How to make a large nutrient removal plant energy self-sufficient. Latest upgrade of the Vienna Main Wastewater Treatment Plant (VMWWTP)

Helmut Kroiss and Franz Klager

ABSTRACT

The goal of making nutrient removal wastewater treatment energy self-sufficient or even energy producing has become a worldwide accepted goal of technology development. The latest upgrade of the Vienna Main Wastewater Treatment Plant (VMWWTP) with a design capacity of 4 million (M) population equivalent (PE) will produce about 20% more energy on a yearly basis than needed for operation due to a special process scheme. It consists of primary sedimentation, a special 2-stage activated sludge (AS) process configuration where excess sludge is only withdrawn from the first stage AS plant. Raw sludge is subject to mechanical thickening to ∼8% digested sludge (DS) for digestion at high solids concentration. The reject water after nitritation is used for denitrification in the first stage AS plant. This results in markedly reducing the energy requirement for aeration. The design of this last upgrade for energy optimization of sludge treatment is based on the long-term full-scale data from the existing plant, results of mid-term pilot investigations, sound theoretical mass balance calculations and an adapted dynamic model development. All this is presented in this paper. The full-scale upgrade is under construction and will start operating in 2020.

Key words | 2-stage activated sludge process, COD/energy balances, dynamic modelling, reject water nitrification/denitrification, sludge digestion with high solids concentration

INTRODUCTION

The book Activated Sludge – 100 Years and Counting (Jenkins & Wanner 2014) includes a chapter titled ‘Energy Considerations’, which contains most of the scientific background information for this paper. The chapter analyses the actual energy requirements for mechanical–biological wastewater treatment plants (WWTPs) and their relationship to treatment efficiency, process configuration and equipment efficiency. It also contains an analysis of the influence of energy costs on operational costs. Keller & Hartley (2003) also report on the relevance of process configuration for wastewater treatment with regard to greenhouse gas emissions and climate change abatement; this paper concentrates more on anaerobic processes for wastewater treatment. By using microbial fuel cells, wastewater pollution can directly be converted to electric energy (Logan & Regan 2006) which opens up new prospects for energy production from wastewater, although experience of full-scale operations for municipal wastewater is still lacking.

From theoretical considerations and experience of full-scale operations, it can be concluded that the energy content of the organic fraction of municipal wastewater is sufficiently high for achieving energy self-sufficiency and even excess energy production from 2-stage activated sludge (AS) nutrient removal wastewater treatment plants as demonstrated by Wett et al. (2007).

One key for achieving energy self-sufficiency or even excess energy production is process selection, so as to minimize aeration energy demand and to maximize the conversion of organic pollution to sludge. Anaerobic sludge digestion allows the recovery of electric energy via biogas. One successful solution is to use 2-stage instead of the conventional 1-stage AS process after primary sedimentation (PS) as will be analyzed for the extension of the
Vienna Main Wastewater Treatment Plant (VMWWTP) under construction.

For theoretical background: the oxygen and energy demand for 1- and 2-stage activated sludge processes (AS) that meets the Austrian standards for urban wastewater treatment are shown in Table 5.

Figure 1 shows the influence of the sludge age (as mean cell residence time, MCRT) on the chemical oxygen demand (COD) balance. In the 1st stage as well as in the 2nd stage of a 2-stage WWTP for full nitrification (T > 8°C) and >70% N removal requirements at a temperature of ≥12°C, a mean sludge age of about 10–12 days has to be selected for the design of large WWTP [DWA 2016]. In the 1st stage of a 2-stage AS plant the sludge age is selected to be ≤1 day so that most of the COD removed will be transferred to excess sludge while the oxygen consumption is low.

COD of the excess sludge can be interpreted as its energy content (~14 kJ/g COD) and allows the calculation of methane production by sludge digestion (1 g COD-removed corresponds to 0.35 L of methane).

