MBR technology: a promising approach for the (pre-)treatment of hospital wastewater

S. Beier, C. Cramer, C. Mauer, S. Köster, H. Fr. Schröder and J. Pinnekamp

ABSTRACT

Membrane bioreactor (MBR) technology is a very reliable and extensively tested solution for biological wastewater treatment. Nowadays, separate treatment of highly polluted wastewater streams especially from hospitals and other health care facilities is currently under investigation worldwide. In this context, the MBR technology will play a decisive role because an effluent widely cleaned up from solids and nutrients is absolutely mandatory for a subsequent further elimination of organic trace pollutants. Taking hospital wastewater as an example, the aim of this study was to investigate to what extent MBR technology is an adequate ‘pre-treatment’ solution for further elimination of trace pollutants. Therefore, we investigated – within a 2-year period – the performance of a full-scale hospital wastewater treatment plant (WWTP) equipped with a MBR by referring to conventional chemical and microbiological standard parameters. Furthermore, we measured the energy consumption and tested different operating conditions. According to our findings the MBR treatment of the hospital wastewater was highly efficient in terms of the removal of solids and nutrients. Finally, we did not observe any major adverse effects on the operation and performance of the MBR system which potentially could derive from the composition of the hospital wastewater. In total, the present study proved that MBR technology is a very efficient and reliable treatment approach for the treatment of highly polluted wastewater from hospitals and can be recommended as a suitable pre-treatment solution for further trace pollutant removal.

Key words | costs, energy consumption, hospital wastewater, MBR

INTRODUCTION

There is growing concern regarding the presence and effects of pharmaceutical substances and their degradation and transformation products in the water cycle (Heberer 2002; Crane et al. 2006). Therefore, it is necessary to develop adequate treatment technologies in order to minimize the emissions of these substances into the aquatic environment. The separate treatment of hospital wastewater might be a promising approach which is currently under investigation in several European countries (Beier et al. 2010b; Escher et al. 2011). A far-reaching elimination of pharmaceuticals from hospital wastewater requires advanced treatment technologies such as ozonation, nanofiltration or reverse osmosis (Beier et al. 2010a). An essential prerequisite for the use of these advanced technologies is that the influent is widely cleaned up from solids and nutrients. Membrane bioreactors (MBRs) have become a broadly accepted option for biological wastewater treatment (Lesjean & Huisjes 2008). However, the treatment of hospital wastewater is challenging due to its very complex wastewater matrix. Thus, hospital wastewater contains different pollutants such as pharmaceuticals, heavy metals, detergents, X-ray contrast media and disinfecting agents (Boillot et al. 2008). Furthermore, a high eco-toxicity of hospital wastewater has been reported (Emmanuel et al. 2005). This situation leads to the question whether there are any adverse effects on the operation and performance of MBR systems deriving from the specific composition of hospital wastewater. Taking hospital wastewater as an example, the aim of this study was to investigate to what extent the MBR technology is an adequate ‘pre-treatment’ solution for further elimination of trace pollutants. Therefore, we investigated – within a two-year period – the performance of a full-scale hospital wastewater treatment plant (WWTP) equipped with a

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MBR by referring to conventional chemical and microbiological standard parameters.

**MATERIAL AND METHODS**

**Hospital wastewater treatment plant Waldbröl**

The case study was carried out at the county hospital Waldbröl. Waldbröl is a small town in North Rhine-Westphalia (Germany) with about 20,000 inhabitants. The hospital is a medium-sized hospital with 340 beds, approximately 800 employees and eight different wards. In 2006 the hospital was equipped with its own WWTP that consists of a full-scale MBR. In addition, within a further research project advanced treatment technologies were tested in pilot scale ozonation, activated carbon adsorption and nanofiltration/reverse osmosis (Pinnekamp et al. 2009). Figure 1 shows the different process steps of the MBR which consists of five membrane modules (Type Kubota EK 400). The active membrane layer is made of chlorinated polyethylene. The most relevant design and operation parameters of the MBR are summarized in Table 1.

After the initial starting phase the MBR has been in regular and continuous operation since the beginning of the year 2007. Within the years 2007 and 2008 the sanitary sewer of the hospital was separated from the storm water flow. Therefore, the storm water overflow decreased significantly since 2008. However, as some roof and traffic areas are still connected to the wastewater system the overflow is still needed in heavy rainfall periods.

