Desalination and Water Treatment
www.deswater.com
51 (2013) 1063–1069
January

doi: 10.1080/19443994.2012.700006

Taylor & Francis
Taylor & Francis Group

The IFAS-MBR process: a compact combination of biofilm and MBR tecnnology as RO pretreatment

T. De la Torre[a,]*, C. Rodríguez[a], M.A. Gómez[b], E. Alonso[c], J.J. Malfeito[a]

[a]*Acciona Agua, Av. de les Garrigues 22, 2ª, 08820, Barcelona, Spain*
Tel. +34 933351500; Fax: +34 933366021; email: teresa.torre.garcia@acciona.es
[b]*Department of Civil Engineering, Technologies for Water Management and Treatment Research Group, University of Granada, 18071 Granada, Spain*
[c]*Department of Analytical Chemistry, University of Seville, C/Virgen de África, 7, E41011 Seville, Spain*

Received 29 February 2012; Accepted 29 May 2012

ABSTRACT

An advanced treatment for wastewater reclamation has been studied for nine months in a pilot plant in the south of Spain. This consisted in a combination of integrated fixed-film activated sludge (IFAS) and membrane bioreactor (MBR) technology (called here IFAS-MBR) with posterior reverse osmosis (RO) for the achievement of a high-quality effluent. The pilot plant was obtained from a former MBR plant, where plastic carriers for the support of the biology were introduced in the second aerobic chamber. The system consisted of two parallel lines, one working with a hollow fibre module and the other with a flat sheet module. After the hollow fibre line, an RO system treated the effluent. The permeability of the process decreased gradually along the experimentation period and after six months, the membrane modules of both lines were chemically cleaned. The RO membranes showed a stable permeability working with the IFAS-MBR permeate and chemically cleaned after four months of operation. The studied system combined the advantages of both IFAS and MBR technologies and it is an interesting choice when the footprint is limited or a high effluent quality is required and it is an attractive pretreatment for reverse osmosis systems.

Keywords: Membrane bioreactor; Biofilm; IFAS; Reverse osmosis

1. Introduction

Both membrane bioreactor (MBR) and biofilm technologies are interesting choices when the footprint is limited. The combination of these technologies must therefore result in a very compact process. In the case of the MBR, the use of a membrane for the biomass separation instead of a settling tank and the possibility of working at higher total suspended solids (TSS) permit reducing the volume of the plant considerably. In the biofilm systems, the carriers introduced to support the biomass increase significantly the capacity of a conventional plant. This is applicable both to moving bed bioreactors (MBBR) and to integrated fixed-film activated sludge (IFAS) technologies. The main difference between those two is that part of the IFAS biomass is suspended and part of it supported, whereas the active biomass in the MBBR is mainly supported on the carriers. Some studies have dealt with the combination of MBBR and MBR, called here MBMBR. Leiknes et al.

*Corresponding author.

Presented at the International Conference on Desalination for the Environment, Clean Water and Energy, European Desalination Society, 23–26 April 2012, Barcelona, Spain

[1] reported sustainable fluxes working with an MBMBR up to 50 L/m^{2}h, indicating an increase in permeability in comparison to the conventional MBR. However, Yang et al. [2,3] could not confirm these results. They performed some lab-scale studies in order to investigate the membrane fouling of the MBMBR process in comparison with a conventional MBR, as well as the nitrification capacity of the new system and found an increased microbiological activity for the MBMBR but higher fouling than in the MBR. This had been already observed by Lee et al. [4] who reported a filtration resistance seven times higher working with MBMBR than working with a conventional MBR. This issue was attributed to the formation of a *secondary* membrane with the suspended flocs in the case of the MBR, which protects it from severe fouling. This effect was already been noticed by other authors working with MBR [5,6]. Taking this into account, the existence of suspended biomass in an IFAS-MBR may be an advantage compared to the MBMBR. Recently, Liu et al. [7] studied an IFAS-MBR system by introducing carriers in MBR and operated it for 400 d. When the biofilm had formed, the permeability of the system improved substantially as well as the nitrification efficiency. According to their results, the IFAS-MBR seems to be a promising technology to overcome fouling problems and at the same time obtain a very compact technology. However, the use of this process as RO pretreatment is still unknown and is being studied for the first time during this project. The use of MBR as RO pretreatment has been extensively studied and the results indicate that the MBR permeate is more interesting than conventional activated sludge (CAS) followed by MF as RO feed. Qin et al. [8] compared in a pilot study the effluent of an MBR/RO with the effluent of the MF/RO and reported the same or higher effluent quality in the case of the MBR/RO, with lower and more stable total organic carbon and lower ammonia and nitrate concentration. Tam et al. [9] conducted a similar study comparing MF/RO and MBR/RO and reported a higher elimination of estrogens for the MBR/RO system.