Tables 1–3 compare the COD balance for 1-stage (Figure 2) and 2-stage (Figure 3) AS plants with PS in order to show the differences (Table 3). The theoretical background has been published by Svardal & Kroiss [2011]. The tables show the oxygen demand for COD removal, nitrification and nitrogen removal for 1 PE120 (120 g COD/d) in the influent. The energy contents of the excess and primary sludge as well as of the biogas from anaerobic sludge digestion are also expressed as COD. 1 PE120 corresponds to 1 PE60 60 g BOD5/d. PE in this paper is always related to COD unless specially defined by another index.

The necessary assumptions (in italics) made for Tables 1–3 are in accordance with theoretical considerations (stoichiometry, ASM 1) and experience of full-scale operations from many large Austrian WWTPs.

Table 1 | COD and oxygen uptake (OU) for 1-stage AS process with PS (Figure 2), for N/COD

<table>
<thead>
<tr>
<th>Process</th>
<th>COD influent (N influent 12 g N/PE/d, 85% N removal)</th>
<th>COD effluent primary sedimentation (COD removal 33%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD influent</td>
<td>120 g/PE/d</td>
<td>80 g/PE/d</td>
</tr>
<tr>
<td>COD effluent primary sedimentation (COD removal 33%)</td>
<td>40 g/PE/d</td>
<td>8 g/PE/d</td>
</tr>
<tr>
<td>COD in primary sludge</td>
<td>40 g/PE/d</td>
<td>8 g/PE/d</td>
</tr>
<tr>
<td>COD in digested sludge</td>
<td>30 g/PE/d</td>
<td>39 g/PE/d</td>
</tr>
<tr>
<td>COD of digester gas production (CH4) 69 – 30 =</td>
<td>30 g/PE/d</td>
<td>39 g/PE/d</td>
</tr>
<tr>
<td>ODC (denitrified 12 * 0.85 – 2 * = 8.2)</td>
<td>13.9 g/PE/d</td>
<td>13.9 g/PE/d</td>
</tr>
<tr>
<td>OUC (nitrate in effluent 12 – 2 * 8.2 = 18)</td>
<td>8.3 g/PE/d</td>
<td>8.3 g/PE/d</td>
</tr>
</tbody>
</table>

N in dewatered digested sludge 2° g N/PE120, COD in digested sludge 30 g/PE120.

OUC, oxygen uptake for carbon removal; OUN, oxygen uptake for nitrification (4.6 g O2/g N); OUDN, oxygen uptake for nitrogen removal (1.7 g O2/g N).

Table 2 | COD and Ou for 2-stage AS process with PS (Figure 3), N/COD

<table>
<thead>
<tr>
<th>Process</th>
<th>COD influent (N influent 12 g N/PE/d, 75% N removal)</th>
<th>COD effluent primary sedimentation (COD removal 33%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD influent</td>
<td>120 g/PE/d</td>
<td>80 g/PE/d</td>
</tr>
<tr>
<td>COD effluent primary sedimentation (COD removal 33%)</td>
<td>40 g/PE/d</td>
<td>8 g/PE/d</td>
</tr>
<tr>
<td>COD of primary sludge</td>
<td>40 g/PE/d</td>
<td>8 g/PE/d</td>
</tr>
<tr>
<td>COD effluent (ηCOD = 93%)</td>
<td>40 g/PE/d</td>
<td>8 g/PE/d</td>
</tr>
<tr>
<td>COD removal aeration tanks 80 – 8 =</td>
<td>72 g/PE/d</td>
<td>72 g/PE/d</td>
</tr>
<tr>
<td>OUC (40% 1-stage/ 60% 2-stage)</td>
<td>29 g/PE/d</td>
<td>29 g/PE/d</td>
</tr>
<tr>
<td>COD in excess sludge, 60% of COD removal</td>
<td>43 g/PE/d</td>
<td>43 g/PE/d</td>
</tr>
<tr>
<td>COD input digester: 40 + 43 = 83 g/PE/d</td>
<td>83 g/PE/d</td>
<td>83 g/PE/d</td>
</tr>
<tr>
<td>COD in digested sludge</td>
<td>30 g/PE/d</td>
<td>30 g/PE/d</td>
</tr>
<tr>
<td>COD in digester gas production (CH4) 83 – 30 =</td>
<td>53 g/PE/d</td>
<td>53 g/PE/d</td>
</tr>
<tr>
<td>ODC (denitrified 12 * 0.75 – 2 * 7.0, 7 = 17)</td>
<td>11.9 g/PE/d</td>
<td>11.9 g/PE/d</td>
</tr>
<tr>
<td>OUN (nitrate in effluent 12 – 2 * 7 = 3 g N/PE/d)</td>
<td>13.8 g/PE/d</td>
<td>13.8 g/PE/d</td>
</tr>
</tbody>
</table>

