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Biological nutrient removal in a small-scale MBR treating household wastewater

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A B S T R A C T

The biological nutrient-removal potential of an on-site Membrane bioreactor (MBR) located in the basement of a four-person house treating domestic wastewater was investigated. The reactor consists of two tanks in series. This treatment plant differs from other conventional MBRs by a highly fluctuating influent water flow and a lack of pretreatment. During the first period, the first reactor was operated as a primary clarifier, resulting in nitrogen and phosphorus removals of 50% and 25%, respectively. Primary sludge production and bad odors in the basement were further disadvantages. When using the first reactor as an anaerobic/anoxic reactor by recycling activated sludge and mixing the first reactor, nitrogen and phosphorus removals of over 90% and 70% were achieved, respectively. By applying a dynamic model of the plant, the return sludge ratio was identified as the most important parameter. With a return sludge ratio of about 1.2, optimal PAO growth and phosphorous removal up to 90% was reached. Since only activated sludge is produced with this operational mode, on-site sludge dewatering is possible. During vacation periods without loading, the Bio-P activity is kept constant if the aeration is reduced to 5–20 min d^{-1}.

1. Introduction

The purification capacity of small-scale wastewater treatment plants (WWTPs) for the two nutrients nitrogen and phosphorus is often limited. Nitrification and denitrification may occur to a certain degree in biological systems, depending on the plant layout and the operating conditions. In contrast, phosphorus is only removed to a substantial extent with the aid of chemical precipitation.

Table 1 compares removal efficiencies of different treatment systems with a central WWTP. These values were estimated by Swiss experts based on measurements in several small-scale treatment plants (VSA, 2005).

Flasche (2002) estimates that the 10% of the population connected to small-scale WWTPs in Lower Saxony (Germany) account for 20% of the organic and nitrogen loads in domestic wastewater, assuming that the plants are maintained and operated properly. In reality, this value is expected to be much higher.

Since decentralized wastewater treatment is seen as a possible future technology allowing the sanitation requirements to be met (Green and Ho, 2005; Wilderer, 2005), nutrient removal in small-scale plants should move into the focus of research interest.

The optimum technology and plant size will depend on the specific circumstances of each site. However, membrane bioreactor (MBR) technology may be of interest for small-scale wastewater treatment (Fane and Fane, 2005). Thanks to their small reactor size and good effluent quality, which makes the effluent available for reuse, MBRs are an attractive option for decentralized sites. Nutrient removal in (decentralized) MBRs has been studied by several researchers who showed that high levels of both nitrogen and phosphorus removal can be achieved by

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Table 1 – Removal efficiencies for several small-scale wastewater treatment plants, compared with the WWTP Werdhoelzli, Zurich

	COD removal (%)	N removal (%)	P removal (%)	Source
Septic tank	20–30	0–10	10	VSA (2005)
SBR	>90	10–70	10–70	VSA (2005)
Trickling filter	>90	10–40	10	VSA (2005)
Reed bed	>80–90	10–90	10–60	VSA (2005)
Sand filter	>80–90	10–20	10	VSA (2005)
WWTP	95	60	90	Plant data

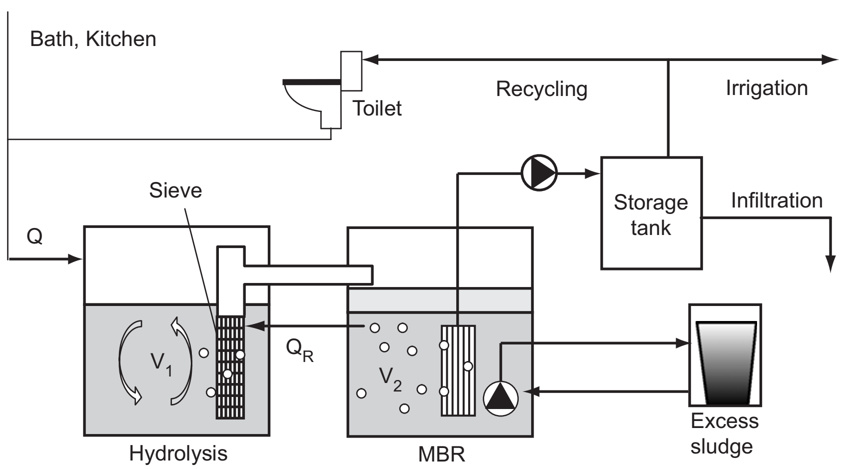

Fig. 1 – Modified flow scheme with hydrolysis chamber. During operation with the primary clarifier, no sieve and return sludge pump were in operation and the first reactor was neither mixed nor aerated.

biological means (e.g. Ahn et al., 2003; Lesjean et al., 2005; Monti et al., 2006; Patel and Nakhla, 2006). However, all these reactor systems are adaptations of the conventional activated sludge system: they rely on continuous water flows and pretreatment (e.g. screen), and they are designed for 100–1000 PE.

Conventional reactor designs cannot be applied on a household scale for several reasons: water flows are subject to high fluctuation, the reactor size needs to be designed for buffering the water flow and it is difficult to implement clearly defined environmental conditions in every part of the plant. Operating stability, maintenance requirements and soft factors such as noise and odors also need to be considered.

In this study, we investigated the operation of a two-chamber MBR used to treat the domestic wastewater of a four-person household. Two reactor configurations were compared with respect to their operational stability and nutrient removal. The configurations studied included a primary clarifier in the first reactor followed by an MBR in the second reactor for the first period, and an anaerobic/anoxic reactor followed by an MBR for the second period.

2. Material and methods

2.1. *Wastewater treatment plant*

The treatment plant is located in the basement of a four-person household in Switzerland. All the wastewater produced within the building flows through the treatment plant. The effluent is stored in a tank outside: 35% of it is recycled for toilet flushing and irrigation, while the rest is percolated.

The plant consists of two reactors each with a volume of 1.5 m^3 (Fig. 1). A flat-sheet membrane (4 m^2, 0.04 μm pore size) with coarse bubble cross-flow aeration is installed in the second reactor. Oxygen is supplied by fine bubble aeration.

The first tank was initially used as a primary clarifier and subsequently as a biological reactor. During the second period, the sludge from the MBR was pumped to the first tank by an airlift pump. Excess sludge is pumped to a filter bag outside the building at intervals of 1–2 weeks.

2.1.1. *Operation with primary clarifier*

The first reactor was initially used as a sedimentation tank. A baffle with an opening at the bottom was installed in the middle of the reactor to prevent short circuits. The hydraulic retention time was approximately 3 d. This led to an equalization of the pollutant concentration. A stable, malodorous sludge blanket formed within a short time. The primary sludge was removed when the operational mode was changed.

2.1.2. *Operation with sludge recycling*

The first reactor was retrofitted for several reasons: bad odors, limited nutrient removal and primary sludge production. In order to overcome these disadvantages, mixing between the