In this study, plastic carriers for the support of the biology have been introduced in the second aerobic chamber of an existing MBR plant treating municipal wastewater. The IFAS-MBR plant consists of two parallel lines to compare hollow fibre and flat sheet configurations. Moreover, the effluent of the hollow fibre line is further treated in an RO system in order to evaluate the effectiveness of the IFAS-MBR as RO pretreatment.

2. Experimental

In Fig. 1 the scheme of the plant is presented. The influent was taken from the wastewater treatment plant (WWTP) of Almuñécar (Granada), which operated with CAS technology. After sand and grit removal, a constant flow of 4.6 m^3/h wastewater entered the pilot plant and was divided into two lines: one working with a hollow fibre module (HF) from Koch Membrane Systems (Puron, Germany) and the other working with a flat sheet module (FS) from Kubota (Japan). The pilot in a former MBR plant which is 50% of the volume of the first aerobic reactor was filled with recycled polyethylene plastic carriers (Christian Stöhr, Germany) in order to study and

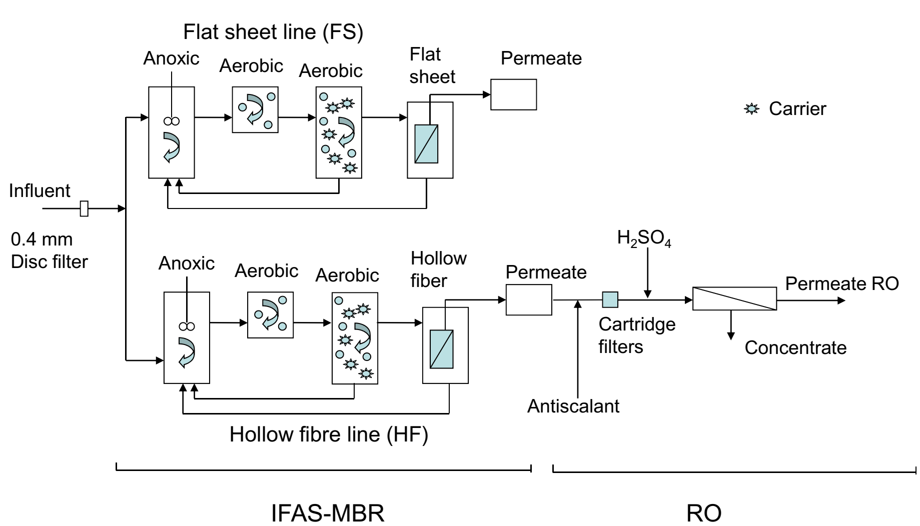

Fig. 1. Scheme of the advanced treatment process for wastewater reclamation.

Table 1
Mean parameters of the IFAS-MBR

Line	Supplier	Pore size (μm)	Membrane surface (m^2)	Flux (L/m^2h)	Specific aeration demand (m^3/m^2h)	Total volume line (m^3)	TSS (g/L)	Filtered COD influent (mgO_2/L)	*T* (℃)
Flat sheet (FS)	Kubota	0.4	160	16	0.6	37	8.7	146	15–27
Hollow fibre (HF)	Koch membrane systems	0.01	250	10	0.4	29	8.5	146	16–27

Table 2
Parameters of the RO system

Membranes	Material	No. tubes	Area (m^2)	Recovery	No. elements/tube
TRISEP 4040-X201-TSA	Aromatic Polyamide-Urea	1	165.9	40%	7

evaluate a new process that may increase the capacity of the system and improve nitrification. The new system was called IFAS-MBR. Before entering the RO system, an antiscalant was dosed to the hollow fibre effluent (Osmotec 1261, BKG Water Solutions, Germany) and the pH was adjusted to 7.1 using sulphuric acid. The recovery of the RO was restricted to 40% due to mechanical limitations of the pilot plant.