N in dewatered digested sludge 2° g N/PE120, COD in digested sludge 30 g/PE120.

OUC, oxygen uptake for carbon removal; OUN, oxygen uptake for nitrification (4.6 g O2/g N); OUDN, oxygen uptake for nitrogen removal (1.7 g O2/g N).

For Table 3 the following assumptions have been made:

- oxygenation efficiency of aeration system (operational conditions): 2.1 kg O2/kWh
- dissolved oxygen concentration (DO) in aerobic nitrification volume: 2 mg/L
Table 3 | Comparison of oxygen uptake for carbon and nitrogen oxidation and of the yearly energy demand (∑) and production (∑+) between 1-stage and 2-stage AS plants using the data from Tables 1 and 2

<table>
<thead>
<tr>
<th>Process</th>
<th>OU (C + N)</th>
<th>Aeration energy</th>
<th>Other energy</th>
<th>Total energy demand</th>
<th>El. energy from biogas</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension</td>
<td>g O₂/PE/d kWh/PE₁₂₀/a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-stage AS</td>
<td>65.2</td>
<td>-13.0</td>
<td>-7.3</td>
<td>-20.3</td>
<td>+17.9</td>
<td>-2.4</td>
</tr>
<tr>
<td>2-stage AS</td>
<td>54.7</td>
<td>-11.4</td>
<td>-8.4</td>
<td>-19.8</td>
<td>+24.3</td>
<td>+4.5</td>
</tr>
</tbody>
</table>

N in dewatered digested sludge 2 g N/PE₁₂₀, COD in digested sludge 30 g/PE₁₂₀/d.
OUC, oxygen uptake for carbon removal; OUN, oxygen uptake for nitrification (4.6 g O₂/g N); OUDN, oxygen uptake for nitrogen removal (1.7 g O₂/g N).

Table 3 shows that the process concept of the 2-stage process (as at VMWWTP) produces more energy from biogas than the plant’s energy demand while the 1-stage AS plant can recover only about 85% of its energy demand even when a 10% higher N-removal efficiency is achieved.

Energy demand and production are strongly dependent on the electrical efficiency of the aeration and the gas motor/generator system irrespective of process selection.

**FULL-SCALE IMPLEMENTATION OF ENERGY SELF-SUFFICIENCY AT VIENNA MAIN WASTEWATER TREATMENT PLANT (VMWWTP)**

The VMWWTP is under reconstruction and extension in order to become energy self-sufficient by the year 2020. The most relevant driving forces for this investment have been the climate change abatement policy requiring for decreased fossil CO₂ equivalent emissions and the necessity to rebuild the 1st step of the 2-step AS treatment plant (in operation since 1980) which has reached the end of its construction lifetime.

In order to understand the design considerations which are now implemented, it is important to describe the specific local situation in Vienna, including the legal requirements for treatment efficiency in Austria, as well as the specific climatic, morphological and hydrological conditions that have strongly influenced the historic development of the water supply, sewer network and treatment plant design and construction (Table 4).

