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Membrane Bioreactor (MBR) Technology – a Promising Approach for Industrial Water Reuse

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Abstract

Membrane bioreactor technology (MBR) a combination of the activated sludge process with micro- and ultrafiltration is widely regarded as an effective tool for industrial water treatment and water reuse due to its high product water quality and low footprint. Due to their robustness and flexibility submerged MBR systems are more and more preferred. This paper highlights two case studies for industrial application in a commercial laundry and in a textile factory. A large-scale integrated water reuse process based on MBR+RO technology (capacity 200 m^3/d) has been designed and established in a German laundry within an EC funded project eventually resulting in a reuse ratio of around 80% of the total wastewater. The process was in full operation at the beginning of 2007 and has been operated economically since that time without any failure. Within another EC funded project a small-scale MBR (capacity up to 0.4 m^3/d) has been successfully tested in a Chinese textile factory. Despite high concentration of low biodegradable chemical in the wastewater, the COD removal rate achieved around 90%. However, the MBR permeate quality was not as high as in the laundry due to remaining colored dyestuff what makes an additional treatment step such as nanofiltration or reverse osmosis necessary in order to increase the proportion of reused water. In order to improve rejection of low molecular weight organics Karlsruhe University of Applied Sciences and the Institute of Membrane Technology have started a new EC funded project within a consortium of 11 partners in total which aims at developing novel membrane materials providing a basis for the development of a NF MBR reactor.

Keywords: industrial water reuse; membrane bioreactor, MBR, laundry, textily industry

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Nomenclature

BOD	Biochemical Oxygen Demand	SRT	Sludge Retention Time
COD	Chemical Oxygen Demand		
Flux	Permeate water flow per m^2		
HRT	Hydraulic retention time		
MLSS	Mixed Liquor Suspended Solids		

1. Introduction

Reuse and decentralisation will be essential for meeting human needs for water and sanitation in both developing and developed countries. Water resources management has become an important operational and environmental issue. Wastewater reclamation and reuse are effective tools for sustainable industrial development programmes. Increasingly stringent environmental legislation and generally enhanced intensity, efficiency and diversity of treatment technologies have made the reuse of water more viable in many industrial processes. Membrane bioreactor (MBR) technology is a combination of the conventional biological sludge process, a wastewater treatment process characterised by a suspended growth of biomass, with a micro- or ultrafiltration membrane system [1]. The biological unit is responsible for the biodegradation of the waste compounds and the membrane module for the physical separation of the treated water from the mixed liquor. The pore diameter of the membranes is in the range between 0.01–0.1 µm so that particulates and bacteria can be kept out of permeate and the membrane system replaces the traditional gravity sedimentation unit (clarifier) in the biological sludge process. Hence the MBR offers the advantage of higher product water quality and low footprint. Due to its advantages, membrane bioreactor technology has great potential in wide ranging applications including municipal and industrial wastewater treatment and process water recycling. By 2006, around 100 municipal full-scale plants (>500 p.e.) and around 300 industrial large-scale plants (> 20 m^3/d) were in operation in Europe [2]. The main industrial applications are in food and beverage, chemical, pharmaceutical and cosmetics, textile industry as well as in laundries. The technical feasibility of this technology has been demonstrated through a large number of small and large-scale applications [2-7].

In cases were only low/medium water quality is required MBR treated water can be directly reused as process water on industrial scale (e.g. as washing water). Moreover MBR technology is an excellent pre-treatment for a subsequent additional membrane treatment step if higher water quality is needed (nanofiltration, reverse osmosis). In doing so the water quality can be further enhanced. Generally water reuse on industrial scale depends on the specific processes and types of industry. Hence water treatment for reuse purpose needs to be tailored to the requirements in the particular application and besides treatment technologies the application of chemicals also needs to be adapted to the respective process.

2. Objectives

The objective of this paper is to highlight two case studies on integrated processes for industrial water reuse applying MBR technology. Firstly basic findings of a full scale combined MBR/RO water reuse system in a commercial laundry in Darmstadt, Germany will be reported. This project “Laundry innovative wastewater recycling technology” (LIWATEC) has been realized within an EC funded project in the LIFE programme [3,8,9]. In addition results of pilot trials will be summarized which were conducted in a Chinese textile factory in Changzhou within another EC funded project “Technology partnership for innovative treatment of drinking and industrial water (INNOWA) in the AsiaProEco programme [10]. Both case studies saliently demonstrate the potentialities and limitations of current MBR technology in industrial water reuse.

