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Energetic refurbishment of an existing large-scale MBR

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Abstract

Operations of an existing municipal MBR serving 80,000 inhabitants were improved energetically by implementing new automation routines for biology and membrane filtration. Finally, the MBR was refurbished by adding primary clarification and anaerobic sludge digestion to the treatment process, while specific energy consumption was reduced by one third to 0.65 kWh/m^3 permeate produced. A combined heat and power engine generates electrical power on site from digester gas. The projected carbon footprint of plant operations will thus be halved by reducing indirect emissions from electricity consumption.

Key words: energy efficiency, GHG-emissions, MBR case study, process design

INTRODUCTION

Energy consumption of membrane bioreactors (MBRs) is not only accountable for operational expenditures but is also an important factor in environmental footprint. Results from lifecycle environmental impact assessments have shown that a major impact could be attributed to indirect emissions, tracing back to electricity generation (Ioannou-Ttofa *et al.* 2016). Despite efficiency increases through new module constructions, membrane materials, aeration and operational regimes (Buer & Cumin, 2010; Judd, 2011; Lesjean & Leiknes, 2009; Miyoshi *et al.* 2018), it has been reported that full-scale MBR applications do not operate membrane filters with their optimal efficiency, as inflow variations result in operation at low flux rates or long periods of stand-by operation. This opens up potentials to reduce the energy consumption of existing MBRs (PUB 2011; Sun *et al.* 2016).

In addition to process optimisations, an existing MBR (Brepols, 2010), which has already been in operation for 15 years, was refurbished by a new anaerobic digestion system. So far, only few MBR reference sites exist that use separate anaerobic biomass stabilization to generate electrical energy on-site instead of a more consuming simultaneous stabilisation. These installations result from MBRs built at conventional wastewater treatment plant (WWTP) sites, where anaerobic digesters existed beforehand (e.g. Rietliau WWTP in Wädenswil, Switzerland; Traverse City WWTP in Michigan, US).

The following case study highlights main achievements and prospects like reductions in energy consumption, new operational parameters for MBRs and projected greenhouse-gas emissions, which might be eventually transferred to other full-scale MBR applications.

CASE STUDY

The MBR at Kaarst-Nordkanal is one of 36 municipal wastewater treatment plants (WWTPs) operated under the authority of the Erftverband, a regional river water association located in the German federal state of North-Rhine Westphalia. In 2004, the MBR replaced an existing WWTP, while the plant site was moved 2.5 kilometres west from the existing facility, giving space and opportunity for further municipal development. The catchment of the WWTP comprises three municipalities and an area of 1,235 ha of paved surface with mixed sewer systems.

The MBR was designed to treat wastewater from up to 80,000 residents at a maximum storm weather inflow of 45,000 m^3/d. The biological treatment was originally designed for full biological nitrogen removal, simultaneous phosphorous precipitation and simultaneous aerobic biomass stabilization. The MBR is divided into four separate bioreactor lines, each one equipped with two lines of immersed hollow fibre membranes. At its commissioning, the Nordkanal MBR was the world's largest MBR in hydraulic treatment capacity. Reliability of membrane operations and full plant availability had been the main priorities of process design and automation. However, it had to be recognised that this operational paradigm came at the expense of a low energy efficiency (Brepols 2010). Meanwhile, sewer rehabilitations in the catchment reduced infiltration rates. Thus, the gap between dry-weather and storm-weather inflow conditions increased and so did the specific energy demand during dry-weather conditions.

Initial efforts to reduce the energy consumption during dry-weather conditions focused on filter operations, mechanical pre-treatment and biological process aeration (Brepols 2012; Drensla & Janot 2017). In 2012, photovoltaic devices were installed on roof surfaces at the plant. Drastically rising tariffs for electrical energy in Germany spurred further plans to refurbish the MBR with anaerobic digestion and on-site co-generation. Governmental initiatives to increase the resource efficiency of wastewater treatment finally paved the way to implement new primary sedimentation, anaerobic sludge treatment and a combined heat and power unit (CHP) on site. First ideas were issued in 2012/2013 (Brepols *et al.* 2013) and finally construction works started in March 2017. The works were completed by the end of March 2019.

The new process layout of Nordkanal MBR (Figure 1) consists of an inlet screen, a grit chamber, primary sedimentation, sieves, and the MBR. Excess biomass is given to a new mechanical thickener before entering the digester together with the primary sludge, which is first fed to a static thickener together with sieving goods from the fine sieve unit. Biogas is stored, cleaned and converted into thermal and electrical energy at a CHP unit. Ammonia-rich concentrates from the final sludge dewatering are treated separately by anaerobic ammonia oxidation in a converted sludge storage tank. This reduces the nitrogen load to the main MBR. Key figures of the process units are listed in Table 1.