**Historic development of VMWWTP**

The historic development of the VMWWTP design, construction and operation is the result of an almost unique long-term co-operation between the Vienna Authorities currently responsible: ebs wien hauptkläranlage Ges.m.b.H (ebs wien), the Institute for Water Quality and Resource Management at Vienna University of Technology and private consultants since the 1960s. The Institute was given the authority to decide on the process design based on scientific knowledge, pilot plant investigations and modelling performance, and was responsible for meeting the legal effluent quality requirements at any time at minimum cost and maximum reliability in close co-operation with the responsible authority. The detailed design was done by different private consultants. For the Institute this co-operation resulted in four doctoral theses closely related to pilot investigations on the site of the VMWWTP for the process design and operation in the past and for the future.
Table 4 | Characteristics of specific local situation in Vienna

Vienna’s morphology favors one centralized wastewater treatment plant discharging to the Donaukanal and finally the Danube (mean flow ~1,800 m³/s)

Mainly combined sewer system, ~20% separate system; mainly gravity flow

Temperature in aeration tanks between 8 °C (snow melting) and 23 °C, yearly mean ~15 °C

Mean yearly precipitation 550 mm

High dilution capacity in River Danube (>1:100)

Mean domestic drinking water (from karstic springs) consumption 130 L/person/d

Actual wastewater flow at dry weather conditions (DW) is ~550,000 m³/d

Actual treated wastewater flow ~200 M m³/year

Limited area for VMWWTP: 42 ha (without sludge dewatering and incineration)

Sludge disposal responsibility is with Austrian provinces (according to Austrian Waste Legislation). Agricultural sludge application in Vienna Province impossible: ~450 km² of agricultural land would be necessary, total province area 415 km², therefore decision on raw sludge incineration in 1976

Slow (~1%/y) growth of population for ~15 years, continuation of trend expected

(Dornhofer 1998; Wandl 2005; Reichel 2015; Schaar 2016) and a great number of other publications.

The first VMWWTP was designed by W. von der Emde in the late 1960s as a high-load carbon removal AS plant with primary settling tanks, and went into operation in 1980. The treatment efficiency requirement was ≥70% 5-day biochemical oxygen demand (BOD₅) removal. This first VMWWTP was fully integrated into the extension of the plant that began operating in 2005 and can be seen in Figure 2 (labelled ‘First plant 1980’). It was designed for 3.2 M PE₁₂₀ and consisted of six influent screw pumps (maximum total capacity 24 m³/s), six lines screens and longitudinal grit chambers, four PS tanks (PST) (maximum flow 24 m³/s) and two high-rate AS lines (maximum flow 12 m³/s).

During the design phase of this plant the idea of energy self-sufficiency had already been taken into consideration by using anaerobic sludge digestion, gas motors for energy production and land application of digested sludge. This concept was abandoned primarily due to a lack of reliability regarding legal requirements for sludge disposal in agriculture. In 1976 it was decided to implement raw sludge incineration and ash disposal. After extension to the required capacity the incineration plant is currently in full use.

This paper is mainly related to the thesis of Reichel (2015) based on the results of intensive pilot investigations performed in order to prove and improve the design considerations for the so-called EOS Project (Energy Optimization of Sludge treatment). This project is now under construction and the main topic of this paper. The pilot investigations were also used for verification and calibration of the dynamic mathematical model of the whole sludge treatment system.

VMWWTP extension 2005

Due to a change in legal requirements (AEVKA 1996) an extension of the VMWWTP became necessary, along with an extension of the biological treatment plant to a maximum hydraulic capacity of 18 m³/s and a design pollution load of 4 million PE₁₂₀.

The effluent standards for the extension of the VMWWTP are summarized in Table 5. They are in compliance with the EU Urban Waste Water Directive (UWWD). Austria as a whole is a ‘sensitive area’ according to the EU UWWD, which results in nutrient removal requirements.