The main operational parameters of the plant are given in Table 1 for the IFAS-MBR and in Table 2 for the RO system. The IFAS-MBR was operated at SRT (sludge retention time) of 10 d for the first six months and after that it was increased to 20 d.

Operational parameters such as flow, dissolved oxygen, pH, temperature, and transmembrane pressure (TMP) were continuously monitored with a supervisory control and data acquisition system.

Twenty-four hours composite influent and effluent samples from each experimental installation were daily collected using a time controller (4 h) to determine COD, SS, N_T, NH_4^+, P_T, turbidity, nematode eggs and *Escherichia coli*. Activated sludge samples were daily collected directly from each bioreactor to determine TSS. Physical and chemical analyses were determined according to Standard Methods [10]. The presence of *E. coli* was studied using the membrane filtration procedure UNE-EN ISO 9308-1:2000 and the modified Bailenger method was used to determine the nematode egg concentration [11]. The silt density index (SDI) and modified fouling index (MFI) values were measured as described in Ref. [12]. Soluble extracellular polymeric substances (SMP) were separated by centrifugation for 5 min at 5,000 g and the supernatant was filtered through a 0.45 μm filter following Ref. [13]. For the extraction of bound EPS from the precipitate, it was firstly washed with distiled water and then heated. After that, it was centrifuged at 7,000 g for 10 min and filtered. After extraction, proteins were measured following Ref. [14] and carbohydrates [15].

Before the second chemical cleaning, membrane samples were taken from each module for their cross section and subsequently analysed using scanning electron microscopy (SEM) using a Zeiss DSM 950 SEM operating at 5–30 kV. The material attached to the membrane was detached with ultrasound and its soluble microbial products (SMP) and bound EPS content was extracted by centrifuging and heating methods and analysed for total carbohydrates and proteins [16].

3. Results

The mean effluent quality obtained in both lines of the IFAS-MBR can be observed in Table 3. The plant achieved practically total ammonium and COD removal with no statistically significant differences between the two lines. The nutrient removal rates were lower because the plant was not designed for biological phosphorus removal and the nitrate elimination was affected by the dissolved oxygen recirculation from the membrane tank. Similar microbiological characteristics were obtained in both effluents, with total removal of *E.coli* and nematode eggs. According to these data, the permeate was suitable to be reused based on Spanish reuse guidelines regardless of

Table 3
Mean effluent quality parameters of the IFAS-MBR

	Hollow fibre permeate		Flat sheet permeate	
	Concentration (mg/L)	Removal (%)	Concentration (mg/L)	Removal (%)
Amonnium	0	99	0	99
COD	14	98	13	98
Ntotal	11	79	14	72
Ptotal	3	62	4	53
E.coli	0	100	0	100
Nematode eggs	0	100	0	100
Turbidity	<0.1	100	<0.1	100
TSS	<1	100	<1	100

whether microfiltration or ultrafiltration membranes were used.

3.1. IFAS-MBR

The evolution of the total resistance in the IFAS-MBR lines can be seen in Fig. 2. The resistance to filtration Rt was calculated as follows:

$$Rt = \frac{\text{TMP}}{J\mu} \tag{1}$$

where J is the flux, TMP is the transmembrane pressure, and μ is the permeate viscosity.

It is remarkable that the two lines showed a similar pattern and responded the same way to the disturbances in the plant. This seems to indicate that the variations in the influent quality had a big impact in the fouling rates.

Total resistance was higher for the HF, which is logical because this was UF and the FS was MF. The plant performed in general quite stable but the typical TMP jump reported in the literature for conventional MBR plants [17,18] was observed after some months of operation. This was more pronounced by the FS line, which was attributed to the proliferation of worms (Fig. 3), which reduced the amount of biomass critically by predation. Its proliferation was related to the low F/M ratio encountered in the flat sheet line, as the incoming water showed a low concentration of soluble COD during the experimentation. The reason why this problem appeared in the FH line and not in the HF line was probably due to the higher compactness of the HF module ($4\,m^2$ for HF module vs. $12\,m^2$ for FH membrane tank). That means that, although the SRT and TSS for both lines were kept the same, the F/M ratio was lower for the FS line. Once the permeability of the FS line was too low, both lines were chemically cleaned with sodium hypochlorite and citric acid.