RESULTS AND DISCUSSION

Figure 2 shows the time series of annual inflow and energy consumption from the first complete year of operations in 2005 onwards. After commissioning the MBR, specific energy consumption remained relatively stable at a level between 0.9 and 1.0 kWh/m^3 permeate. More experiences and confidence were gained in the operational stability of the filtration units and thus attempts were taken to divert from original operational set-points and improve control strategies of the biological treatment as well as the filtration process. Although these process optimisations started already in 2010, it took almost two years before significant reductions could be achieved. Finally, the specific energy demand (SED) of the filtration process was decreased from 0.42 to 0.22 kWh/m^3 with the original membrane filters still in use. The SED of the entire plant was lowered from 0.93 in 2005 to 0.65 kWh/m^3 in 2015. Drensla & Janot (2016, 2017) have described a number of measures that were mainly responsible for this reduction:

- Increasing the instantaneous flux from 25 LMH to 30–40 LMH, longer filtration intervals of 900 s instead of 600 s, and repeated relaxation instead of backwashing contributed to an increased permeate yield while cross-flow aeration rates were reduced by changing to a new air-cycling mode.

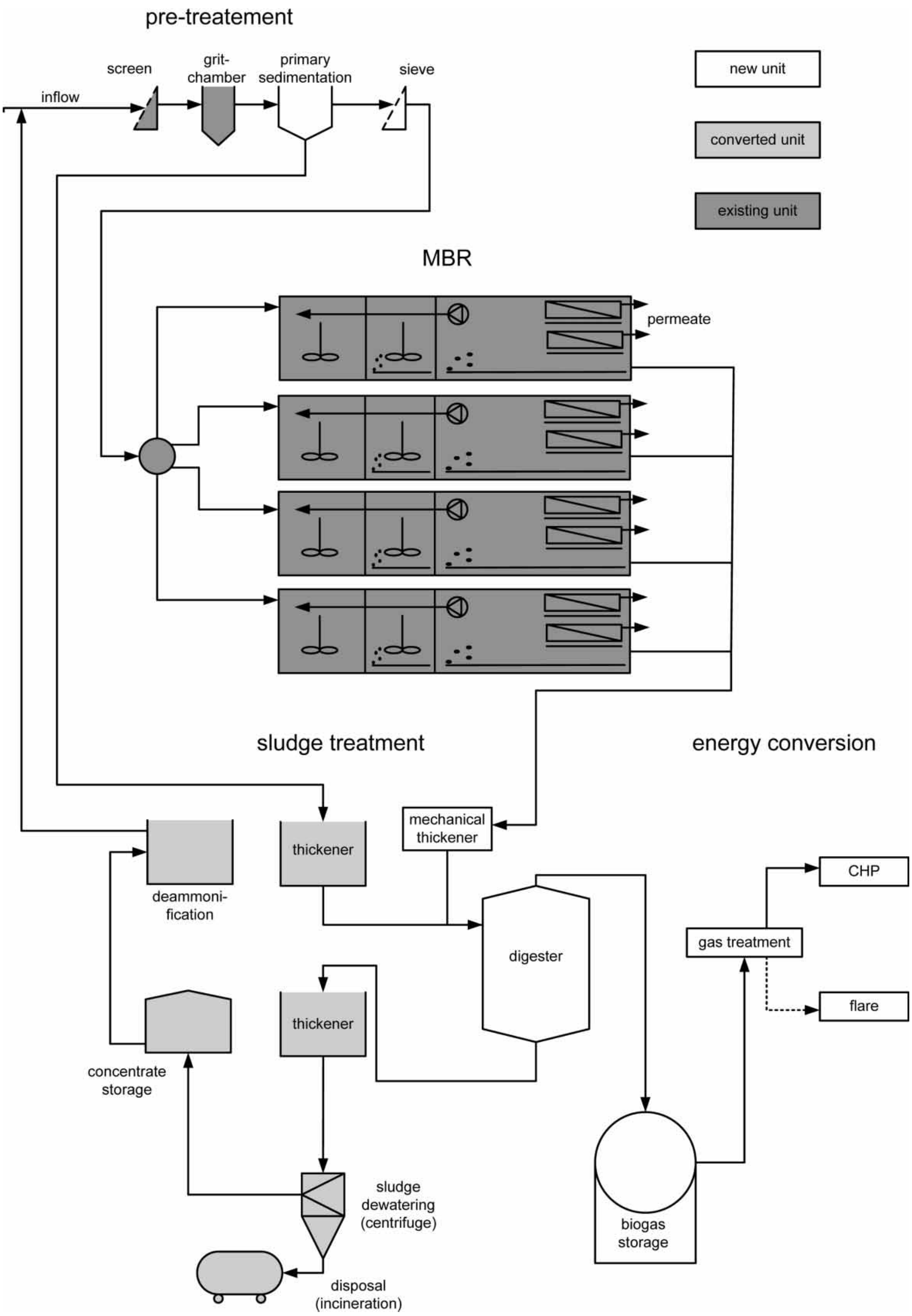

Figure 1 | Process scheme of the refurbished Nordkanal MBR.

- Operation of bioreactors and filtration further improved by actively channelling inflow to dedicated treatment lines. As a result, active filtration lines operate at their optimal set-point while remaining lines rest in an energy-reduced stand-by mode.
- Bioreactor operation also contributed to energy savings. MLSS concentration was lowered from its original design value of 12 gMLSS/L to less than 8 gMLSS/L without hampering effluent quality. This also increased aeration efficiency though a higher oxygen transfer rate and reduced oxygen demand for endogenous biomass respiration was observed.

Table 1 | Key technical and operative data of Nordkanal MBR, original plant design and after optimisations and refurbishment

	Design (2004)	**New (2019)**
Nominal design capacity, PE	80,000	80,000
COD influent load, 85-percentile, kg/d	9,600 (design)	12,590 (measured)
Average inflow, m^3/h	650	580
Primary sedimentation, volume in m^3	–	670
Bioreactor		
Volume in m^3	9,300	9,300
MLSS concentration, g/L	12	<8
Membrane filtration		
Surface, m^2	84,800	84,800
Peak flux set point, LMH	<25	<40
Filtration interval, filtration/backwash time in sec	400/50	900/50
Digester volume in m^3	–	2,700
Deammonification, volume in m^3	–	250
CHP, electric power in kW	–	300
specific energy demand, total WWTP		
kWh/m^3	0.97	0.65
kWh/a/PE	65	40
kWh/kgCOD	1.5	0.4