3. Wastewater reuse in a commercial laundry

This integrated process has been developed through cooperation between the Karlsruhe University of Applied Sciences and *Textil-Service Klingelmeyer*. Within the project, extensive research was undertaken to study membrane processes at bench and pilot scale in order to produce effluent suitable for direct reuse in the laundry [8,9]. The wastewater is treated in a two-step process and is recycled in the laundry´s washing and rinsing process (see Figure 1). After coarse screening using a vibrating sieve to retain suspended particles, the wastewater is collected in a storage tank (WW). Subsequently, the wastewater is treated in a membrane bioreactor as the principal cleaning unit. Air is injected into the reactor to scour the membranes and to drive the biological treatment. The microfiltration permeate is stored in a collecting tank (TWW). It is free of turbidity and considerably reduced in microbes. Some of the microfiltration permeate is treated in a second step by a low pressure reverse osmosis unit with spiral wound modules to retain salts as well as organic residues. The MF and RO permeates are mixed in a tank (MW) and are used for washing and rinsing. The ratio of mixing (RO permeate : MBR permeate) lies between 2:1 to 1:1 depending on the salt level of the MBR permeate. Prior to storage, the MBR and RO permeate is treated by a small amount of chlorine dioxide to prevent any growth of germs. Since rainwater does not meet the water quality criteria for the process, it is introduced in the wastewater collecting tank. The integrated process generates two kind of waste that needs to be disposed. The surplus sludge is stored in a separate tank and is collected by commercial waste management enterprises. The concentrate from the RO treatment is drained to the municipal treatment plant.

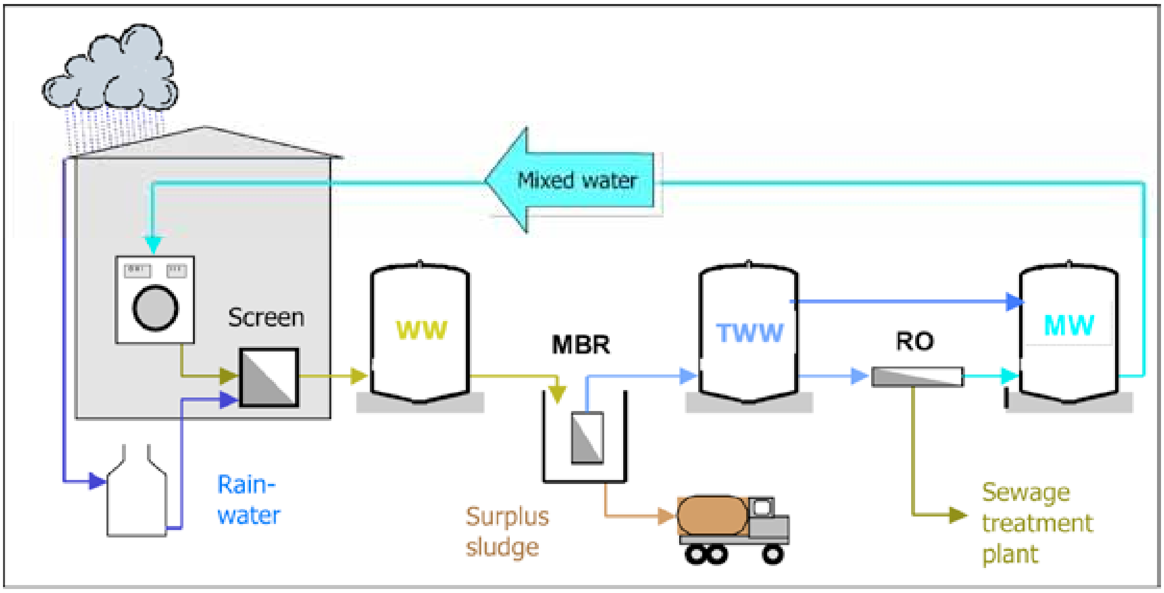


Fig. 1 Schematic of the water reuse process

3.1. Plant components

The large-scale unit are each basically composed of

- vibrating sieve (company Sweco) with mesh size 200 µm,
- MBR reactor,
- reverse osmosis filtration unit and
- three storage tanks (wastewater, MBR permeate, mixed MBR+RO permeate)

The MBR reactor contains submerged Kubota Type 510 microfiltration plate and frame membranes (single plate: 0.8 m^2) with 0.4 µm pore size, made of chlorinated polyethylene. The MBR tank has a total volume of 126 m^3. It is separated by a barrier in two compartments connected by a spill. One compartment is designed only for biodegradation, the other for biodegradation and membrane filtration; this gives maximum flexibility for adjusting aeration to the needs of the filtration and biodegradation process.

