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# Biological nutrient removal in an MBR treating municipal wastewater with special focus on biological phosphorus removal

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ABSTRACT

The performance of an MBR pilot plant for biological nutrient removal was evaluated during 210 days of operation. The set point values for the internal recycles were determined in advance with the use of an optimisation spreadsheet based on the ASM2d model to optimise the simultaneous removal of C, N and P. The biological nutrient removal (BNR) efficiencies were high from the start of operation with COD and N removal efficiencies of 92 ± 6% and 89 ± 7, respectively. During the course of the experiment P removal efficiencies increased and finally a P-removal efficiency of 92% was achieved. The activity of poly-phosphate accumulating organisms (PAOs) and denitrifying poly-phosphate accumulating organisms (DPAOs) increased and the specific phosphate accumulation rates after 150 days of operation amounted to 13.6 mg P $g^{-1}$VSS $h^{-1}$ and 5.6 mg P $g^{-1}$VSS $h^{-1}$, for PAOs and DPAOs, respectively.



## 1. Introduction

Membrane bioreactor (MBR) technology usually results in high quality effluents with low concentrations of organic matter and suspended solids (Judd and Jefferson, 2003), as well as in a near complete absence of (pathogenic) bacteria (Arrojo et al., 2005). Furthermore, MBR effluent presents a superior source for water reclamation, since prior to high-end use water reclamation a pretreatment with ultra-filtration membranes is required to protect the employed reversed osmosis membranes (Côté et al., 2004). Besides efficient organic matter removal, it was demonstrated that an MBR easily obtains efficient nitrogen removal, ascribed to the improved retention of nitrifiers and the prolonged sludge retention times (SRT) at which MBRs generally operate, provided that an anoxic zone for denitrification is present (Fleischer et al., 2005; Judd, 2006; Kubin et al., 2002; Monclús et al., 2010). In contrast, bioreactor operation at high SRT is usually characterised by a reduced biological phosphorus removal (Metcalf, 2003) as ultimately phosphate removal is the result of phosphate incorporation into new cell material and its wastage from the reactor.

Although, biological phosphorus removal requires principally different operational conditions than carbon (C) and nitrogen (N) removal, i.e. high biomass yields and short sludge retention times, its feasibility using MBR has been demonstrated (Lesjean et al., 2003). Successful biological phosphate removal in an MBR is ascribed to the development of poly-phosphate accumulating organisms (PAOs). The growth of PAOs is favoured in an MBR due to their competitive advantages over non-poly-P accumulating microorganisms to survive starvation periods, characteristic of an MBR operating at low F/M ratios (Yilmaz et al., 2008). Bacteria containing poly-P maintain for a longer time a high activity as a consequence of the accumulated energy.

The extended poly-phosphate storage capacity of specialized microorganisms used in wastewater treatment is known as enhanced biological phosphorus removal (EBPR). Poly-phosphate-accumulating organisms (PAOs) require anaerobic conditions in order to assimilate organic matter, such as volatile fatty acids (VFAs) (Puig et al., 2008), with the release of phosphorus from stored poly-phosphate. Phosphate is taken up, under aerobic conditions, by PAOs (Mino et al., 1998) as well as under anoxic conditions in the presence of nitrate by denitrifying-poly-phosphate-accumulating organisms (DPAOs) (Kishida et al., 2006; Mino et al., 1998; Wachtmeister et al., 1997). Thus, phosphate uptake occurs either under anoxic or aerobic conditions increasing phosphorus removal efficiencies. Unlike in processes employing sedimentation, the final separation phase in an MBR is aerated to reduce membrane fouling, which favours the overall P-removal efficiency as no P-release is expected during final effluent production. Furthermore, due to the complete retention of suspended

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solids, an MBR is capable of generating an effluent with total phosphorus ($P_T$) levels lower than a conventional enhanced biological phosphorus removal (EBPR) process (Monti et al., 2006).

A pre-requisite for efficient BNR is, therefore, the presence of anaerobic, anoxic and aerobic zones, for which the University of Cape Town (UCT) configuration (Vaiopoulou et al., 2007) was adopted in this work. The UCT process configuration is a typical single-sludge system, in which the sludge is recycled to the anoxic tank and the mixed liquor is continuously returned from the anoxic to the anaerobic compartment. This paper reports the BNR performance using a pilot plant MBR with UCT configuration in the treatment of raw municipal wastewater, with special focus on biological phosphorus removal.

## 2. Methods

### 2.1. UCT–MBR pilot plant

The pilot plant MBR is equipped with a pre-screening system to prevent the entrance of large particles. The bioreactor with a total volume of 2.26 $m^3$ was designed according to the UCT configuration, i.e. the MBR consists of an anaerobic (14% of the total volume), an anoxic (14%) and an aerobic compartment (23%), that are ultimately followed by a compartment (49%) with submerged hollow fibre membranes. The used microfiltration membranes with a total membrane area of 12.5 $m^2$ (Microza™, Asahi Kasei Chemicals Corporation, Tokyo, Japan) are characterised by a nominal pore size of 0.1 μm. A schematic representation of the used pilot plant MBR is shown in Fig 1.