After the chemical cleaning, the SRT was increased from 10 to 20 d with the purpose of having a more stabilised activated sludge and less EPS, as it has been reported in the literature that a lower SRT is related

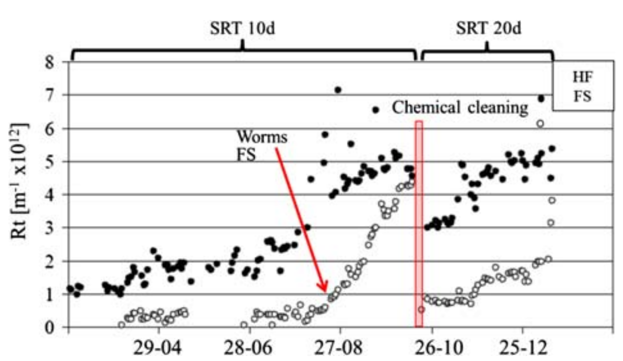

Fig. 2. Total resistance evolution of the flat sheet module (FS) and the hollow fibre module (HF) of the IFAS-MBR.

Fig. 3. Oligocheata (worm) in the flat sheet line.

Table 4
SMP and bound EPS mean values in the activated sludge

	SMP (mg/L)		Bound EPS (mg/L)	
	SRT		SRT	
	10 d	20 d	10 d	20 d
FS	28	14	112	54
HF	23	10	120	45

to higher accumulation of EPS in the activated sludge and which supernatant showed a more pronounced fouling potential [19]. This was confirmed with the data in Table 4, which shows higher mean values of SMP and bound EPS in both lines at 10 d h than at 20 d. It remarked the similarities in the two lines, having both similar quantity and distribution of soluble and bound EPS.

However, despite the change in SRT and the consequently lower EPS content encountered, the plant experienced again a gradual fouling and finally was chemically cleaned for a second time after only two months of operation. Nevertheless, the fouling rates encountered in the two lines of the IFAS-MBR throughout its operation were in the range of those found in a conventional MBR for irreversible fouling (0.001–0.01 mbar/min) [20] during fouling periods (for instance during the worm event) and comparable to typical long-term fouling rates when the IFAS-MBR was stable.

3.2. Membrane autopsy

Although the permeability evolution of both lines was similar, the HF showed higher membrane fouling than the flat sheet when SEM pictures were evaluated. Numerous clean areas were found on the FS membrane (Fig. 4), whereas other areas presented some biopolymeric material attached to the membrane (Fig. 5). In Fig. 6, a picture of a fouled area from the HF membrane can be observed, and this picture was considered as representative of the whole surface of the sampled fibre.

In Fig. 7, the mass values of polysaccharides and proteins of the SMP and bound EPS detached from the membrane are presented. As it can be seen, the majority of the foulants attached to the membranes were proteins. More EPS quantity was found in the HF and the two sides of the FS membrane (sides A and B) showed significant differences in the EPS quantity. This was in agreement with the SEM, that presented side A more covered than side B and a highly fouled HF membrane.

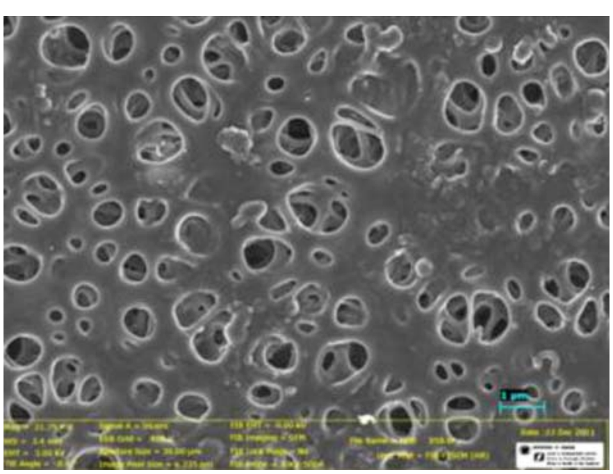

Fig. 4. Flat sheet membrane, clean area.

