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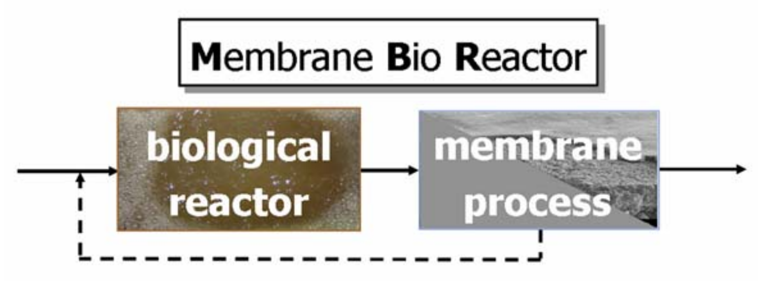

Greywater Treatment with Membrane Coupled Biological Processes

René Gildemeister (TU-Berlin), Matthias Kraume (TU-Berlin)

Abstract
Greywater reuse will play an important role in the sustainable water management approach. Depending on its intended use different treatment technologies are needed. This paper focuses on the membrane coupled biological processes like membrane bioreactor (MBR) or submerged membrane sequencing batch reactor (SM-SBR) processes. First analyses with a 30L SM-SBR treating synthetic greywater show a good performance under different boundary conditions, e.g. varying cycle times as well as the volumetric exchange ratio (VER).

Introduction
Wastewater generated by bathtubs, showers, bathroom sinks, and washing machines are consistently defined as sources of greywater in the literature. Wastewater from kitchen sinks and dish washing machines might be sometimes included, called “dark grey water”, but with a high potential to introduce microbial contaminants and/or oils and greases that would negatively impact the receiving treatment system.
Greywater treatment with membrane coupled systems can be either of physical or biological nature. Purely physical separation simply holds back the hazardous substances of greywater due to the membrane discharging a clean effluent. The polluted concentrate is collected and treated in a further step sometimes together with a different wastewater (blackwater). The biological treatment reduces degradable organic matter measured as the chemical oxygen demand (COD) and the amount of nutrients.
Within the last 20 years, biological treatment of wastewater coupled with a membrane separation unit (Figure 1) has come out of research into full scale application plants. It is an accepted and more and more used treatment technique for decentralised solutions ranging from small domestic implementations (family houses) up to wastewater treatment plants in municipalities with 80,000 inhabitants, equal to an amount of 48,000 m^3/d (WWTP Nordkanal, Germany), as well as specialised industrial use [9]. In contrast to its big advantages of a small footprint and very good effluent quality stands its disadvantages of short membrane life time (up to 8 years [3]) and high membrane costs. A recent study shows that at a wastewater flow greater than 5,000 m^3 MBRs needs lower investment capital as well as lower operation and maintenance costs compared to the conventional activated sludge treatment [3].
Within the Zer0-M project greywater treatment with a membrane coupled biological treatment is going to be investigated and monitored for its applicability in our Mediterranean partner countries. Although membrane bioreactors (MBR) are a high-tech application, they are anywhere suitable where space is of big concern, e.g. in hotels in tourism centres. The reuse of treated greywater plays a significant role in the sustainable water management approach, as the low polluted greywater (COD ~ 200 mg/L) represents 70% of the domestic water flow rate. Especially in regions where water restrictions are a severe problem, and water supplies are rapidly declining the utilisation of drinking water for toilet flushing seems to be inappropriate. Society has to become aware of efficient and appropriate water (re)use. Examples of such ‘demand side management’ improvements include the use of water saving

devices (faucets, showers, toilets etc), segregation of wastewater streams, and as already mentioned the reuse of greywater. [12], [1]

Sources, Characteristics and Treatment of Greywater

The characteristics of greywater vary regionally and over time. Three factors significantly affect greywater composition: “water supply quality, the composition of the system that transports both gray and drinking water, and the activities in the house” [4].
Depending on the final use of greywater different treatment technologies are needed, in order to remove substances “which may be harmful to

- plants,
- health,
- the wider environment” [1].

Usually simple treatment systems for the purpose of landscape irrigation, like sand/gravel filtration or settlement and flotation are operated to prevent clogging of the distributing system. A more sophisticated design is needed, if the treated water is used “in-house”, e.g. for toilet flushing. A disinfection step is added to remove microbial contaminants since the potential for human contact is greatly increased in these applications. [14]
Treating greywater with an MBR goes one step further. On a very small footprint hygienically acceptable water is produced. Its application can be seen in hotels of water scare tourism areas to save valuable drinking water due to the reuse of greywater from showers, and where else a high effluent quality is needed.

Applications

As shown in Figure 1 three different types of greywater treatment systems combined with membranes are available. On the one hand there is the pure physical separation of pollutants and water. If used e.g. in cruise ships permeate will be disposed into the sea; the organic fraction is not decreased and accumulates in the concentrate which then is treated with the blackwater in an MBR [13]. On the other hand there are systems of membrane coupled biological reactors. Here the organic matter of the feed flow is reduced due to the activities of microorganisms. It also facilitates good removal of pathogens. Running the system with low sludge loading rates, greywater is needed more for metabolism than growth of bacteria, producing a low amount of excess sludge.