The biomass is circulated between both compartments every other day. The filtration compartment contains two double deck Kubota stacks System EK300 with 600 plate and frame modules (total membrane area of 480 m^2). The RO unit is fitted with six 8040 spiral wound modules (Dow LE-400). The plant is composed of three collecting tanks (wastewater, MBR drain, MBR+RO drain), the first with an enamelled steel collecting tank of 400 m^3 for the wastewater and additionally two 200 m^3 tanks for MBR drain and MBR+RO drain.

3.2. Results

The reuse process reached full operation at the beginning of 2007. The average flux was around 15 L/(m^2 h) at a permeability between 300-1000 L/(m^2 h bar) (see Fig. 2). After 1 year operation without chemical cleaning the flux lowered to 12 L/ (m^2 h) at an average permeability of 150 – 300 L/(m^2 h bar) as can be seen in Fig.3. Fig. 4 shows the COD values in feed and permeate as well as the elimination rate over more than 2 years of operation. The feed COD started at 600–800 mg/L and increased to more than 1000 mg/L whereas the COD in permeate remained at values below 100 mg/L and the elimination rate was higher than 90%. The aeration rate in the filtration compartment of the MBR tank was 5.2 m^3/min. The biodegradation compartment is intermittently aerated by a fine diffuser at 7.2 m^3/min. The flux rate does not represent full flow capacity; the plant has been designed for an eventual flux rate of 12–15 L/m^2 h. The Mixed Liquor Suspended Solids (MLSS) concentration in the reactor increased from 3 to 10-15 kg/m^3. The COD sludge loading decreased from 0.14 to 0.04 $kg_{COD}/kg_{MLSS} \cdot d$. The average yield factor for biomass growth is calculated to 0.13 kg MLSS per kg COD degraded. The surplus sludge is collected in a storage tank and delivered to a commercial sludge processing unit.

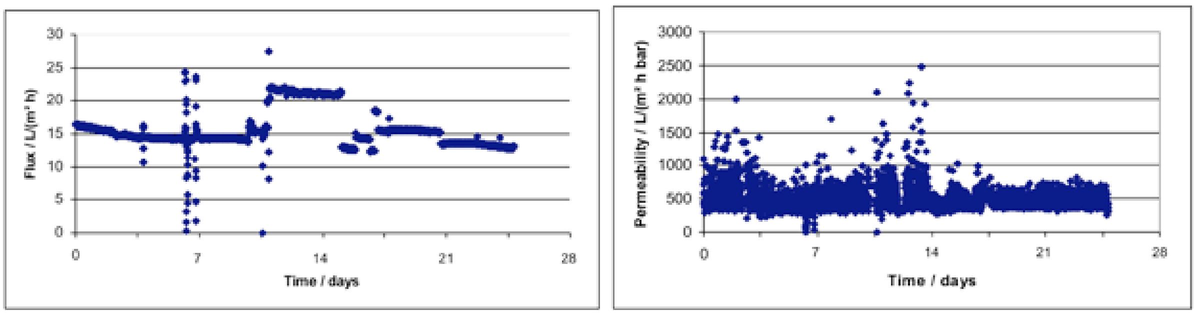


Fig.2 Permeate flux and permeability of the MBR treatment plant during typical operation period of 28 days after start up

