Membrane bioreactor technology for the treatment of greywater from a sports and leisure club

Merz, Cornelia[1], Scheumann, René[1*], El Hamouri, Bouchaib[2] and Kraume, Matthias[1]

[1]Department of Chemical Engineering, Technische Universität Berlin, Germany
[*]corresponding author: TU Berlin, FG Verfahrenstechnik, ACK 7, Ackerstr. 76, 13355 Berlin, Tel.: +49 30 314 72731, email: rene.gildemeister@tu-berlin.de
[2]Department of Rural Engineering, Institut Agronomique et Vétérinaire Hassan II, Rabat, Morocco

Abstract
Especially in the Mediterranean region water is a scarce resource and new approaches to water supply need to be focused. An important contribution can be realised by greywater recycling in decentralised structures. This paper describes the results of a technical feasibility study to treat greywater with membrane technology in view of its reuse for applications which do not require potable water quality. A 3L-lab-scale membrane bioreactor (MBR) treating the shower effluent from a sports club in Rabat, Morocco, was operated with a hollow fibre membrane (Zeeweed, Zenon) for 137 consecutive days. Removal performance and membrane behaviour were assessed. The permeate was of excellent quality and complied with commonly proposed standards for domestic reuse except for bacterial contamination. Non-detectable levels of faecal coliform could not be continuously guaranteed due to bacterial re-growth in the permeate pipe from the open permeate storage tank.

Keywords: membrane bioreactor, greywater, shower effluent, sports club

Introduction

In recent years, membrane bioreactor (MBR) technology has gained popularity in wastewater treatment and especially for decentralised and reuse applications [1 – 4]. The technology consists of a compact unit which combines activated sludge treatment for the removal of biodegradable pollutants and a membrane for solid/liquid separation. MBRs have a small footprint making them attractive where space is limited and water treatment for internal recycling is desirable, e.g. for buildings (equipments being generally located in the cellar) or on ships. Further advantages of the system are the high quality of its effluent. However, investment and operational costs are high. Such high-tech solutions are normally too expensive for developing countries so that potential benefits have to be precisely evaluated.
This paper describes the attempt to treat the greywater effluent from the showers of a sports and leisure club in Morocco with an MBR.

Materials and methods

Raw greywater

Greywater was received from the showers of the sports and leisure club of the "Association Culturelle et Sportive de l'Agriculture (ACSA)" located next to the campus of the Agronomic and Veterinary Institute Hassan II in Rabat, Morocco [5]. The composition of this raw greywater is listed in Table 2 and was comparable to that found in other studies where kitchen effluents were not included [2].

Water analyses

Analyses were performed from February to May 2006. The average values presented in this study were calculated as an arithmetic mean of the data collected at the different sampling dates. The standard deviation is indicated as ±x. All analyses except for nitrate determination were performed following Standard Methods [6]. Nitrate was determined according to Rodier [7]. For the determination of BOD_5 nitrification was not inhibited. Anionic surfactants were determined as methylene blue active substances using dodecyl sodium sulphonate (molecular weight = 288.38gmol^{-1}) as standard.

3L-lab-scale MBR

A 3L-lab-scale MBR (Figure 1) with a hollow fibre UF-membrane, type ZeeWeed by Zenon, was continuously operated for 137 days. The submerged membrane module had a membrane area of 400cm².