The standards (Table 5) are relevant for the design of the VMWWTP as they differ from other national regulations in EU member states (e.g. Germany) in important details. All standards have to be met in completely mixed daily flow proportional composite samples. Austria has also not implemented wastewater discharge fees as, for example, in Germany. Non-compliance with the standards in the case of negligence can be punished according to criminal law.

The extension of the VMWWTP went into operation in 2005 as 2-stage AS process. Its design concept was based on long-term pilot investigation and a basic process design developed again by W. v.d. Emde (Wandl et al. 2006).

Table 5 | Austrian effluent standards for municipal wastewater treatment plants >50,000 PE₁₂₀

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>75 mg/L</td>
</tr>
<tr>
<td>BOD₅</td>
<td>15 mg/L</td>
</tr>
<tr>
<td>Total nitrogen (TN) removal</td>
<td>&gt;70% yearly mean for temperatures &gt;12 °C in the aeration tank</td>
</tr>
<tr>
<td>Total phosphorus (TP)</td>
<td>1 mg/L</td>
</tr>
<tr>
<td>Ammonium nitrogen (NH₄-N)</td>
<td>5 mg/L 85%ile on a yearly basis, at temp. &gt;8 °C, max. in daily sample 10 mg/L</td>
</tr>
</tbody>
</table>

according to EU UWWD, as 85%ile on a yearly basis

yearly mean, maximum in daily composite samples 2 mg/L

85%ile on a yearly basis,

85%ile on a yearly basis, at temp.

yearly mean for temperatures
Design data: 4 M PE_{120} (480 t COD/d, 240 t BOD_{5}/d), design loads are defined as 85%ile of the yearly data; the mean yearly design load is \sim 3.5 M PE_{120}, max. dry weather (DW) flow 9 m^{3}/s, max. wet weather (WW) flow 18 m^{3}/s.

Wastewater concentrations (yearly mean at DW):
- Influent COD \sim 750 mg/L
- Influent TN \sim 60 mg/L
- Influent TP \sim 9 mg/L.

The volumes in Table 6 for the 1-stage AS plant were calculated using the German Design Guideline DWA A-131 (2016). The volumes for the 2-stage AS plant were calculated using the full-scale volumes of the VMWWTP to meet the same reliability requirements as the 1-stage plant design.

From Table 2 it can be concluded that the 2-stage plant needs \sim 30% less total tank volume (240,000 m^{3} for the VMWWTP) than the 1-stage plant. The 2-stage concept therefore results in lower construction costs as compared to a 1-stage process.

The first VMWWTP (1980) remained unchanged as the 1st stage and was complemented by the newly constructed 2nd-stage AS plant with 15 lines (Figure 4). While the 1st-stage aeration tanks with a mean depth of 2.4 m remained equipped with cone aerators (1.7 kg O_{2}/kWh), the 2nd-stage aeration tanks were constructed with a mean depth of 5.5 m and are equipped with fine bubble aeration (\sim 2.5 kg O_{2}/kWh under real operational conditions) in order to minimize energy consumption.

**Modes of operation**

The new plant has two modes of operation (Figure 5) in order to maximize nitrogen removal (bypass mode) and to reliably avoid bulking (hybrid mode). For both modes of operation the MCRT in the 2nd stage has to be adapted to the temperature development in the aeration tank over the year in order to reliably meet low-ammonia effluent concentrations (Wandl et al. 2006). All the excess sludge of the 2nd stage is transferred to the 1st stage. Excess sludge is only removed from the 1st stage in order to maximize sludge production by adsorption and bacterial growth and to minimize oxygen demand. In regard to sludge management, the Vienna concept is just the opposite of the AB-process developed by Böhnke Diering (1979). The related patent was based on the idea of separating the heterotrophic (A stage) from the autotrophic bacteria (B stage) and was developed for reliable full nitrification and not for N removal.