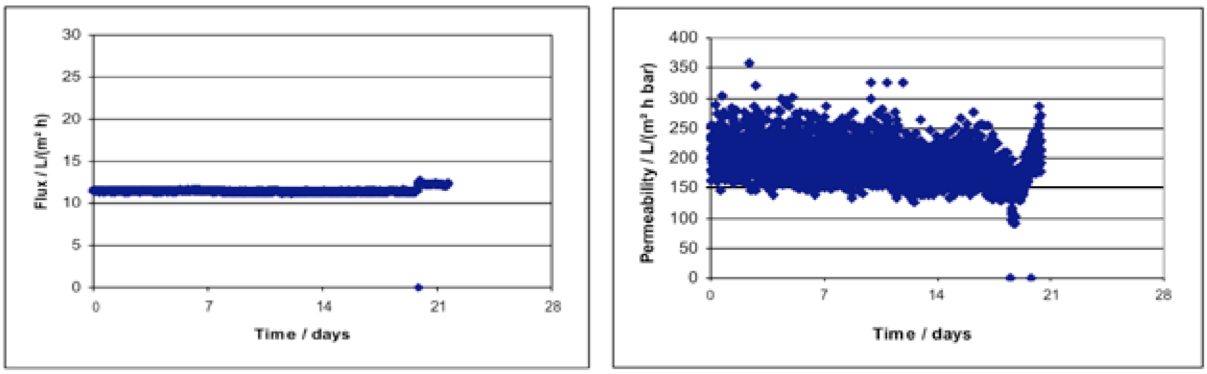


Fig.3 Permeate flux and permeability of the MBR treatment plant during typical operation period of 28 days after 1 year operation

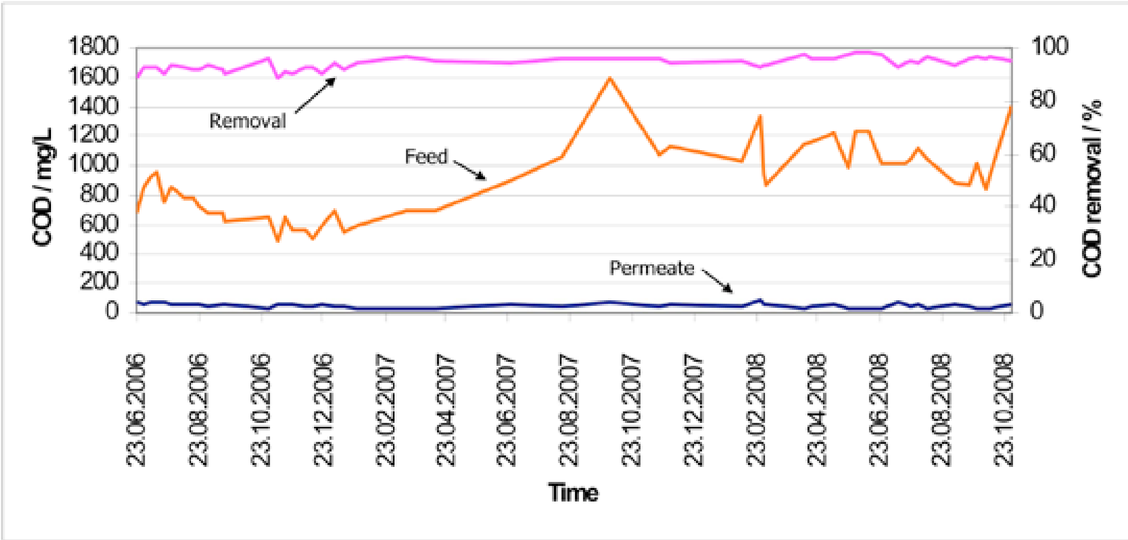


Fig. 4 COD values in MBR feed, permeate and COD removal efficiency

Tab.1 summarizes typical water quality parameters of the MBR unit.

Tab. 1 Typical water quality parameters of the MBR unit

Parameter	Unit	Feed* (waste water)	Permeate* (microfiltrate)	Elimination rate %
BOD_5	mg/L	390	<9	>97
COD	mg/L	1120	67	94
$N\text{-}NO_3^-$	mg/L	77	21	73
$N\text{-}NH_4^+$	mg/L	1.5	0,1	93
Total N	mg/L	160	45	72
$P\text{-}PO_4^{3-}$	mg/L	14	13	7

* Typically average values based on several measurements

Some of the microfiltrated water is treated by reverse osmosis filtration. This filtration unit is very important for the recycling process because it prevents an increase in the salt level although there is a steady influx of salts by washing agents and the biological mineralization process. Furthermore, RO treatment further reduces the COD value. The concentrate is discharged to the municipal treatment plant. Eventually, low energy spiral wound FILMTEC modules – type LE-400 from Dow – were selected for the large-scale unit.
The Dow LE membrane was preferred to the Dow XLE, which was tested on the pilot scale, since its salt retention was better (see Dow product sheets [11]). The average flux of the RO unit was 25–30 L/m^2 h at around 16 bar. The average recovery of the RO unit increased to around at 80%.

