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FROM ENERGY CONSUMING TO ENERGY PRODUCING WASTEWATER TREATMENT PLANTS. VIENNA MAIN WASTEWATER TREATMENT PLANT (VMWWTP) AS AN EXAMPLE

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Introduction

The energy consumption on a global scale is still growing and is still mainly based on fossil resources. The climate change abatement policy has resulted in a certain stagnation of primary energy input at least in the so called high income countries. This effect is mainly attributed to increased energy efficiency and a shift from the use of high to low entropy energy, mainly electric energy, where also the development of renewable energy sources is in progress. Efficient wastewater treatment for water protection is actually only applied to about 20% of the global waste water produced. Municipalities, industry and trade still markedly contribute to the pollution of the fresh and coastal waters worldwide. For most of the river basins prevention of water quality deterioration and reduced water usability often caused by oxygen depletion and eutrophication can be achieved by efficient wastewater treatment before discharge. “Efficient” means removal of organic pollution and in many cases also nitrification as well as nitrogen and phosphorus removal.

It is often claimed that especially the middle and low income countries cannot afford efficient wastewater treatment because of its high energy consumption, which plays an important role for municipalities even if its energy consumption on a national level is comparatively low. In many low and even middle income countries the lacking reliability of electric energy supply might be a greater problem for efficient wastewater treatment plants than energy consumption per se. The transformation of wastewater treatment plants from an energy consuming to energy producing could therefore not only be interesting regarding cost

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reduction but also regarding energy supply in those regions where continuous 7/24 power supply from the grid is not available.

It is state of scientific knowledge that part of the energy contained in the organic pollution of municipal waste water can be transformed to electric energy by adequate technology to an extent that the whole energy demand of nutrient removal treatment plants can be covered and even some excess energy can be produced.

In actual terminology "energy self-sufficiency" in most cases is used for a situation where the yearly energy demand for the operation of a wastewater treatment is lower than the energy recovered from the waste water. This primarily applies for electric energy but also includes in principle thermal energy. There is mid-term full scale experience at several plants which proves this statement (Wett et al. 2007).

The goal of this paper is to demonstrate:

- The relevance of energy consumption for wastewater treatment in the context of total energy consumption under different local situations in order to demonstrate the relevance of its energy demand and operational costs.
- The theoretical background for energy self-sufficiency using energy balances for different technologies and the relevance of equipment efficiency.
- The development of the Vienna Main Wastewater Treatment Plant (VMWWTP) to energy self-sufficiency by the year 2020. The core of this transformation is the so called EOS-project (energy optimization of sludge treatment) which is under construction.
- The benefit of a long-term close co-operation between a city (Vienna) and scientific research institutions (Institute for Water Quality and Resource Management at Vienna University of Technology).

Relevance of wastewater treatment in comparison to global aspects

The following data on water flows and energy consumption allow a rough estimation of the relevance of humans on a global and a local perspective. The accuracy of all the following data is low but the order of magnitude is the main aspect which has to be considered in their interpretation. An important aspect is that water used by humans for domestic and industrial water supply remains available for other purposes if pollution is controlled. Surface or ground water used for irrigation in agriculture for food production is evapo(transpi)rated and hence "lost" for other purposes in the region even if it remains in the natural water circuit.

Water data (m^3/capita/year).

Water used for hygiene and drinking	10 to 50.
Water used for industry	100 to 200.
Water evaporated for food production	1000 to 3000.
Mean global fresh water availability	> 15 000 but extremely unevenly distributed on the globe.

These data show that domestic wastewater flow is low as compared to food production but it can be reused after adequate treatment. It is only of local relevance and mainly depends on the climatic conditions, the size and density of population and agricultural environment. For the climatic conditions the total regional fresh water availability and the temporal distribution of rainfall over the year are decisive. A typical example for valuable wastewater reuse would be an agglomeration in a semi-arid or arid region. The by far largest "flow of water" to a settlement is the "virtual water" necessary for the food production which neither can be reused nor recycled. We also should never forget that nature too needs huge amounts of water for evapotranspiration by plants but also for the transport of nutrients and trace elements for natural flora and fauna (Vörösmarty et al. 2000).