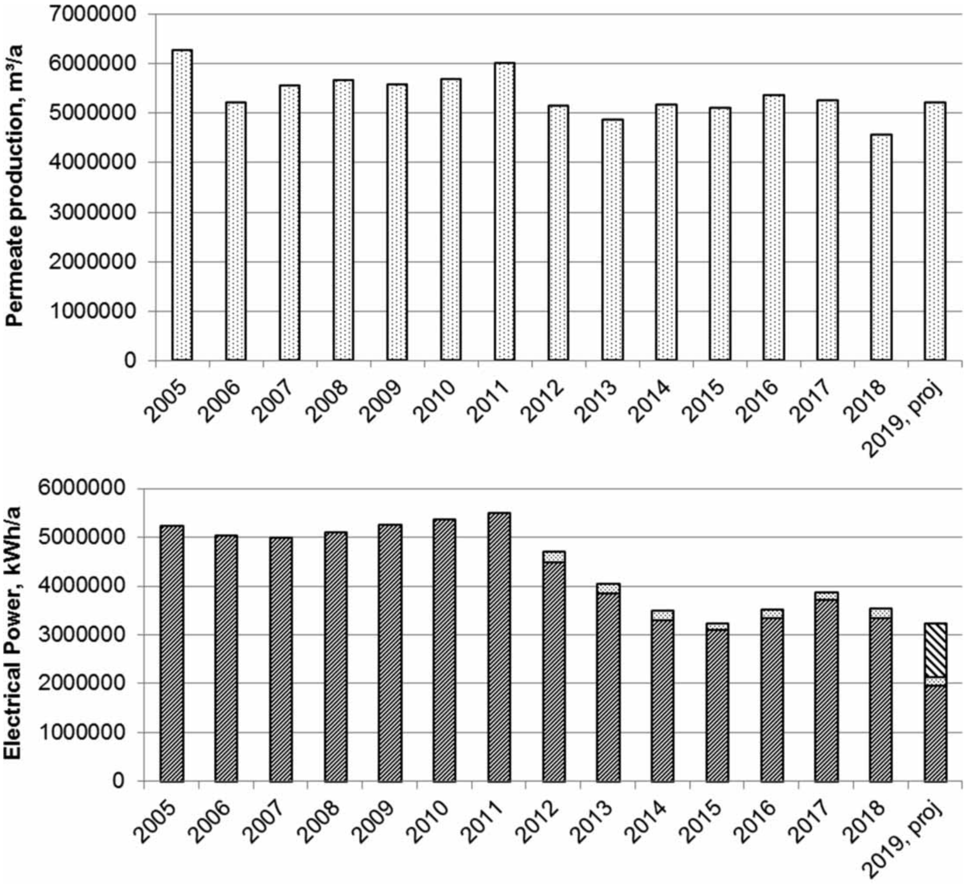

Figure 2 | Annual permeate production and energy consumption at Nordkanal MBR, 2005 to 2018 and projected values after refurbishment (2019).

- Finally, replacements of inefficient equipment like blowers, additional measurements and control units took place and much of the existing SCADA system was re-programmed.

Due to construction works and various provisional states of operation, specific energy consumption increased in 2017 and 2018. The CHP was commissioned in February 2019 and immediately produced up to 5,000 kWh/d. During the start-up of the digester and the gas-processing, several minor problems occurred that for a while resulted in unstable operating conditions. However, energy consumption has already been reduced significantly as the organic load of the bioreactor has been lowered by primary sedimentation while the CHP reduces electricity consumption from the public grid. Values for power production and consumption for the year 2019 are shown in Figure 2 based on first operational results. Energy production by CHP here is accountable for one third of the total electrical energy consumed, while photovoltaic energy contributes 6% as a yearly average. The projected SED per capita for the new MBR process is at 40 kWh/a/PE. Compared to this, SED values for conventional WWTPs with anaerobic digestion in Germany are in a range between 10 and 85 kWh/a/PE with a median value at 30 kWh/a/PE (DWA 2015). These statistical values include also data from WWTPs which have an inferior effluent quality compared to MBR.

Greenhouse gas (GHG) emissions of the refurbished plant have been estimated preliminarily based on assumptions from a previous research project (Genzowsky *et al.