4. Effluent treatment in textile industry

Pilot trials were conducted within an EC funded project INNOWA [10] at a printing and dying factory in Changzhou, PR China. Fig.5 represents a schematic of the treatment process , in which the pilot MBR system was replacing the biochemical tank, secondary settlement tank and final settlement tank [12].

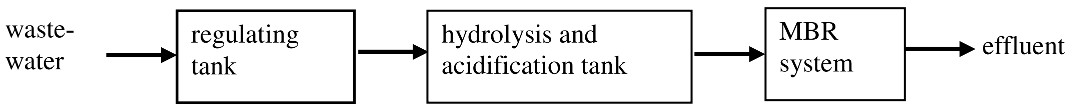
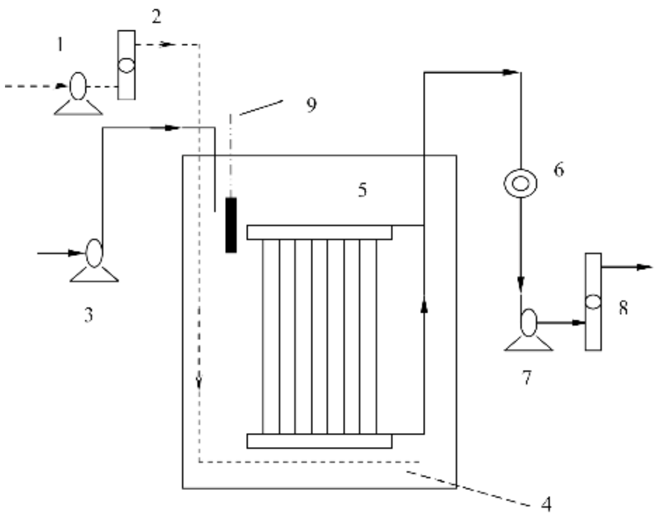


Fig. 5. Flow chart of the applied effluent treatment in the printing and dyeing factory

4.1 Materials and methods

A schematic of the experimental set-up is shown in Fig. 6. The aeration biochemical tank was made of PVC with a dimension of 0.5 m (length) × 0.3 m (width) × 0.7 m (height) and a working volume of 90 L. Two hollow fiber membrane modules were submerged opposite each other in a biochemical tank and two air bubble diffusers placed directly under the membrane modules. The maximum and minimum water levels were controlled by the water level controller, and the product water suction period was set by PC connected to the MBR. The hollow fiber membrane modules used in the submerged MBR, which are made of PVDF, were provided by Tianjing Motian Membrane Co. Ltd. Each of the two modules has an effective membrane area of 1 m^2 and a pore size of 0.2µm. The length, inner diameter and outer diameter of the fibers are 400 mm, 0.65 mm and 1.0 mm, respectively. The capacity of the MBR is up to 0.4 m^3/d.



1 Air pump 2 Gas flowmeter 3 Feedwater pump 4 Air bubble diffuser 5 Membrane module 6 Vacuum pressure gauge 7 Product water pump 8 Effluent flowmeter 9 Water level controller