Relevance of energy for wastewater treatment in comparison to global aspects

The following data will show **orders of magnitude** for energy flows in order to get an impression on the relevance of energy consumption for wastewater treatment on a global scale as compared to other energy flows.

Global solar irradiation, our source of life:

- Total solar energy input ~ 200 000 kWh/capita/d

Power of an adult person (nutrition) ~ 2,5 kWh/capita/d

External (mainly fossil) energy input for us

- Total primary energy input ~ 100 kWh/capita/d
- Energy input at home ~ 10 kWh/capita/d

If we look at the historic development of our external energy input, the following statements can be made:

- 300 years ago agriculture and forestry produced the only external power (solar energy) for feeding humans (0,1 kW), domestic animals (0,7 kW/horse), supplying industry and providing heating.
- Today we globally rely on ~ 80 kWh/capita/d primarily from fossil sources. This corresponds to ~ 30 “slaves”/capita working continuously for us without consuming nutrition. In high income countries the energy consumption is even higher, up to 250 kWh/capita/d (~ 100 ”slaves”/capita/d). This is a unique development in human history.
- Actual developments will cause unpredictable chances and risks by new technologies, ideas and applications (renewable energy sources, big data, industry 4,0, artificial intelligence, global networking etc.)

The following table shows data for the energy input into urban water management

- Drinking water pumping ~ 0 to 1,0 kWh/capita/d
- Drinking water treatment ~ 0 to 0,2 kWh/capita/d
- Sea water desalination for DW ~ 0,8 kWh/capita/d (e.g. Israel)
- Wastewater reuse for drinking ~ 0,4 kWh/capita/d (e.g. Singapore)
- Wastewater pumping ~ 0 to 0,3 kWh/capita/d
- Hot water production at home ~ 2,0 kWh/capita/d

From this table we can conclude that the energy input for urban water management strongly depends on the local situation and varies in a broad range. It also shows that the highest single input is for heating water. Heating can also be achieved by using solar energy mainly in hot periods of the year or in hot climates, by district heating using waste heat from power plants or industry and as in many high income countries with electric energy.

Comparing the data of the table with the data for the total external energy input into our society's water management is in the range of single percent or even below 1%. Nevertheless, in many cases it is the largest energy consumer of a municipality.

Energy content of municipal waste water and energy consumption for treatment

Using COD as an energy parameter, the mean energy input into a treatment plant by the organic pollution is approximately 160 kWh/population equivalent (PE)/year. 1 PE is equivalent to 120 g COD/d corresponding to the internationally accepted PE of 60 g BOD_5/d.

Efficient modern nutrient removal plants have mean power consumption in the range of 20 to 50 kWh/PE/year) depending on treatment plant size and process selection. (Lindtner 2014).

From these data it can be concluded that energy self-sufficient operation should be possible in principle by using the organic pollution as energy source. The technological problem is to overcome the difference in entropy level between organic pollution and electric energy.

Economic relevance of energy consumption for wastewater treatment

The economic relevance of energy costs is strongly depending on the specific local situation especially the level of economic and industrial development. Detailed analyses of operational costs for wastewater treatment exist for Central Europe where the differences in energy and personal costs are low between different countries.

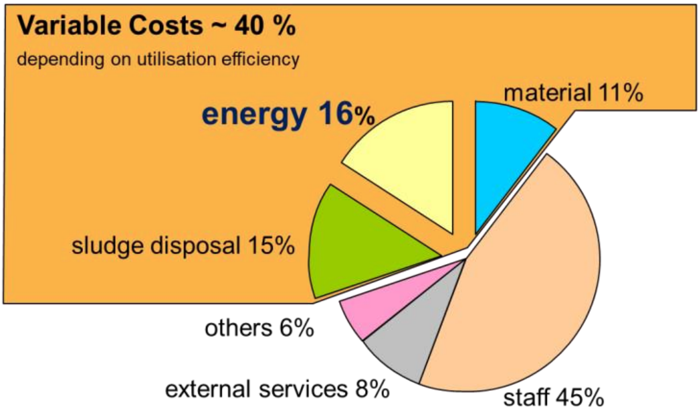

Fig. 1. Analysis of operational costs for WWTP (≥ 50,000 PE) in Austria (LINDTNER)

Fig. 1 shows the dominance of staff costs for operation (45%). Energy costs are only 16% which is still a relevant cost factor. In the case of energy self-sufficiency the energy cost can drastically be reduced and will depend on the contract between grid operator and treatment plant as long as there is a mutual power exchange.