Table 2 lists the most important operating features of the MBR system. A quite low sludge load was chosen to stimulate the growth of slowly growing bacteria species. The design flux was chosen by following typical fluxes of municipal WWTP which are equipped with MBR technology. It operates very stable and no on-site operating staff were required. After more than four years of operation the membrane permeability can be assessed as very stable so that a chemical cleaning is only rarely necessary (three times since the start of operation).

**Sampling and analysis**

The period of investigation was from April 2007 to May 2009. In order to evaluate the removal efficiency we took water samples from the MBR influent (raw hospital wastewater) and the MBR effluent (permeate) and analysed physicochemical and microbiological parameters. All analyses were conducted in the Environmental Analytical Laboratory of the Institute of Environmental Engineering.
of RWTH Aachen University. Water samples were collected as 24 h flow proportional composite samples and transported at 4 °C. Sludge samples were taken from the aeration tank.

The analyses were carried out according to generally recognized standard methods. The analyses were performed on non-filtered raw samples. The concentrations of NH₄-N, DOC and total-P were determined photometrically according to DIN 38406, DIN ISO 15705 and EN ISO 6878, respectively. The spectral absorption coefficient (SAC) was measured by UV-absorption at 254 nm (ISO 7887). TOC was analysed by infrared spectrometry (NDIR) after a thermo-catalytic oxidation of the carbon compounds (ISO 6878). The concentrations of organic halogen compounds (AOX) were measured in accordance with EN ISO 9562. After sample preparation and combustion of the organically bound halogens form gaseous hydrohalogens which were detected by micro-coulometry. The quantitative detection of the microbiological indicator parameters Escherichia coli and intestinal enterococci was done according to EN ISO 9308-3 and EN ISO 7899-1 by using MUG (4-methylumbelliferone glucuronide) and MUD (4-methylumbelliferyl-β-D-glucoside) microplates from BIO-Rad Laboratories (Hercules, Canada). Both methods are based on the hydrolysis of special substrates demonstrating the bacterial enzymatic activity. The end product is fluorescent and can be detected by using an ultraviolet lamp. Finally, the data on energy demand and the determination of the size were carried out according to DIN 38406, DIN ISO 15705 and EN ISO 7899-1.

The identification of filamentous organisms was done according to Jenkins (1992), Eikelboom & Van Buijsen (1992) and Jenkins et al. (2004). Nitrifying bacteria (i.e. ammonium-oxidizing bacteria (AOB); nitrite-oxidizing bacteria (NOB)) were detected by fluorescence in-situ hybridization (FISH) using commercially available Nitri-VIT kits (Vernicon AG, München, Germany). The quantification of the nitrifiers in the activated sludge and the determination of the floc size were carried out by using the image analysis software Image-Pro Plus Version 4.5 and the high-resolution digital camera CoolSNAP-Pro_c (MediaCypernetics, Inc, Silver Spring, USA).

### RESULTS

#### Removal performance with regard to physicochemical parameters

The MBR treatment was highly efficient concerning the removal of classical parameters such as solids, carbon and nitrogen (see Table 3). For further phosphorous removal an additional treatment step (e.g. precipitation) would be necessary.

The measured AOX concentrations in raw hospital wastewater were significantly higher than in domestic wastewater. Our results are in line with other studies that found high levels of AOX (between 0.55 and 1.7 mg/L) in hospital wastewater (Emmanuel et al. 2005; Boillot et al. 2008). It has been shown that iodinated X-ray contrast media are an important source of AOX, whereas chlorine releasing or halogen-organic disinfectants might be a minor source (Gartiser et al. 1996; Kümmayer et al. 1998). With regard to eco-toxicalogical aspects AOX and iodinated X-ray contrast media seem to be of minor importance (Steger-Hartmann et al. 1998). Thus, the reliable reduction of iodinated X-ray contrast media emissions has to be addressed when investigating the separate treatment of hospital wastewater.