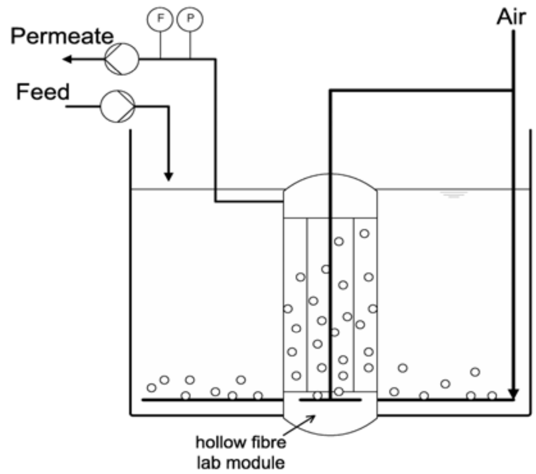

Figure 1. 3L lab-scale MBR, operated in the IAV laboratory

The MBR was operated in a cycle of 45 minutes of permeation phase and 15 minutes of relaxation phase. For permeation a peristaltic pump (Minipuls 2, Gilson) was used.
The reactor was fed quasi-continuously by a membrane pump (Prominent Electronic, CfG) to maintain a constant volume of 3 liters. The transmembrane pressure (TMP) was measured with an analogue precision manometer (WIKA, display accuracy +-0.1%, scaling 0.01). It was adjusted not to exceed 400mbar. Table 1 shows the operating parameters of the lab-scale reactor.

Table 1. Operating parameters of the lab-scale MBR

Operating Parameters	Average	Maximum	Minimum
Hydraulic retention time (h)	13	18	9
Membrane area (cm²)	400	-	-
Pore size (μm)	0.1	-	-
Transmembrane pressure (mbar)	249	402	73
Flux (Lm^{-2}h^{-1})	8	11	7
MLSS (mgL^{-1})	1.30	0.42	1.85
MLVSS (mgL^{-1})	0.94	0.26	1.32
Organic loading rate (kgCODm^{-3}d^{-1})	0.16	0.21	0.09
Feed/Biomass (mgCODd^{-1}g$_{VSS}$$^{-1}$)	256	390	118

Before entering the MBR, the raw greywater was passed through a 1cmx1cm and a 1mmx1mm screen successively.

To achieve oxygen saturation and complete mixing in the reactor, compressed air was continuously supplied at a flow rate of $0.32 m^3h^{-1}$. It was partly introduced from the bottom of the membrane to enhance membrane cleaning. To prevent bacteria from adhering to the reactor wall and settling in its edges, an aeration pipe was placed on the bottom around the reactor perimeter. During the reported period the reactor temperature increased from 9 to 20°C. The pH lay in the range of 7.6±0.4.

Results and discussion

Analytic parameters

Table 2 summarises influent and effluent characteristics as well as overall removal performance. The influent from the showers showed an average COD-concentration of $109 mgL^{-1}$ and daily peak loads did not exceed $170 mgL^{-1}$. Hence, it can be said that this greywater was highly diluted. Similar values have been reported for a shower effluent of a students residence in Tunisia where a mean COD of $102 mgL^{-1}$ and a mean BOD_5 of $56 mgL^{-1}$ were found [9]. Remarkably, the ratio COD/BOD_5 was very low with values between 1.1 and 2.0 which indicates high biodegradability. In literature values up to 4 are reported [2, 3].

Table 2. Greywater characteristics, incl standard derivation, and removal performance of the 3L MBR

Parameter	Influent	Permeate	removal [%]
pH	7.6±0.4	7.9±0.4	-
EC (μScm^{-1})	645±67	711±130	-
DO (mgL^{-1})	0.4±0.2	8.4±0.3	-
Turbidity (NTU)	29±11	0.5±0.3	98
COD (mgL^{-1})	109±33	15±11	85
BOD_5	59±13	4±1.2	94
TKN (mgL^{-1})	15.2±4.5	5.7±1.9	63
NH_4^+ (mgL^{-1})	11.8±4.2	3.3±2.9	72
NO_3^- (mgL^{-1})	0.0±0.0	2.1±2.5	-
Total phosphorus (mgL^{-1})	1.6±0.5	1.3±0.4	19
PO_4^{3-} (mgL^{-1})	1.0±0.4	0.9±0.2	4
Surfactants (LAS, μgL^{-1})	299±233	10±5	97
Faecal Coliforms $((100mL)^{-1})$	$1.4*10^5 \pm 1.1*10^5$	68±120	99

EC: electrical conductivity; DO: dissolved oxygen; TKN: Total Kjeldahl Nitrogen

Treatment in the MBR reduced the COD-load on average by 85% and a mean effluent concentration of $15 mgL^{-1}$ was obtained (Figure 2). The COD/BOD_5-ratio in the permeate reached values up to 25 indicating that BOD_5 was almost completely removed.