A complete separation of the WWTP from the grid would result in an increase of the capital costs in order to provide the same reliability of power supply. This partly could compensate the reduction in energy cost (operational costs). As the price for energy from the grid is dominated by the cost for the grid, this option should not be completely abandoned for future considerations.

Energy demand for urban wastewater treatment in compliance with European Legislation for sensitive areas (UWWD 91/271/EEC)

The goal of the Urban Wastewater treatment Directive is to avoid oxygen consumption in surface waters, eutrophication in lakes and coastal waters and to maintain aquatic ecosystems close to natural conditions (EU WFD). This legal requirement results in:

- nearly complete removal of org. pollution (BOD_5, COD);
- oxidation of ammonia (nitrification) in order to avoid oxygen consumption and fish toxicity;
- nitrogen and phosphorus removal (avoiding excessive algae growth in coastal waters and suitability of rivers for drinking water supply).

All these processes need oxygen supply by a mechanical aeration system. The energy demand for aeration with modern equipment is ≤ 0,5 kWh/kg O_2.

Oxygen demand for removal of organic pollution expressed in Chemical Oxygen Demand (COD)

During the biological treatment the pollution is removed from the waste water by bacteria using it as a substrate for growing. This process results in oxygen uptake for respiration OU_C and sludge production which can be expressed as COD.

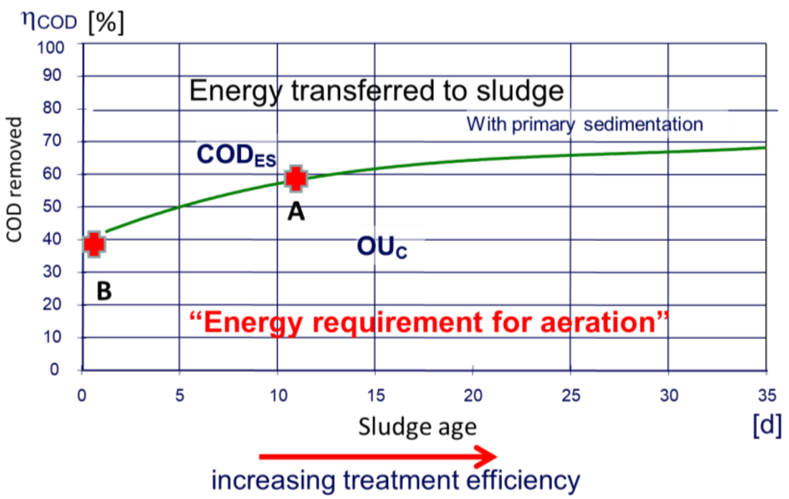

Fig. 1. COD balance for biological treatment by activated sludge process (ASP)

According to the first law of thermodynamic, energy cannot disappear. COD of organic pollution can be converted to energy: 1 g COD corresponds to ~14 kJ. The oxygen uptake by the bacteria results in an energy release for the bacteria of 14 kJ per g of oxygen. Hence the sum of oxygen uptake for removal of organic pollution OU_C (kg O_2/d) and the COD of the excess sludge (COD_{ES}) must be equal to the COD (energy) removed from the waste water. Fig. 1 shows this balance which is depending on sludge age and temperature. Increasing sludge age (and temperature) results in higher treatment efficiency (lower COD in the effluent) while the oxygen uptake of the bacteria increases and the COD of the sludge production decreases.