#### Removal performance with regard to microbiological parameters

Table 4 illustrates the levels of microbial indicators per 100 mL in influent and effluent of the MBR. The removal efficiencies are divided up into log10 reduction and percentage reduction. Log removals for the bacterial indicator organisms (E. coli, intestinal enterococci) were up to 4.5. These log-removals are in line with other reported removal rates (Ueda & Horan 2000; Ottoson et al. 2006) and prove that MBR membranes are very efficient in the removal of...
bacteria. As most bacterial cells are more than 0.5 μm wide and 2 μm long they exceed the membrane cut-off level of 0.2 μm and, therefore, they are reliably removed. In terms of microbiological parameters the effluent of the MBR fulfilled the quality requirements of the European bathing water directive (2006/7/EG). Following the directive the measured effluent quality was classified as ‘excellent’. We did not gain any results concerning the elimination of viral indicators. It has been shown that MBR treatment is less efficient with regard to the retention of viruses (Ottoson et al. 2006; Marti et al. 2011). However, a significant proportion of viruses seems to be eliminated by MBR treatment in spite of their small dimensions (Da Silva et al. 2007). This issue has also to be investigated in future studies.

Characterization of the activated sludge

Normally, the biocenosis in the MBR systems differ from those in a conventional activated sludge process. The sludge flocs are rounder and they normally show a more or less weak and diffuse morphology. In comparison to conventional systems the average floc size was small (measured floc diameter was 40–70 μm). The smaller floc size is very typical for MBR plants (Manser et al. 2004). Furthermore, we observed some typical bridging effects between the flocs. The dominant filamentous organisms were Filament type 0092 and to a minor degree Nocardia and Filament type 0041. Type 0092 is frequently found in wastewaters with high concentrations of grease and oxygen concentrations below 2 mg/L (Kunst et al. 2000).

The amount of nitrifiers were quantified by analysing 25 sludge samples using FISH technology (Figure 2). The measured proportion of nitrifiers was between 4.4 and 12.7% of the total biomass. This finding is comparable with results from other studies (e.g. Carvalho et al. 2006).

Energy consumption and costs

At the average flow rate (108 m³/d) the specific energy demand of the entire MBR scheme (wastewater plus exhaust air treatment) was about 4.0 kWh/m³. Particularly important is that the optional exhaust air treatment had a very high energy demand of approximately 1.8 kWh/m³. Thus, the resulting specific energy consumption of the MBR itself was about 2.2 kWh/m³ (see Figure 3). With higher flow rates the specific energy consumption decreased to about 1.5 kWh/m³. This specific energy consumption is comparable with the typical energy demand of small municipal MBR in Germany (compare Engelhardt 2003; Stein & Kerklies 2005). As expected, the most relevant energy consuming components were the blowers in the aerated tank and in the filtration tank (cross-flow aeration). The specific energy consumption can be optimized by increasing the filtration flux and by reducing the intensity of cross-flow aeration. The treatment costs for the MBR treatment (including exhaust air treatment) are approximately 4.10 €/m³ including all capital and operating costs.

Table 4 | Performance of the MBR: microbiological parameters

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<thead>
<tr>
<th></th>
<th>Raw hospital wastewater</th>
<th>After MBR treatment</th>
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<tbody>
<tr>
<td></td>
<td>N</td>
<td>Median MPN L⁻¹</td>
</tr>
<tr>
<td>E. coli</td>
<td>6</td>
<td>13 × 10⁴</td>
</tr>
<tr>
<td>Enterococci</td>
<td>5</td>
<td>19 × 10³</td>
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Figure 2 | Fluorescent nitrifiers in activated sludge (FISH technology).
CONCLUSION

Hospital wastewater is comparable with ordinary domestic wastewater plus a very special mixture of different pollutants such as pharmaceuticals, heavy metals, detergents, X-ray contrast media and disinfecting agents. The present study proved that MBR technology is also a very efficient treatment approach for the treatment of such highly polluted wastewater from hospitals and comparable health care facilities. The investigated MBR operated very stable and required only little maintenance. Solids, carbon compounds, nutrients and bacteria are widely removed from the wastewater. As expected the decoupling of the rainwater drainage system has led to a more efficient treatment of the hospital wastewater. Only with regard to the sum parameter AOX the treatment performance was not satisfactory. However, the permeate was completely free of solids so that the most important prerequisite for further treatment for trace pollutants removal was fulfilled. Also worth mentioning is that within the MBR system a gradual treatment for trace pollutants removal was fulfilled. The permeate was completely free of solids so that the most important prerequisite for further treatment was fulfilled. Overall, the MBR technology can be recommended as suited (pre-) treatment solution for hospital wastewater.

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REFERENCES


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