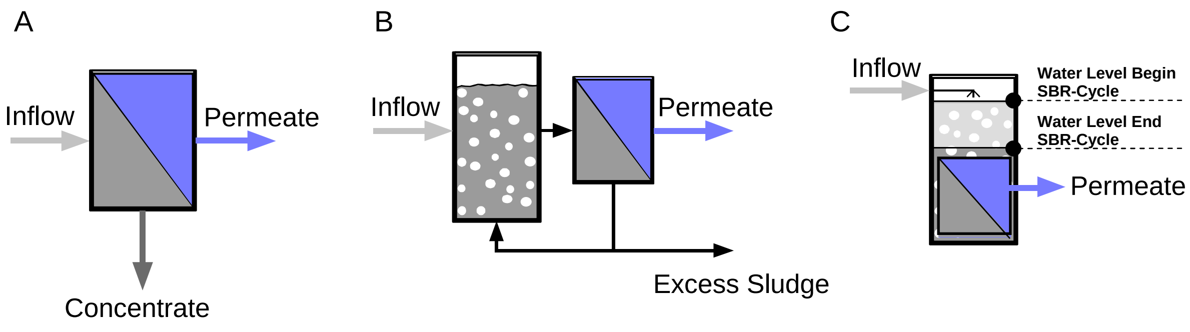

Figure 1: *Greywater treatment systems combined with membranes*
A: *Physical Separation;* ***B:*** *MBR;* ***C:*** *SM-SBR*

Looking at Figure 1c, the SM-SBR process eliminates the restrictions of a simply SBR process, because the effluent quality of an SBR process depends on its sludge settleability and its decanting facility. Several more advantages of the SM-SBR can be outlined:

- Reduction of the cycle time through partly simultaneity of biological degradation, solids settlement, and withdrawal;
- Increase of the MLSS concentration and thus reduction of the reactor volume;
- Improvement of the effluent quality through complete solids retention (including germs);

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- Simple modification of process conditions dependent upon influent characteristics or effluent objectives → additional controlling needed;
- Possible reduction in operational cost;
- Improved process control leading to good nutrient removal;
- No entrainment of oxygen from pre-denitrification (as in MBR).

The membrane coupled SBR therefore can be technically and economically viable for application to greywater reuse. [2], [10], [7]

Experimental Setup

In the Department of Chemical Engineering at the TU Berlin investigations were carried out using a 29L bioreactor (see Figure 2) with a submerged plate and frame module (A3 GmbH) comprising twelve elements with a total membrane area of 0.38 m². The main goal is to minimise operational cost by optimised biological performance towards COD- and nitrogen removal. Permeate was removed using a peristaltic pump. The reactor volume was controlled by pressure transducers and together with the information from the probes (DO, pH and Redox-potential) recorded directly on a computer. Air was introduced through a fine bubble membrane diffuser (ENVICON GmbH) and controlled via a needle gauge. For complete mixing during the anoxic phase a stirrer was used. The process was automatically controlled using a programmable logic controller (PLC; Siemens – LOGO 12/24 RC). The solid retention time can be set > 500 d, because no biomass was taken out, except for sampling.

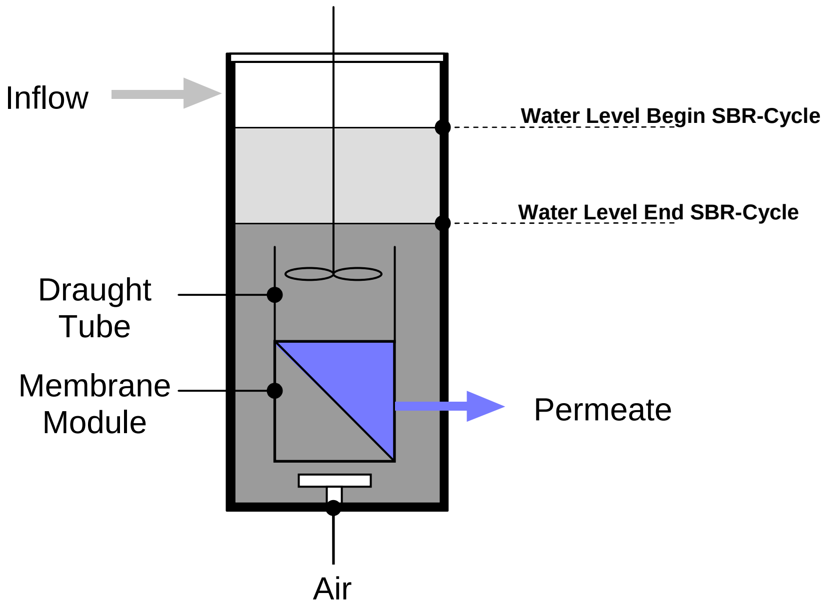

Figure 2: *Scheme of biological reactor*

The cycle time for the experimental set-up varies from 60 to 90 min for the anoxic/anaerobic and 180 min to 300 min for the aerated phase. The filling takes only 2 min at the beginning of the anoxic phase and can be therefore neglected. The air flow rate is set at 260 L/h, mainly for a sufficient shear stress on the membrane. The volumetric exchange ratio (VER) is the volume taken out divided by the total rector volume, and is held so far at either 0.3 or 0.5.