Fig. 1 shows the results of theoretical considerations (ASM 1) and full scale experience from municipal plants with primary sedimentation for a mean temperature of 15 °C. In order to meet the EU requirements with large one stage conventional activated sludge plants a design sludge age of 10 to 12 days is necessary (A in fig. 1).

From Fig. 1 it can be concluded that for a conventional 1-stage activated sludge plant (designed according to e.g. DWA A131) 60% of the COD load removed shows up as oxygen uptake (needing aeration energy) while only 40% of the COD removed is transferred to the excess sludge.

Oxygen demand for nitrification (NH_4-N to NO_3-N) and nitrogen removal (NH_4-N to N_2)

Also nitrification and nitrogen removal require oxygen uptake by the bacteria and hence aeration energy. There are 2 different processes for NH_4-N oxidation which need oxygen supply and hence aeration energy:

- Nitrification, converting ammonia to nitrate-nitrogen in the effluent
  1 g NO_3-N in the effluent of the treatment plant “needs” 4,6 g O_2 (OU_N).
- Oxygen uptake for ammonia nitrogen conversion to $N_2\uparrow$ gas (OU_{DN}) to atmosphere
  1 g N removed as N_2 “needs” 1,7 g O_2, irrespective of biological process applied: denitrification or deammonification. The difference is that denitrification depends on the available carbon source (degradable COD) while deammonification does not.

These considerations cannot be used for the design of the aeration system. They consider the treatment process as a black box with TN in the influent and different N-compounds in the effluent and the consequences for the overall (yearly) oxygen demand. The dynamic behavior of oxygen demand caused by the strong fluctuations of pollution loads which have to be covered by the aeration system at any time is not considered in this context but decisive for aeration system design.

For energy minimisation process configurations are advantageous where the aerobic degradation of COD in the strict aerobic nitrification zones is minimised so that most of the COD is available in the anoxic zones for denitrification:

$$\text{org. carbon (COD)} + NO_3\text{-N} \rightarrow CO_2 + N_2\uparrow + \text{sludge.}$$

N-removal efficiency (%) by denitrification strongly depends on the N/COD ratio in the influent of the biological treatment step. For N/COD ratios $\geq$ 0,13 in most cases N-removal becomes limited by availability of biodegradable COD. Also the process configuration and aeration control play important roles for N-removal efficiency (pre- and simultaneous denitrification).

Part of the total nitrogen (TN) in the influent of the biological treatment ($TN_{infl.}$) is transferred to the excess sludge (TN_{sludge}) contributing to nitrogen removal ($TN_{removed}$) from the waste water, too.

For the whole biological treatment process the following mass balance for total nitrogen (TN) can be written as:

$$TN_{infl.} - TN_{effl.} - TN_{sludge} = TN_{removed.}$$

A small part of $TN_{effl.}$ is present as org. N (~ 1 to 2 mg/l) and NH_4-N. There are several good reasons to keep the NH_4-N_{effl} concentration ≤ 1 mg/l.

From the paragraphs above the following conclusions can be drawn regarding the energy consumption for mechanical-biological wastewater treatment:

- The higher the efficiency of COD – removal by primary settling the lower OU_C and hence aeration energy demand but also the lower the COD load available for denitrification.
- At a very low sludge age (B in Fig. 1) oxygen demand (OU_C) is low and sludge production (COD_{sludge}) is high but also COD removal efficiency is low (no nitrification).
- The lower the nitrate effluent concentration the lower the aeration energy consumption for nitrification, maximizing N-removal by denitrification reduces energy demand.

Independent of process configuration and aeration control the energy efficiency of the aeration system (kgO_2/kWh) is decisive for the energy consumption for aeration as about 70% of the total energy demand of a WWTP is consumed by aeration.

Energy recovery (via biogas) from anaerobic sludge digestion

In order to minimize external power supply for aeration and other power consuming machinery at a treatment plant, part of the energy contained in the sewage sludge from primary and biological treatment can be recovered as biogas by applying (mesophilic) anaerobic digestion, which also plays an important role in sludge management and odor formation by simultaneous stabilization of the organic matter. This process is advantageous for sludge handling e.g. for storage and dewatering. If sludge is incinerated, it has to be considered that the energy content of the digested solids is lower than those of raw sludge. The difference is equal to the energy content of the biogas.