Temperature and biomass concentration did not have a marked influence on removal performance (day 40: removal 86% at 11°C and $0.4 g_{VSS}L^{-1}$; day 137: removal 88% at 20°C and $1.4 g_{VSS}L^{-1}$).

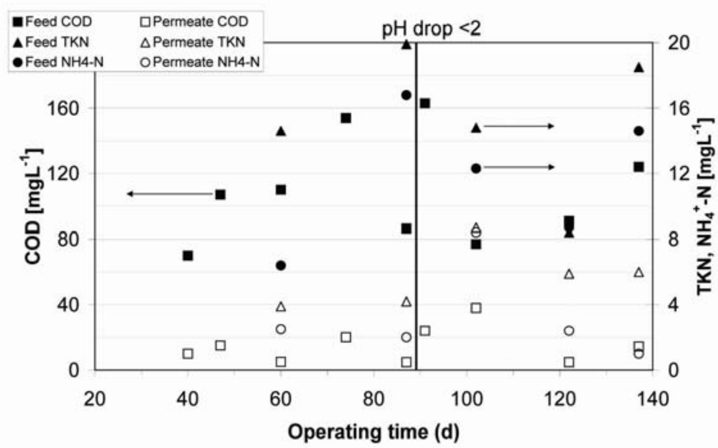

Figure 2. COD & Nutrient concentrations in the 3L- MBR

During the reported period the fraction of ammonium to total nitrogen (TKN) in the influent increased from 44 to around 80% and even reached 100% on day 122 (Figure 2). This is explained by the rising temperature, which allowed a faster degradation of organic nitrogen in the conveying pipe system.

In the permeate nitrate accounted for the difference between TKN and ammonium. Remarkably, in spite of the oxygen saturation and the high HRT, no complete nitrification was achieved in the MBR. The high ammonium percentage in the permeate on day 102 is explained by an accidental pH-shock (overnight drop to pH 2) on day 89. Apparently, it had a lasting effect on the nitrifying population so that even 13 days afterwards no nitrification could be observed and practically all nitrogen (97%) in the permeate was present as ammonium.

MBR-treatment increased the ratio of orthophosphate to total phosphorus by about 7%. The reactor was not optimised for phosphorus elimination and overall removal was low. Remarkably, the COD to nutrient ratio was favourable for biological treatment (100:14:1.5 COD:NH_3:P). Jefferson, 2000 [8] reported that ratios for greywater can reach up to 1030:2.7:1 compared to common values for domestic wastewater in the range of 100:5:1.

Anionic surfactant concentration was reduced by 97% to a concentration of 13μgL^{-1} in the permeate.

Suspended and colloidal matter were retained by the membrane and permeate dissolved oxygen concentration (near saturation) indicated that bacterial activity in the permeate was very low. Thus the effluent was very clear (turbidity <1NTU) and completely free from odours.

Bacteriological Contamination

The membrane pore size of ZeeWeed membranes is approximately 0.1μm so that most bacteria and particularly faecal coliforms should be retained. However, in the first analysis after 60 days of operation, a concentration of 2log units per 100mL was detected as shown in Table 2. Visibly, a biofilm (algae, bacteria) had developed inside the suction pipe of the permeate pump. To remove it in order to confirm membrane tightness for bacteria a disinfection of the permeate pipe and the membrane was carried out (3h chlorinated water, 3h only water with 10min backwash). Afterwards no bacteria were detected for 37 days. On operating day 122 analysis revealed the presence of bacteria, but no faecal coliforms were detected. Further evolution has to be followed closely in order to assess the possible appearance of faecal coliforms.