The biomass was fed with synthetic greywater. The recipe was adapted from literature [6], [8] to represent a family household. The produced greywater concentrate was diluted to a COD of near constant 200 mg/L, as a typical value for that parameter [5]. To evaluate the biological performance, detailed cycle analysis have been carried out, measuring beside

COD also TN, NO_3-N, NO_2-N, NH_4-N and PO_3-P. Online data are available for pH, Redox and DO.

Results and Discussion

The reactor has been operated for seven month continuously without any major failures. First investigations on membrane behaviour were needed to determine the critical flux, important for the aerated cycle length. The critical flux was tested for t_{cycle}=4.5 h and a VER=0.5 and resulted in the flux of approximately 13.5 L/(m*h), when MLSS concentration was at 3500 mg/L. For working under sub-critical conditions the flux was hold between 9 and 12 L/(m*h) to minimise the fouling effects on the membrane.
Besides the membrane behaviour it is important to know its biological performance concerning COD and Nitrogen removal. Therefore the reactor worked with different boundary conditions as

- VER;
- cycle times for anoxic and aerated phase;
- and feed concentrations

were varied. As can be seen in Figure 3B, a decline in total nitrogen (TN) was achieved, resulting in a removal of ~50% for a VER = 0.5 up to 80% for a VER = 0.3. The COD removal went from 50% up to 85%, depending on the feed concentration, with a final value in the range of 20 to 30 mg/L. For a higher feed COD, the better removal rate was reached. In figure 3A, it's shown the online available data (dissolved oxygen – DO, pH and redoxpotential), recorded in a time step of 1s.
An observed increase in MLSS concentration is due to the accumulation of non hydrolysable substances, e.g. from particles within the toothpaste. The VSS/SS ratio went down from 60% to a low value of 35%. That means the active biomass stays nearly constant at a value of 900 to 1100 mg/L, depending on the feed concentration. To use the advantage of membrane coupled systems, the sludge loading rates should be increased by minimising the cycle time. Bacterial growth than has be expected.

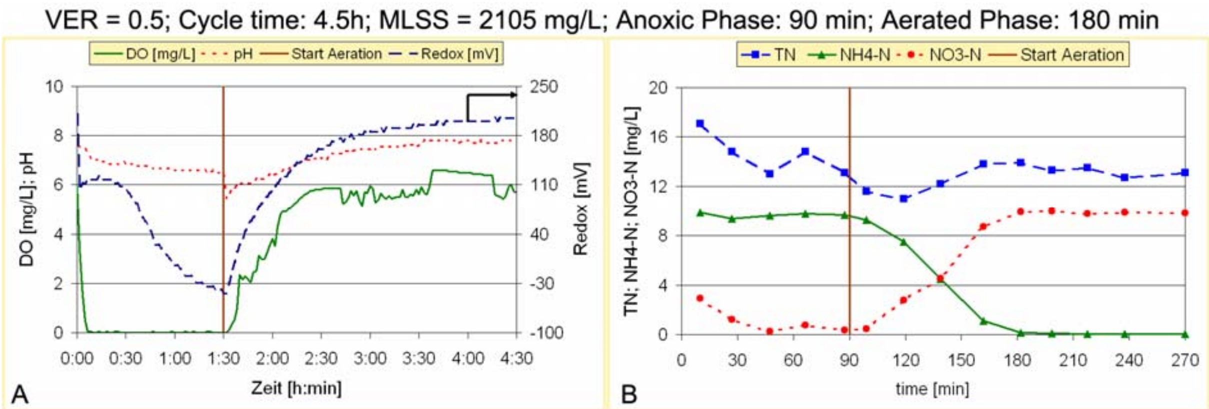

Figure 3: *Biological performance of one cycle*
A: Online-data; B: Experimental results

Conclusion

The SM-SBR system is suited for domestic greywater treatment. Biological performance analysed is consistent to their corresponding boundary conditions throughout the operating period. The poor nitrogen removal has still to be optimised. Also the water quality is in the range for irrigation purposes [11], which means values for nitrate are under or around 10 mg/L. The constant increase in sludge due to accumulation of non-biodegradable substances asks for a smart sludge management, i.e. a reduction of the amount. Additionally a cleaning of the membrane should be done at least 2-3 times a year. Compared to other technologies, like constructed wetlands, the membrane coupled systems need less space for the same greywater flow rate. It also saves the additional disinfection step.

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Mention of Author

Dipl.-Ing. René Gildemeister is scientific co-worker at the Department of Chemical Engineering, Technische Universität Berlin, Germany; Email address: rene.gildemeister@tu-berlin.de
Prof. Dr.-Ing. Matthias Kraume is head of the Department of Chemical Engineering, Technische Universität Berlin, Germany