The following scheme describes the flow of energy and materials during anaerobic digestion:

org. sludge compounds (COD) → CH_4 (methane gas) / CO_2 (carbon dioxide) — **Biogas**

Sludge digestion converts part of the high entropy energy contained in the raw sludge to biogas which can be converted to low entropy electric and thermal energy:

biogas → gas-motors driving generators → electric energy (up to ~ 40%) / heat (50 to 60%)

The electric energy generated can be either fed to the electrical grid or directly used as power supply of the treatment plant. The heat is normally used for heating the raw sludge to 35 to 40 °C (mesophilic conditions) and heating.

For energy self-sufficiency considerations high electric efficiency of gas motors (%) is a dominant factor. With modern equipment an efficiency of η_{el} ~ 40% can be achieved. In the past 30% was a common value. This difference cannot be compensated by process optimisation.

The higher the concentration of the thickened raw sludge the lower is the sludge volume and hence the required digester volume. It results in lower capital costs and lower energy demand for heating the sludge to 35 – 40 °C.

With increasing solids concentration also viscosity of the sludge markedly increases which is important for the design of pumps and pipes and is relevant for digester mixing. (Reichel 2013, Füreder 2017).

Energy balance for digestion based on stoichiometry:

1 kg COD degraded in the digester results in 350 NL Methane (CH_4).

With this relationship the energy content of the biogas can be calculated from the difference between the COD of the raw (feed) and the digested sludge.

$$COD_{raw\ sludge} - COD_{digested\ sludge}\ [kg/d] = COD\ of\ CH_4.$$

Nitrogen conversion during digestion

Digestion only converts organic carbonaceous compounds to biogas while the nitrogen content of the organic material is released to the digested sludge as ammonia nitrogen NH_4-N. This additional N-load is normally contained in the reject water from dewatering of the digested sludge. The N load in reject water can reach up to 25% of the influent N-load and needs special design considerations. For nitrogen removal from the reject water different processes can be applied.

Consequences for energy self-sustaining treatment plants

First of all mechanical equipment of the whole plant has to achieve high electrical efficiency. This is especially important for aeration system, gas motors and generators. Aeration control has to be optimized to achieve continuous stable nitrification for water protection and maximum nitrogen removal for energy minimization. The N/COD ratio of the wastewater influent can have a strong influence on energy demand, which cannot be fully compensated by process configuration.

It is meanwhile state of knowledge that 2-stage activated sludge treatment systems result in lower energy demand than conventional 1-stage plants: a first stage with a sludge age of ≤ 1d for carbon removal (nitrification) and denitrification and a second stage with a sludge age of 6 to 10 days (depending on minimum temperature) for nitrification and denitrification. The details of a very favorable process configuration has been developed by the Institute for water quality and resource management at the Vienna University of Technology and is applied at the Vienna Main Wastewater Treatment Plant (VMWWTP) which is described later.

Pretreatment by primary sedimentation transfers part of the organic pollution (energy) to the sludge without energy consumption and results in higher biogas production potential. On the other hand it reduces the carbon source for denitrification. Whether primary sedimentation is advantageous for energy minimization depends on the N/COD ratio.

The overall goal of process optimization for energy minimization is to transfer a maximum of the organic pollution and hence energy content to sludge production without compromising N-removal by denitrification.

Lower energy demand does not necessarily result in lowest total (capital+operational) costs for wastewater treatment. This has to be considered especially for smaller plants (below 50 000 PE).

Irrespective of energy cost minimization process configuration selection has to fulfill other important criteria like: adaptability to changing temperatures and load variations over the year, reliability for extreme loading conditions (wet weather) and extremely low temperatures in wintertime, repair and maintenance conditions for civil work, etc.