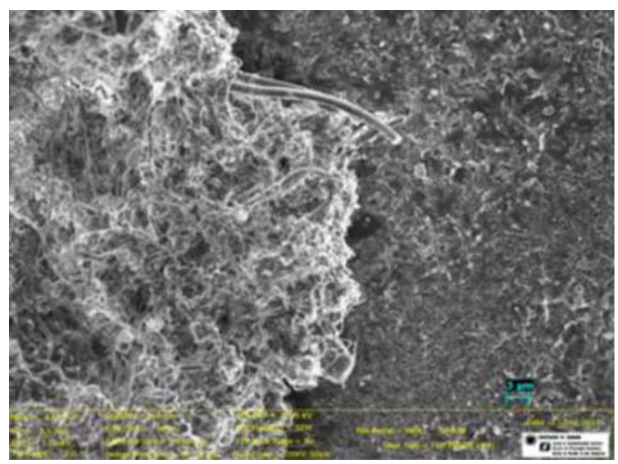

Fig. 5. Flat sheet membrane, fouled area.

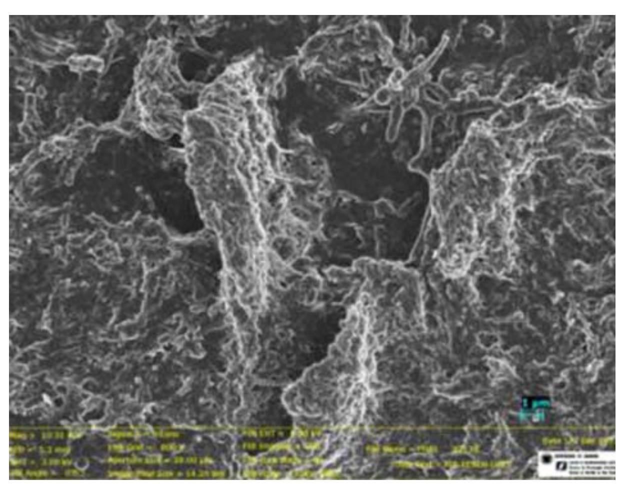

Fig. 6. Hollow fibre.

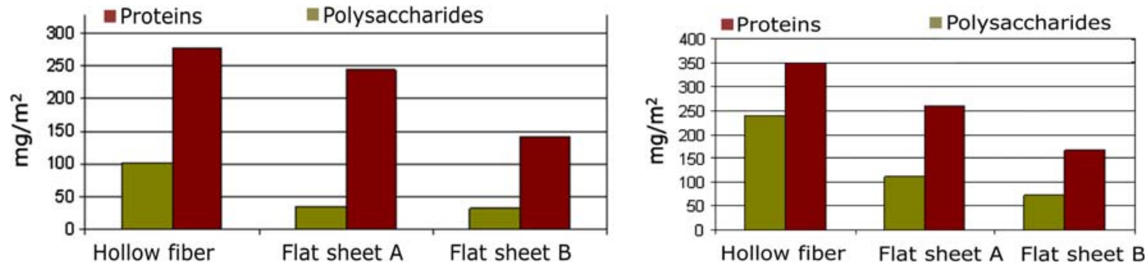

Fig. 7. SMP (left) and bound EPS (right) found on the membrane surface sampled.

Table 5
Mean operational values of the RO system

Pressure (bar)	Feed DOC (mg/L)	Permeate conductivity (μS/cm)	Salt rejection (%)	Particle counts (cnt/mL)	dP (bar)	pH	Turbidity (NTU)	*T* (°C)
9.0	14	16	98.4	567	1.8	7.1	0.05	23

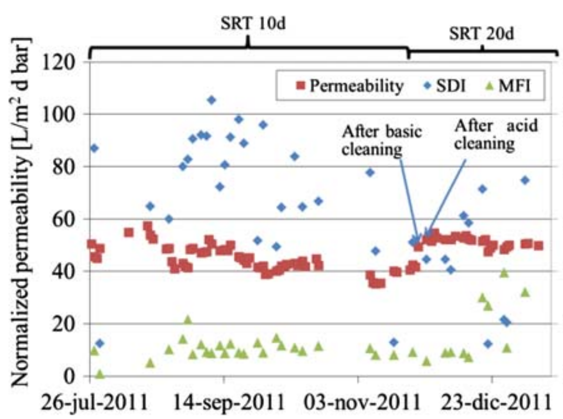

Fig. 8. Permeability evolution of the RO system.