Total suspended solids (TSS) sensors (Solitax; Hach Lange, Düsseldorf, Germany) are installed in the anaerobic and membrane compartments. The anoxic reactor is equipped with an oxidation reduction potential (ORP) sensor (Alldos, Reinach, Switzerland). The anaerobic and anoxic compartments are supplemented with a mixer. In the aerobic reactor a pH sensor (ProMinent, Heidelberg, Germany) is installed. Furthermore, in the aerobic and membrane compartment combined dissolved oxygen (DO)-temperature sensors (Crison, Barcelona, Spain) are installed. The temperature is on-line registered and used to determine the permeability corrected by temperature. The membrane compartment also contains an ammonium sensor (Hach Lange, Düsseldorf, Germany). In the aerobic reactor a PID controller maintains the DO at 1.5 mg $L^{-1}$ using two membrane air diffusers (Supratec, Simmern, Germany). The pilot plant is, further, provided with a Programmable Logic Controller (PLC) and Supervisory Control and Data Acquisition (SCADA) system that acquires digital and analogical data and controls all the automatic control loops of the plant, i.e. aeration, permeate and backwash fluxes, hydraulic retention time (HRT), sludge retention time (SRT), mixed liquor suspended solids (MLSS) concentration and recycle flows.

The wastewater is obtained from the sewer that enters the full-scale wastewater treatment plant at Castell d'Aro (Catalonia, Spain) where the pilot MBR is located. The wastewater, after passing a first coarse screen (5 cm), is pumped to the pilot plant with the use of a centrifuge pump (Grundfos, Bjerringbro, Denmark), crossing a 1 mm nominal pore size filter and stored in a 500 L buffer tank that is continuously mixed. From this buffer tank the wastewater is pumped to the anaerobic reactor with a positive advance pump (Seepex, Bottrop, Germany) passing a second filter with a nominal pore size of 0.6 mm to prevent large particles from entering the bioreactor and damaging the membranes. The pilot MBR treated raw municipal wastewater during the entire experi-

**Table 1**
Influent wastewater characteristics.

| Parameter | Units | Mean ($S_D$) | Max | Min |
|---|---|---|---|---|
| COD | mg COD $L^{-1}$ | 492 (179) | 912 | 184 |
| $BOD_5$ | mg $BOD_5$ $L^{-1}$ | 253 (79.1) | 430 | 238 |
| TKN | mg TKN-N $L^{-1}$ | 53.5 (16.5) | 73.4 | 19.1 |
| $NH_4^+$ | mg $NH_4^+$—N $L^{-1}$ | 35.3 (11.4) | 59.9 | 14.0 |
| $NO_3^-$ | mg $NO_3^-$—N $L^{-1}$ | 0.18 (0.2) | 1.63 | 0.0 |
| $PO_4^{3-}$ | mg $PO_4^{3-}$—P $L^{-1}$ | 4.0 (2.14) | 6.49 | 2.54 |
| C/N/P ratio | | 100/11/0.81 | | |

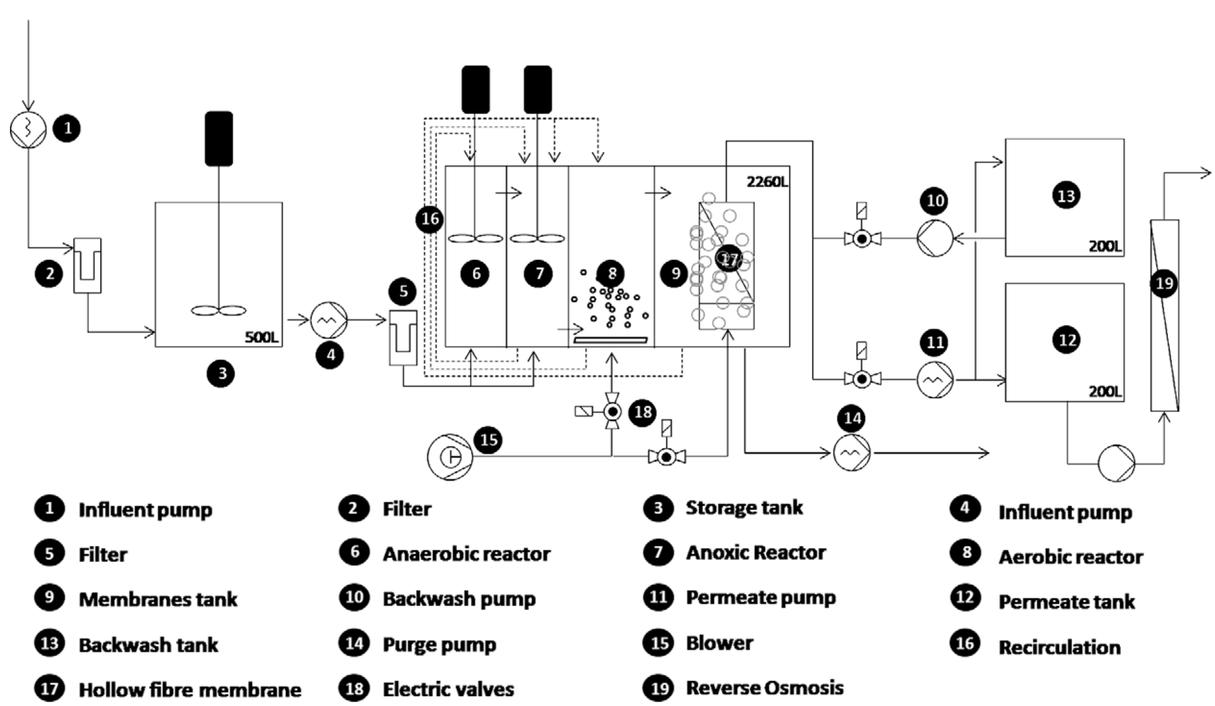


**Fig. 1.** Scheme of the UCT–MBR pilot plant showing the different compartments, flow directions and main instruments and equipment.