Energy Self-Sufficiency at the Vienna Main Wastewater Treatment Plant in 2020 – The EOS Project (Energy Optimization of Sludge Treatment)

Extension of the Vienna Main Wastewater Treatment Plant, start of operation in 1980:

In 2005 the first extension of the VMWWTP plant to 4 Mio PE went into operation (WANDL et.al. 2006) in order to meet the legal requirements of the Austrian wastewater regulation (AEVkA 1996). The already existing high loaded activated sludge plant (start of operation 1980) was converted into the first step of the two stage activated sludge plant without major changes. The second stage was built in the period 2000 to 2005 on an area provided for extension already in 1970.

Fig. 2 shows the aerial view of the VMWWTP as it went into operation in 2005. In the upper part the original high rate activated sludge plant with rectangular primary sedimentation, aeration tanks (with cone aerators) and secondary clarifiers can be seen. In the lower part the new constructed second activated sludge plant with 15 lines can be seen. They are all supplied with the same mixture of return sludge and effluent of the first stage. This new plant consists of mechanically mixed rectangular pre-denitrification tanks, followed by 2 circular flow aeration tanks in series and circular secondary sedimentation tanks (64 m diameter).

Fig. 2. VMWWTP from 2005 to 2015 (EbS GesmbH, Wien)

The responsibility for the process development and basic design concept was of the Institute for Water Quality Management at Vienna University of Technology in continuation of a long-term successful co-operation with the city administration since the mid 1960s. (DORNHOFER 1998) (WANDL et.al. 2006).

The theoretical considerations for the new process concept were tested in pilot investigations onsite and online at the VMWWTP (WANDL 2005) in order select the best option, to prove its reliability under real conditions and to develop an adequate mathematical model.

The layout looks quite similar to the AB Process developed by Böhnke et al. (1979) but there are fundamental differences regarding the operational details. The basic idea of Böhnke was to separate carbon removal by heterotrophic bacteria in the 1. stage from the autotrophic nitrifiers in the 2. stage which is very successful for meeting nitrification requirements only but is less effective for N-removal.

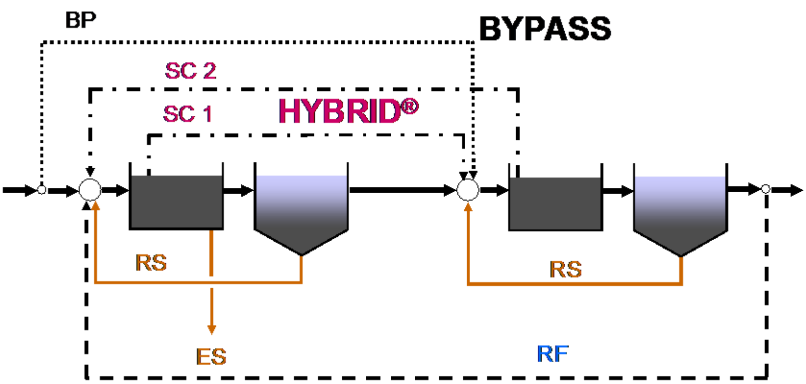

Fig. 3. Process scheme of the VMWWTP 2 – stage activate sludge treatment process

There are 2 modes of operation:

- Bypass (or normal) operation characterized by
    - 20 to 50% of the primary effluent (BP) are directly bypassed to 2. stage for denitrification (depends on monthly mean temperature).
- Hybrid mode in the case of bulking sludge development (May, June)
    - activated sludge from 1. stage is transferred to 2. stage (SC 1) as denitrification substrate (a little bit less effective for denitrification but reliably removes bulking).
- In both operational modes
    - During dry weather flow (actually 7 m^3/s) up to ~ 5 m^3/s of the final effluent are returned to 1. stage (RF) for denitrification which reduces aeration energy requirement (the first compartment of the 1.stage aeration tanks are anoxic);
    - The whole excess sludge of the 2. stage (containing nitrifiers) is transferred to the first stage (SC 2) where bacteria can adsorb COD and also can contribute to N-removal by simultaneous nitrification/denitrification;
    - Excess sludge from the treatment system (ES) is only withdrawn from the 1. stage with a low sludge age (< 1 d) resulting in low oxygen uptake;
    - Due to the return of the excess sludge of 2. stage also nitrifiers are present in 1. stage enabling simultaneous nitrification/denitrification also there;

- Aeration control in second stage: the size of the oxic volume is adapted to nitrification requirement depending on temperature and N-loading. The NH_4-N concentration in the effluent is kept close to ≤ 1 mg/l, the rest of the volume is kept anoxic for simultaneous nitrification/denitrification.

