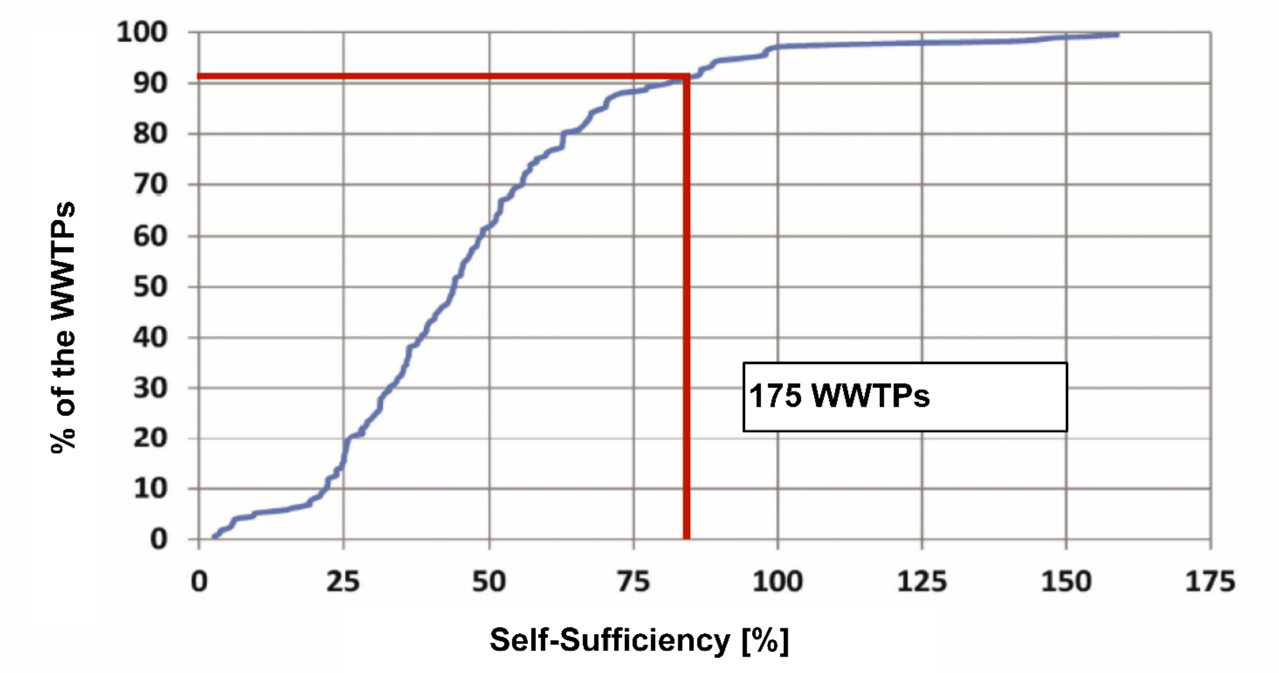
Parameter	Unit	Current Value	Ideal Value
Specific electrical energy consumption, total	kWh/PE/a	32	27
Specific energy consumption for aeration	kWh/PE/a	11	10
Specific gas production (PS, WAS, w/o co-substrate)	L_N/kg VS_{feed})	614	457
Conversion grade from gas to electrical energy	%	33	40
Electrical energy self-sufficiency	%	83	100
Specific external heat purchase	kWh_{th}/E/a	0	0

Picture 1: WWTP Lingen (Ems)

Picture 2: LysoTherm®

Picture 3: EloVac® (in yellow circle) and EloPhos®

Picture 4: WWTP Lingen (Ems) rating in terms of electrical energy self-sufficiency [2]



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