* 2013). Compared to values calculated for the year 2012, it can be seen that indirect emissions are strongly reduced. This is mainly a result of reduced electrical power consumption from the public grid. Direct emissions from the process slightly increase as a consequence of emissions of methane from primary sedimentation and sludge digestions as well as the on-site biogas-to-power conversion (Figure 3). The converted digester gas is considered here as a renewable resource. A more precise estimation of GHG reductions is subject to an ongoing research project.

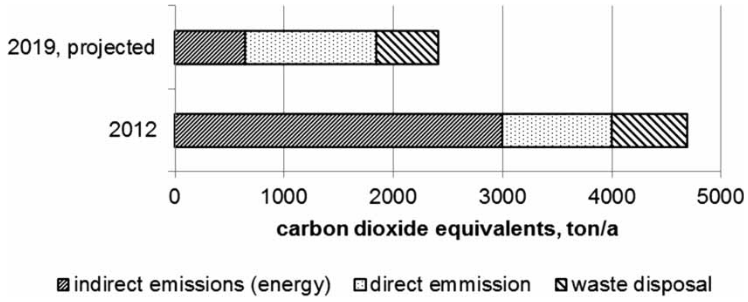

Figure 3 | Estimated greenhouse gas emissions of the original MBR (2012) and projected values for the refurbished MBR with separate sludge digestion.

PERSPECTIVES

The start up of the new anaerobic digestion will also be followed by a phase of further energetic assessments and improvements on site. At the same time, a research project at Nordkanal MBR examines the interactions between PAC (powdered activated carbon) dosage and the filtration process. PAC reduces the micropollutant concentration in the effluent, but there are also hints that PAC may improve the filtration process by altering biomass and fouling properties. Despite the considerable age of the membrane filters of 15 years, concentrations of pathogens in the permeate have remained stable at a low level throughout the years. Compared to the effluent of conventional WWTPs and tertiary sand filters, only very few micro plastic particles could have be detected in the MBR effluent. Similarly, a high micro plastics removal potential of MBRs has also been described in Finland (Talvitie 2018).

CONCLUSIONS

After several years of continuous efforts and improvements, energy demand of the Nordkanal MBR could be reduced strongly, while effluent quality of the MBR is still superior to most conventional WWTPs. Currently, MBRs seem to be the only technology capable of dealing with new challenges in municipal wastewater treatment in a single treatment step: micropollutant and microplastics removal and the containment of antibiotic-resistant microbes.

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