Sludge treatment also remained unchanged for this extension. It consisted of mixed gravity thickening of primary and secondary sludge, thickened raw sludge dewatering by centrifuges and fluidized bed incineration. The ashes are disposed at the city owned sanitary land fill.

Second extension EOS Project (start of operation 2020) for energy self sufficiency

The actually ongoing extension has the goal to produce more energy from sludge digestion than the energy demand of the whole VMWWTP by 2020. The design concept comprises several changes and additions of the existing plant described above:

- The original plant (1980) has reached the end of its life time and has to be rebuilt. This fact is used to reduce the area requirement for primary sedimentation and of the 1. stage activated sludge plant. By choosing much deeper tanks space could be saved which can be used for sludge digestion and energy recovery.
- The new sludge digestion plant is designed for a raw sludge concentration of ~ 8% DS using mechanical thickening with centrifuges and consists of 6 digesters with 12 500 m³ each (cylindric shape 22 m diameter, 30 m high).
- Due to the high solids concentration and the depth of the digested sludge the mixing energy of the gas production under normal operation provides complete mixing of the digesters, no external energy supply is required for mixing.
- The energy recovery plant consists of a gas storage tank, a gas motor station with generators, design capacity ~ 10 MW).
- The ammonia of the reject water from sludge dewatering (NH_4-N concentration ~ 2000 mg/l) will be converted to nitrite (reliable and simple process, short start up period) and transferred to 1.stage for denitrification which results in a reduction of energy requirement because aeration efficiency is much higher in nitritation tank than in 1. stage activated sludge plant. Deammonification was considered as alternative but abandoned mainly due to long start up period and lower reliability).
- The necessary adaptations at the sludge incineration plant are not described in this paper. The plant capacity including dewatering can be reduced to less than 50%. The calorific value of the sludge solids is reduced by about 30 to 40% as compared to raw sludge.

Also for the EOS project all important details for design and operation were investigated in a one-year pilot scale plant (Digester volume 80 m³) online and onsite of the VMWWTP (REICHEL 2015). This also allowed to develop an overall dynamic mathematical model of the whole plant including sludge treatment (SVARDAL 2014). This model was fed with the existing operational data of the existing VMWWTP for the year 2013 multiplied with a constant factor so that the energy and nitrogen flows could be calculated for the design capacity of the plant.

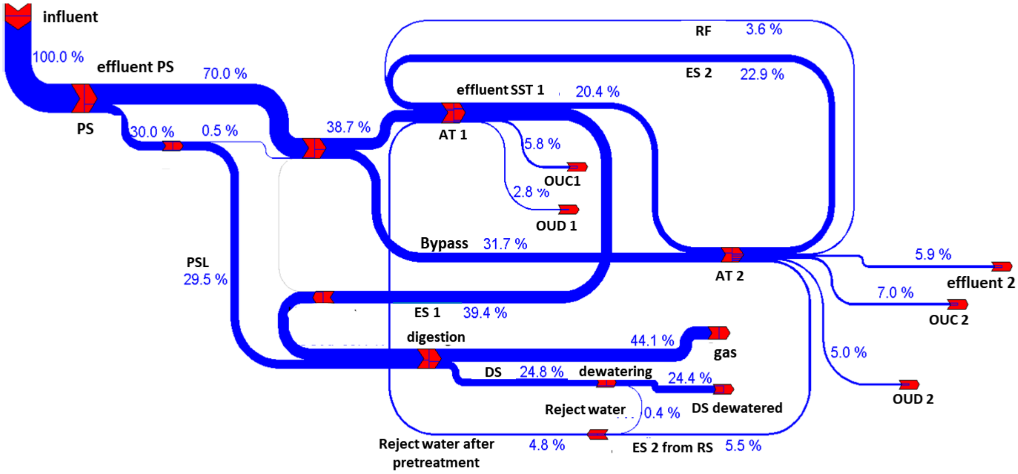

Fig. 4. Sankey diagram of mean yearly COD flow under design load (Kroiss, Svardal 2015)

From the model calculation it can be concluded that under design loading the plant will produce about 20% more electric energy than required for the operation and a mean yearly nitrogen removal of $\geq$ 75% can be expected (KROISS, SVARDAL 2015).