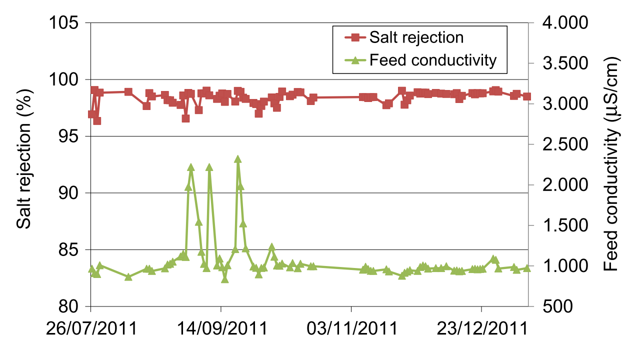

Fig. 9. Feed conductivity and salt rejection of the RO system.

Although the SEM pictures and the detached material showed a more fouled membrane in the case of the HF compared to the FS, this was not reflected in the resistance to filtration (Fig. 2).

3.3. Reverse osmosis

The operation of the reverse osmosis system is shown in Table 5. The mean feed pressure needed for a conversion of 40% was 9 bar. Although the MBR provided an almost particle free effluent, the particle counter detected a considerable number of particles which were attributed to the biofilm present in the pipes and storage tank. In order to control this issue, the residence time in the storage tank was kept as low as possible and a weekly chemical cleaning using hypochlorite was used in the HF system.

As it can be seen in Fig. 8, the permeability of the RO system was quite stable along the operation except for some permeability peaks. These results demonstrated that an RO system can treat permeate from an IFAS-MBR process without any intermediate treatment. Nevertheless, after four months of operation the system was chemically cleaned because the permeability had decreased 15% of its initial value. The cleaning was performed in two steps, namely basic and acid. After the basic cleaning, the system recovered most of the loosen permeability and the initial permeability was recovered after the acid cleaning. The fact that the basic cleaning was much more effective indicated that most of the fouling was organic.

SDI and MFI showed neither a correlation between them (Fig. 8) nor a correlation with the permeability and there was no direct information that can be extracted from their evolution. Furthermore, it is generally agreed that SDI values around 3 and 4 (as in this study) indicated that particulate fouling may be a problem in this system and frequent cleaning would be needed. However, the MFI values were quite low (0–1), which indicated that the feed was adequate for RO and few chemical cleanings were needed. This controversy might be related to the fact that the SDI was not proportional to the concentration of colloidal and suspended matter whereas the MFI does [12], which made it a more reliable parameter for evaluating fouling potential of an RO feed.

The salt rejection did not decrease throughout the experimentation period, as it can be seen in Fig. 9. The chart represented also the feed conductivity, which was almost constant except from some peaks probably corresponding to salinity intrusion events experienced in the WWTP.

4. Conclusions

The combination of MBR and IFAS technology seems to have an interesting potential when high effluent quality is required and/or the available footprint is limited. The effluent data in terms of COD, N and P elimination were comparable to the conventional MBR effluent data, obtaining a high quality effluent for reuse. On the other side, the permeability decreased along the experimentation period, but the fouling rates encountered were comparable to those of a conventional MBR. No significant differences were found between working with hollow fibre (UF) or flat sheet (MF) membranes and both lines performed very similar throughout the whole period.

RO operation treating the IFAS-MBR permeate was stable and no cleaning was needed during four months of continuous operation working at a conversion of 40%. The high permeability recovery of the basic cleaning compared to the acid cleaning indicated that the main fouling was organic. The operation of the RO system seemed more stable when the IFAS-MBR process was operated at a higher SRT, which was attributed to a more stabilised activated sludge with lower EPS content. Salt rejection was maintained continuously at high values of 98.5–99%. These results point at the IFAS-MBR process as an attractive pretreatment for reverse osmosis systems.

Acknowledgments

The authors would like to acknowledge the financial support from the Corporación Tecnológica de Andalucía, the collaboration of Aguas y Servicios de la Costa Tropical, and to thank Juan Luis Santos, Jorge Ignacio Pérez, Jordi Bacardit, Silvia Ruiz, Maria del Mar González, María Auset, and Enrique Ferrero for their work.