The presence of bacteria in the permeate could be explained by protein migration which may facilitate the transport of faecal coliforms through the membrane and their subsequent regrowth in the distribution system as cited in [8]. Another hypothesis is that the permeate was accidentally contaminated by bacteria from the MBR as in the case of this study there was only a 1m distance between the reactor and the open permeate reservoir. This

explanation is supported by observations made at the Middle East Technical University in Ankara, Turkey.
The permeate characteristics in this study met commonly adopted standards regarding recycling for toilet flushing or other household uses, which do not require potable water quality [10, 12] (Table 3). When zero faecal coliform levels have to be guaranteed at all times, disinfection will most probably be necessary.

Table 3. Water quality standards for domestic wastewater recylcing (adopted from [12])

	Total coliforms (100mL)$^{-1}$	**Faecal coliforms (100mL)$^{-1}$**	**BOD_5 (mgL^{-1})**	**Turbidity (NTU)**	**pH**
US EPA		non detectable	10	2	6-9
EC bathing water directive	10000 (mandatory, m)	2000 (m)			6-9
Germany	500 (guideline, g)	100 (g)	20 (g)	1-2 (m)	6-9

Biomass development

The reactor was not inoculated for start-up. Over the first 80 days at a mean temperature of 13°C the bacteria showed a fairly constant growth rate of 19mgL^{-1}d^{-1} (Figure 3). In a study with synthetic greywater at the Department of Chemical Engineering at the Berlin University of Technology values between 20 and 25 mgL^{-1}d^{-1} were found at 15°C.

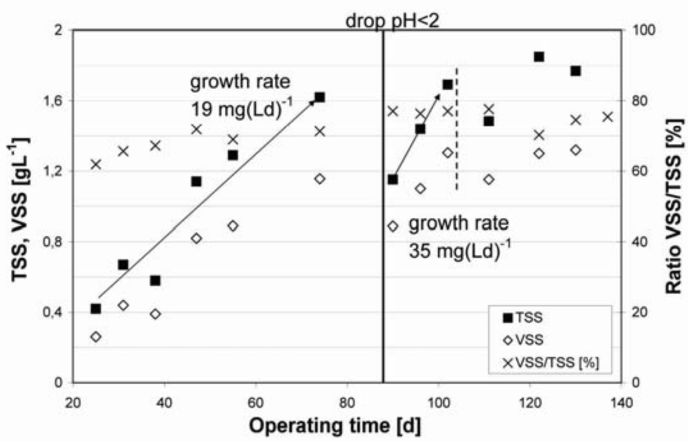

Figure 3. Evolution of total and volatile suspended solids in the MBR

After a pH-shock in the lab-scale MBR, which destroyed nearly 25% of the biomass, a quick recovery with a growth rate of 35mgL^{-1}d^{-1} was observed. One reason for the quicker development could be the higher average temperature (18°C) in the reactor, because the other conditions stayed constant. Another hypothesis is that due to the death of the slow growing nitrifiers a selection advantage for other faster growing organisms was given.
The mean specific growth rate lay around 0.03d^{-1} rising from 0.029d^{-1} to 0.032d^{-1} in the first and second period, respectively. Above 1.3 $g_{VSS}L^{-1}$ biomass stayed nearly constant. This indicates that at an average food to microorganism ratio of 0.12 $g_{COD}g_{VSS}^{-1}d^{-1}$ substrate was almost exclusively consumed by endogenous respiration. Average F/M-ratios for MBR treating municipal wastewater lie in the range of 0.34…1.41 $g_{COD}g_{VSS}^{-1}d^{-1}$ [11].
During the time of operation the suspended organic solids (VSS) increased due to biomass development, but their relative contribution to the total suspended solids (TSS) stayed almost constant. Figure 4 shows that after a slight initial increase the VSS/TSS-ratio stabilised at 76% indicating that about one fourth of the TSS in the reactor was particulate inorganic. No accumulation of external inorganic matter took place in the system, because the augmentation was due to particulate inorganics arising from biomass decay.