The greatest challenge for design and operation is to achieve low-ammonia effluent concentrations at the maximum WW flow of 18 m^{3}/s at a temperature of 8 °C (snow melting) and high nitrogen removal efficiency most of the time. In order to stabilize nitrogen removal at \sim 70% even at low temperatures the plant is equipped with an external recirculation (RF in Figure 5) of the effluent of the 2nd stage for denitrification in the 1st stage. This external recirculation is also used to minimize diurnal flow fluctuations.

**Table 6 | Specific volume requirements per PE_{120} for the tanks of a 1-stage and the 2-stage extension of the VMWWTP meeting the same effluent standards**

<table>
<thead>
<tr>
<th></th>
<th>2-stage AS</th>
<th>1-stage AS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary sedimentation</td>
<td>5 L/PE</td>
<td>5 L/PE</td>
</tr>
<tr>
<td>Aeration tank I</td>
<td>12 L/PE</td>
<td>No</td>
</tr>
<tr>
<td>Secondary sedimentation tank I (12 m^{3}/s)</td>
<td>18 L/PE</td>
<td>No</td>
</tr>
<tr>
<td>Aeration tank (II)</td>
<td>42 L/PE</td>
<td>130 L/PE</td>
</tr>
<tr>
<td>Secondary sedimentation tank (II) (18 m^{3}/s)</td>
<td>51 L/PE</td>
<td>51 L/PE</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>128 L/PE</strong></td>
<td><strong>186 L/PE</strong></td>
</tr>
</tbody>
</table>
which have a detrimental effect on secondary clarifier performance. During DW conditions, external recirculation is controlled in a way that the hydraulic loading of the 1st stage is kept nearly constant over time. The maximum hydraulic load of the 1st stage AS plant is 11 m$^3$/s. In the case of WW flow, external recirculation is stopped and the flow exceeding 11 m$^3$/s is bypassed to the 2nd stage.

During normal (bypass mode) operation about 20–60% of the DW flow is bypassed to the 2nd stage for improved denitrification. The bypass is adapted every 2–3 months to the temperature development in order to control the sludge age (MCRT) in the 2nd-stage AS for reliable nitrification.

If bulking occurs in the 2nd stage, AS operation is switched to the hybrid mode (Winkler et al. 2008), where the bypass is stopped and the AS of the 1st stage is used as the carbon source for denitrification in the 2nd-stage AS. With these two modes of operation a yearly mean N removal $>$80% can be achieved and bulking reliably avoided.

Phosphorus is partly removed by bacterial growth, enhanced biological P removal and complemented by chemical precipitation with iron salts in order to meet the effluent standard at any time and temperature.

The excess sludge is thickened together with the primary sludge in static thickeners and pumped to the adjacent incineration plant where it is dewatered with centrifuges and fed to the fluidized bed raw sludge incinerators. The reject water from raw sludge dewatering flows to the influent pumping station.

**ENERGY OPTIMIZATION SLUDGE TREATMENT PROJECT (EOS PROJECT) 2020**

After about 5 years of operation of the extended VMWWTP (Figure 4), a concept was developed to transform the plant from a major energy-consuming to an energy-producing wastewater treatment plant in order to respond to the climate change abatement policy and to make the plant less dependent on energy prices. After 5 years of design and pilot investigations, the construction phase started in 2015. Figure 6 shows the layout of the EOS Project, Figures 3 and 5 the VMWWTP flow diagrams.

The decision to implement the project was also based on an economic assessment which resulted in full costs (capital and investment costs) recovery within $\sim$12 years strongly depending on assumptions regarding future development of energy, CO$_2$ emission and other costs.

**Pilot investigations for digestion with high solid concentrations**

In order to minimize risks for the design and operation of the EOS Project, a pilot plant was operated for nearly 1.5 years on site and online at the VMWWTP (Table 7). This pilot plant consisted of a mechanical thickener, sludge digester (volume 130 m$^3$), gas motor, reject water treatment plant, dewatering and complete sensor and control equipment. (Reichel 2015).