References

[1] T. Leiknes, H. Ødegaard, The development of a biofilm membrane bioreactor, Desalination 202 (2007) 135–143.
[2] S. Yang, F. Yang, Z. Fu, R. Lei, Comparison between a moving bed membrane bioreactor and a conventional membrane bioreactor on organic carbon and nitrogen removal, Bioresour. Technol. 100 (2009) 2369–2374.
[3] S. Yang, F. Yang, Z. Fu, R. Lei, Comparison between a moving bed membrane bioreactor and a conventional membrane bioreactor on membrane fouling, Bioresour. Technol. 100 (2009) 6655–6657.
[4] J. Lee, W.-N. Ahn, C.-H. Lee, Comparison of the filtration characteristics between attached and suspended growth microorganisms in submerged membrane bioreactor, Water Res. 35(10) (2001) 2435–2445.
[5] H. Choi, K. Zhang, D.D. Dionysiou, D.B. Oerther, G.A. Sorial, Influence of cross-flow velocity on membrane performance during filtration of biological suspension, J. Membr. Sci. 248 (2005) 189–199.
[6] D. Hughes, R.W. Field, Cross-flow filtration of washed and unwashed yeast suspensions at constant shear under nominally sub-critical conditions, J. Membr. Sci. 280 (2006) 89–98.
[7] Q. Liu, X.C. Wang, Y. Liu, H. Yuan, Y. Du, Performance of a hybrid membrane bioreactor in municipal wastewater treatment, Desalination 258 (2010) 143–147.
[8] J.-J. Qin, K.A. Kekre, G. Tao, M.T. Ooa, M.N. Wai, T.C. Lee, B. Viswanath, H. Seah, New option of MBR-RO process for production of NEWater from domestic sewage, J. Membr. Sci. 272 (2006) 70–77.
[9] L.S. Tam, T.W. Tang, G.N. Lau, K.R. Sharma, G.H. Chen, A pilot study for wastewater reclamation and reuse with MBR/RO and MF/RO systems, Desalination 202 (2006) 106–113.
[10] APHA, AWWA, WEF. Standard Methods for the Examination of Water and Wastewater, 18th ed., American Public Health Association, Washington, DC, 1998.
[11] R.M. Ayres, D. Mara, Analysis of Wastewater for use in Agriculture: A Laboratory Manual of Parasitological and Bacteriological Techniques, World Health Organization, Geneva, 1996.
[12] J.C. Schippers, J. Verdouw, The modified fouling index, a method for determining the fouling characteristics of water, Desalination 32 (1980) 137–148.
[13] S. Judd, The MBR Book, Elsevier, London, 2006.
[14] O.H. Lowry, N.J. Rosebrough, A.L. Farr, R.J. Randal, Protein measurement with the folin phenol reagent, J. Biol. Chem. 193(1) (1951) 265–275.
[15] M. Dubois, K.A. Gilles, J.K. Hamilton, P.A. Rebers, F. Smith, Colorimetric method for determination of sugars and relates substances, Anal. Chem. 28(3) (1956) 350–356.
[16] J.W. Morgan, C.F. Foster, L. Evison, A comparative study of the nature of biopolymers extracted from anaerobic and activated sludge, Water Res. 24 (1990) 743–750.
[17] B.D. Cho, A.G. Fane, Fouling transient in nominally sub-critical flux operation of a membrane bioreactor, J. Membr. Sci. 209 (2002) 391–403.
[18] G. Guglielmi, D. Chiarani, S.J. Judd, G. Andreottola, Flux criticality and sustainability in a hollow fibre submerged membrane bioreactor for municipal wastewater treatment, J. Membr. Sci. 289 (2007) 241–248.
[19] S. Liang, C. Liu, L. Song, Soluble microbial products in membrane bioreactor operation: behaviors, characteristics, and fouling potential, Water Res. 41 (2007) 95–101.
[20] M. Kraume, D. Wedi, J. Schaller, V. Iversen, A. Drews, Fouling in MBR—What use are lab investigations for full scale operation? Desalination 236(1–3) (2009) 94–103.