Flux and hydraulic retention time

Stable operation was achieved at a flux of $8Lm^{-2}h^{-1}$ (Figure 4) and $10Lm^{-2}h^{-1}$ were found to be above the critical flux. These values are at the lower end of reported literature data, because a lab-scale module was used in this study. In studies on municipal and domestic wastewater values for submerged membrane modules between 5 and $40Lm^{-2}h^{-1}$ are found [1].

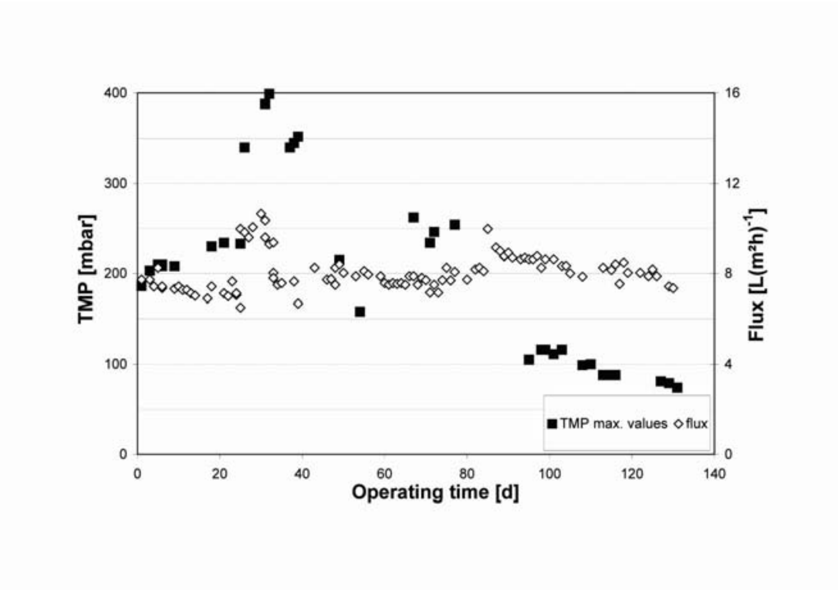

Figure 4. Flux, maximal TMP (=highest TMP in a cycle, i.e. after 45min of permeation)

The low flux may be explained by the fact that in the ZeeWeed membrane used in this study the hollow fibres were not flexible, and therefore not optimised for high fluxes. It gives mainly the ability to work with membrane in small batch vessels. In commercial modules fibres float in the current which creates a self-cleaning effect. Thus, working with such commercial membranes on pilot-scale would yield substantially higher fluxes.
The low flux led to an HRT of 13 h in steady state operation. Membrane cleaning with a chlorine solution provided only a short term of a reduced HRT = 11.3 h, but a dramatic reduction of TMP from 250 mbar down to 100 mbar. Although not shown in figure 4, the value is in the same range as in the beginning of this study, which is a month before day 0.
For economic reasons an increase of the flux is highly desirable. Removal performances of MBR treating domestic wastewater have been found to be quite independent of HRTs in the range of 2 to 24 h [1]. Hu [13] found an optimal HRT of only 1.5 h for greywater treatment with MBR.

Conclusion

This study demonstrates that MBR technology can be used to treat greywater with low COD- and low absolute nutrient content. With a ratio of 100:14:1.5 COD:NH_3:P the relative nutrient content was high in comparison to that observed by other authors.
The permeate characteristics met commonly adopted standards for recycling for toilet flushing or other household uses, which do not require potable water quality. To guarantee zero faecal coliform levels at all times, disinfection of the permeate is very likely to be necessary. The permeate was of excellent aesthetic quality and free from odours, a fact that is very important in view of public acceptance of treated water recycling.
An important drawback of MBR technology remains its high investment cost. If flux cannot be increased the required membrane area and associated costs will be high. Moreover, there is a need for power supply for aeration and mixing. However, in cases of space limitation like e.g. in hotels or leisure clubs, the small footprint of the MBR can outweigh these inconveniences.

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