**Dynamic model development and application**

An adapted dynamic mathematical model of the whole plant from PS to effluent including sludge digestion and reject water treatment was developed. (Svardal & Spindler 2013). The model contains a modified ASM 1 adapted to the 2-stage process and the ADM for the digestion. Calibration is based on full-scale data from the extended plant (since 2005) for the wastewater treatment plant and on the pilot-scale results regarding digestion and reject water treatment.

This model was fed with the VMWWTP loading data of a whole year (2011) in order to integrate the influence of the variations of loading and temperature on the energy consumption for aeration, the energy production...
from biogas and the N-removal results using different operational strategies and assuming different loading conditions. Figures 7 and 8 show the COD and N flows for the design loading situation (4 M PE as 85%ile corresponding to a mean load of ~3.5 M PE$_{120}$).

### Reject water treatment

Regarding N removal from reject water (containing ~25% of the N influent load) it was decided to opt for partial nitritation and denitritation in the 1st stage AS plant instead of deammonification. The main arguments for this decision are based on the results of pilot investigations (Reichel 2015) and theoretical considerations:

- Short start-up phase without seed sludge (<1 week) which is very important for plants of this size.
- Nitritation of reject water (NH$_4$-N concentrations of ~1,600 mg/L) is a reliable and simple process. Up to about 50% conversion with no pH control is needed. For higher conversion rates, lime addition to the nitritation tank for pH control will achieve up to ~80% conversion.
- There is enough biodegradable carbon for full denitrification in the 1st AS plant. In this case oxygen consumption is ~1.5 kg O$_2$/kg N removed (biomass production included) (Wiesmann 1994) irrespective of applying deammonification or denitrification.
- Denitrification results in aeration energy savings for carbon removal as the oxygenation efficiency in the reject water
nitritation tank is markedly higher \((\alpha = 0.7)\) than in the 1st stage AS tanks \((\alpha = 0.45)\).

The digested sludge will be aerated before pumping it to the dewatering station. By stripping \(\text{CO}_2\) with air, the \(\text{pH}\) will increase to a level where magnesium will be precipitated as struvite in the sludge, in order to minimize struvite formation in the sludge pipe from digester to dewatering station, the dewatering centrifuges and in the pipe for the reject water transport to the nitritation plant.

**Energy management**

The VMWWTP will remain connected to the existing electrical grid so that excess energy can be transferred to the grid and energy demands can be met from the grid. The power station has a maximum capacity of \(\sim 12\) MW. The gas motors will be operated such that the electrical efficiency of the gas motor/generator system remains close to maximum at any time.

**CONCLUSIONS**

Theoretical considerations and existing experience of full-scale operations show that mechanical–biological wastewater treatment plants designed for full nitrification and nutrient removal can be made energy self-sufficient and even energy producing by applying 2-stage AS processes without the addition of external substrates to sludge digestion. This is hardly possible with 1-stage AS process as could be demonstrated by comparison of mass balances for COD and N. Two-stage AS processes result in lower energy demand for aeration and markedly increased biogas production from anaerobic sludge digestion. A favourable COD/N ratio of the influent and other local conditions play an important role. The 2-stage concept can also be favourable for the extension of 1-stage plants to higher treatment efficiency and pollution load.

The design of the Energy Optimization for Sludge treatment (EOS) Project at the Vienna Main Wastewater Treatment Plant \((4\, \text{M PE}_{120})\) will result in producing \(\sim 20\%\) more electric energy per year than needed for its operation after start-up in 2020. The core of this project is the introduction of anaerobic sludge digestion and electricity production from biogas, which will result in a change from raw sludge incineration (since 1980) to digested sludge incineration (after 2020).

The adapted dynamic mathematical model for the whole plant, including sludge digestion and reject water treatment, allows the prediction of future yearly energy demand and production with high reliability and accuracy for different loading conditions.

**REFERENCES**


DWA 2016 German Activated Sludge Design Guideline A 151.