Fig. 6 Schematic of the experimental set-up

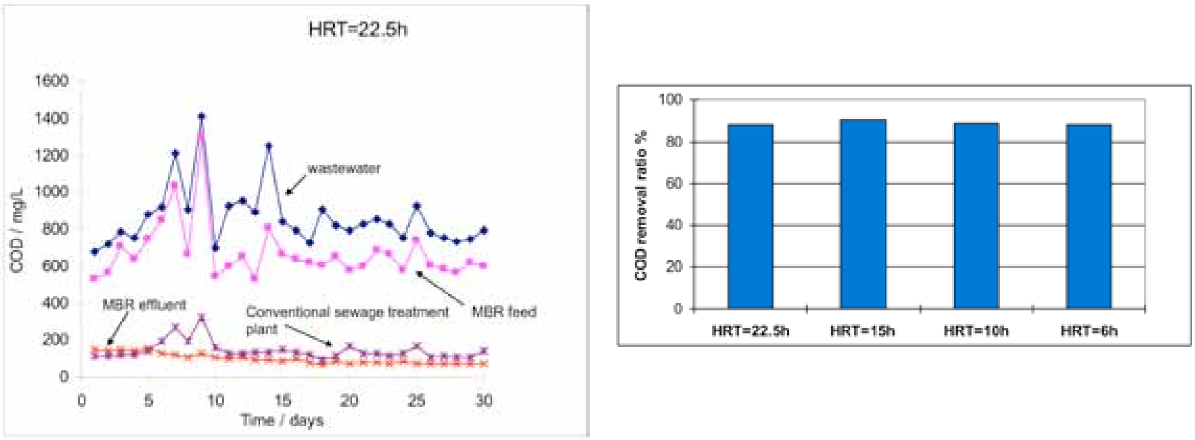
4.2 Results

The sludge used in the MBR system was taken from the wastewater treatment plant of the factory, and needed adaption before use because of the difference in aeration velocity and temperature of the MBR system compared with the traditional biochemical unit. The low ratio of BOD_5/COD (~ 0.15) indicates that the wastewater consists mainly of persistent organic compounds. The hydraulic retention time (HRT) of the MBR system was lowered gradually from 22.5 h to 6 h during the operation cycle (HRT=22.5 h at start; HRT = 15 h and 10 h, after 30 days and 45 days respectively; HRT = 6 h, after 60 days). The respective permeate flux was between 2 and 8 L/(m^2·h.) at a transmembrane pressure of 0.05–0.1 bar. This was close to the pure water flux of about 8 – 10 L/(m^2·h.) at the same transmembrane pressure. The MBR was operated periodically with 15 minutes permeate drain and 3 minutes stop time. No chemical cleaning was needed during the pilot test period. Fig. 7a exemplifies the COD values of wastewater, after hydrolysis and acidification (MBR feed) and the effluent values of the MBR at HRT = 22.5 h and the conventional sewage treatment plant as well. As can be seen in Fig. 7a the COD values of the MBR effluent are significantly lower and smoother than these of the conventional treatment plant. Fig. 7b shows that the COD removal efficiencies at lower HRT are in similar range around 90%. The COD values of effluent from the MBR system can be kept below 100 mg/L although the fluctuation of COD values in inlet water is great (from 710 to 1250 mg/L).

Although the loading capacity of the MBR system fluctuated from 0.5 kg COD/(m^3·d) to 1.5 kg COD/(m^3·d), the effluent quality remained stable. The respective sludge loading range was between 0.05 and 0.15 kg COD/(kg MLSS·d).

The nitrification rate of NH_4^+-N in the MBR system to NO_3^--N equals 90% due to the high sludge age (sludge retention time SRT> 30 days) of the biocenoses, and the NH_4^+-N concentration in product water was lowered from 10-23 mg/L to less than 2 mg/L.

The removal ratio of colour in the MBR system achieved 60% to 75% only through the biochemical degradation (colour reduced from 250-400 to 150-250 m^{-1}) since the MF membrane has almost no retention of the low molecular weight dye molecules. With regard to water reuse due to its colouration an additional treatment step such as nanofiltration or reverse osmosis might be necessary depending on the water quality requirements.



a b

Fig. 7 Comparison of COD values in feed and effluent of the MBR and conventional treatment unit and COD removal ratio

5. Conclusions

In general, it can be concluded that MBR technology proved to be a very efficient tool for water treatment and water reuse due to its advantages such as high water quality, small footprint, modularity and robustness. MBR technology is well-suited for the treatment and reuse of particularly effluents with high biological degradability. Hence MBR can be perfectly used for water reuse in commercial laundries which has been reported in this paper and in food, beverage and cosmetics industry as well. However, due to its high sludge age, MBR technology has also the ability to efficiently treat high persistent compounds which occur in textile effluents. However, in textile industry the dye molecules with low molecular weight can pass the MF/UF MBR membranes and hence the colour may pose a problem in the reuse process dependent on the quality requirements. Consequently the water requires additional treatment such as nanofiltration or reverse osmosis in order to increase the proportion of reused water. Additionally novel membrane materials for MBR reactors need to be developed through R&D activities. This topic is addressed in a newly launched EC funded project BioNexGen which is coordinated by the Karlsruhe University of Applied Sciences [13].

Acknowledgements

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