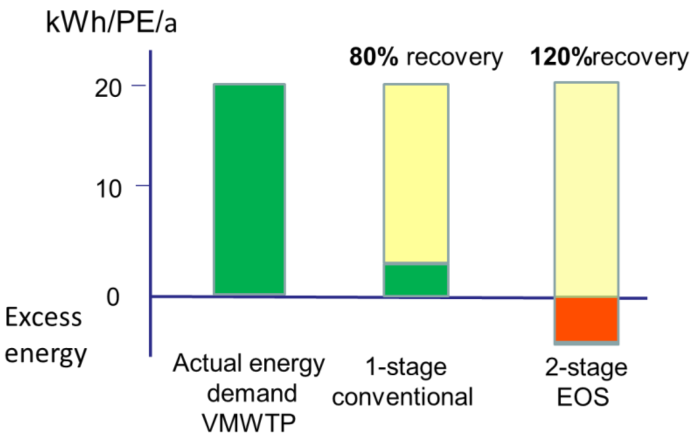

Fig. 5. Energy demand for actual situation, for a 1-stage activated sludge plant and for the 2-stage plant. In both cases the same situation was assumed, e.g. N/COD = 0,1 in the influent, sludge digestion and same efficiency of aeration system, gas motors and generators

From Fig. 5 it can be concluded that with a 1-stage conventional activated sludge plant it is not possible to achieve energy self-sufficiency while it is possible for the 2-stage Vienna concept. For both cases the same reliability of meeting the effluent standards and the same wastewater loading situation was assumed.

Conclusions

Theoretical considerations and full scale experience show that it is possible to achieve energy self-sufficient municipal nutrient removal wastewater treatment plants even with a design based on existing technology with conventional treatment processes. It could be demonstrated that this goal is hardly achievable with conventional 1-stage activated sludge plants even with primary sedimentation, while the 2-stage concept makes it possible. There are two important aspects which have to be considered for the success. One is that the effluent standards are not fixed as TN effluent concentrations which have to be met in grab samples and with a probability of e.g. 4 of 5 consecutive samples as it is the case in Germany. This standard could probably not be met if the influent TN concentrations are > 40 mg/l. The second is that for N/COD ratios > 0,125 in the influent of the 1. activated sludge plant and N-removal requirements > 75% as a yearly mean would at least require deammonification for the reject water. In any case mathematical modelling with careful parameter determination will be necessary to prove whether the specific local N-removal standards can reliably be met.

The two stage concept can especially be recommended in the case of extensions of existing treatment plants for nutrient removal or higher pollution loads as often existing infrastructure can be integrated either as 1. stage or 2. stage of a 2-stage concept. Whether primary sedimentation has a great influence on energy self-sufficiency mainly depends on the N/COD ratio of the plant influent which can be demonstrated by comparing the Strass/Tirol (AB technology without primary sedimentation but with reject water deammonification) with the Vienna Plant (Bypass process with primary sedimentation and reject water nitritation).

The 2-stage concept in Vienna results also in reduced capital costs and area requirements as compared to a one stage concept as the operation can better be adapted to the strong temperature variations over the year.

For small treatment plants (< 50,000 PE) energy self-sufficiency does not necessarily result in minimum total costs for wastewater treatment because energy cost become less and capital costs more relevant. Operational simplicity has to increase with decreasing size.

The design of the extension of the VMWWTP plant to energy self-sufficiency was strongly influenced by several specific local conditions and the historic development, while the theoretical considerations and the methodology developed in this paper are universally applicable.

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