Desalination and Water Treatment
www.deswater.com

4 (2009) 212–217

1944-3994 / 1944-3986

A long-term application of a pilot airlift membrane bioreactor for domestic wastewater treatment

Fei Yang[a], Ying Wang[a], Amos Bick[b,c], Asher Brenner[d], Gideon Oron[a,d,e,f*]

[a]*Zuckerberg Institute for Water Research, J. Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Kiryat Sde Boker, 84990, Israel*
email: feiyang@bgu.ac.il; wangya@bgu.ac.il; gidi@bgu.ac.il
[b]*Department of Industrial Engineering and Management, Jerusalem College of Technology, Jerusalem, 91160, Israel*
email: amosbick@walla.com
[c]*Department of Chemical Engineering, Shenkar College of Engineering and Design, Ramat-Gan, 52526, Israel*
[d]*Unit of Environmental Engineering, Ben-Gurion University of the Negev, Beer Sheva, 84105, Israel*
email: brenner@bgu.ac.il
[e]*Department of Industrial Engineering and Management, Ben-Gurion University of the Negev, Beer Sheva, 84105, Israel*
[f]*The Grand Water Research Institute, Technion, Haifa 32000, Israel*

Received 23 April 2008; Accepted in revised form 27 July 2008

ABSTRACT

Current and impending legislation for public health and environmental compliance regarding effluent are becoming very stringent. For unrestricted domestic effluent reuse and environmental friendly disposal, the need for advanced treatment processes has attracted great attention during the last decade. Membrane-based treatment technologies for low quality water have exhibited improved performance as well as a reduction of operating and maintenance expenses. Membrane technology also provides a preferable alternative for wastewater reclamation in small and isolated communities. This study presents a long term study of an airlift membrane bioreactor (MBR) for domestic wastewater treatment using a hollow fibre membrane module of ZW-10 under ambient desert conditions (Kiryat Sde-Boker, Israel). In this system, the crossflow velocity across the membrane surface was induced by a cylindrical draft tube to reduce the membrane fouling. Under optimal operating conditions, the system was stable and efficient without external chemical cleaning during the experimental period. The system produces a high quality permeate, and the removal efficiencies of COD and BOD_5 were around 94% and 99%, respectively. Nitrate concentration in the effluent (permeate) was higher (by 40%) than that in the reactor mixed liquor, probably due to extra nitrification carried out by *Nitrospira* bacteria on the membrane biofilm. The system shows potential and promising applications for localized, decentralized sewage treatment facilities.

Keywords: Airlift membrane bioreactor; Crossflow velocity; Draft tube; Membrane fouling; Unrestricted reuse

1. Introduction

A membrane bioreactor (MBR) in which membrane separation is combined with the biological processes is considered an efficient alternative for wastewater treatment and reuse [1–5]. In the processes taking place in the MBR, a permeate with minimal suspended solids content is generated through the membrane, whereas microorganisms are retained in the bioreactor, and the solids retention time (SRT) becomes completely indepen-

* Corresponding author.

Presented at the 2nd International Congress, SMALLWAT '07, Wastewater Treatment in Small Communities, 11–15 November 2007, Seville, Spain

dent of the hydraulic retention time (HRT). High sludge concentration can therefore be achieved even under a short HRT. Some macromolecules are also retained in the bioreactor. Consequently, the contact time of the activated sludge and pollutants is extended, facilitating efficient removal of slowly biodegradable pollutants. Membrane bioreactors (MBRs) encompass many advantages in comparison with conventional wastewater treatment processes due to their high organic loading rate, low production of surplus sludge, improved effluent quality, small footprint, flexible design and automated operation [3,5–7]. Therefore MBRs are ideal for localized, decentralized sewage treatment such as for small communities and resorts in the developed world [6–8] and they have also the potential for implementation in developing countries to address the pressing need for improved sanitation [3,5]. However, the major process limitation with MBRs remains the fouling due to the physicochemical interactions between the membrane material and the components in the mixed liquor. Along with the fouling, membrane permeability decreases and energy demand increases. An emerging alternative for the reduction of accumulated fouling effects is to use an airlift phase which induces a crossflow by rising air bubbles, creating a shear stress and generating a mass back-transport of the deposited particles along the membrane surface. The concept of airlift reactor has been adapted in submerged MBR (sMBR) systems for the enhancement of the crossflow velocity by liquid circulation. The idea of induced crossflow is also similar to the crossflow in a side-stream MBR, however, in a much lower intensity. Airlift membrane bioreactors have proved to enhance filtration performance and to minimize membrane fouling [9–11].

In airlift sMBRs the hydrodynamic characteristics, which vary with the operating conditions, play an important role concerning membrane fouling and efficient performance. In a previous work [11] it was shown that optimal operating conditions for the airlift sMBR can be adjusted according to the trans-membrane pressure (TMP) increase over time (dP/dt) during 1.5 h. The purpose of this study was therefore to evaluate the fouling rate and the system efficiency for domestic wastewater treatment, using a dead-end filtration operating mode, under ambient and optimal operating conditions during a long-term application period (114 days) .

2. Materials and methods

The pilot MBR (Fig. 1) was equipped with a hollow fibre ultrafiltration (UF) membrane module of ZW-10 (Zenon Environmental, Canada). The tested cylindrical module was submerged in a 190 L (working volume) drum-tank and operated under constant-flux mode. The membranes had a nominal pore size of 0.04 μm and a total filtering surface area of 0.93 m². A cylindrical draft

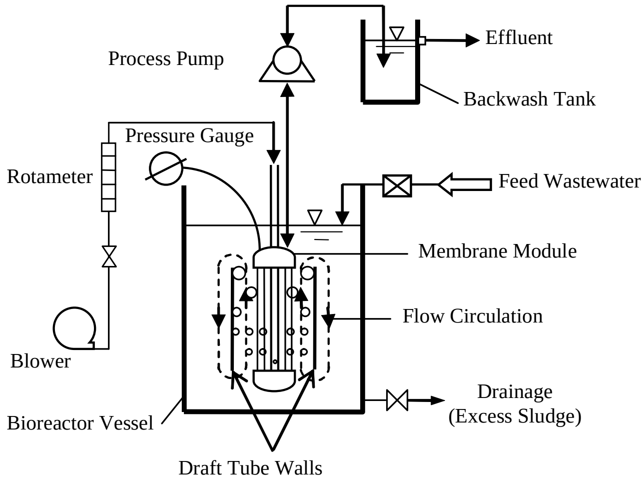

Fig. 1. Schematic description of the airlift MBR system.

tube with the diameter of 235 mm was used to induce an upwards vertical crossflow velocity. The draft tube was located in the centre of the bioreactor and actually divided the bioreactor into a riser zone (inside of the tube), where the membrane module was submerged in the centre, and a downcomer zone (outside of the draft tube), which was connected by a bottom flow channel and an upper flow channel. Air supply was maintained at a rate of 3.4 m^3/h by coarse air bubble sparkling from 4 small holes (Ø = 2 mm) which were located at the bottom of the membrane bundle. Obtained optimal operational conditions are summarized in Table 1. Before the experiment started, the membrane bundle was completely recovered by soaking in Na-SDS solution consisting of NaClO (750 ppm) and sodium dodecyl sulfate (250 ppm).

Table 1
Operational conditions during the 114-day study of the MBR system

Parameter	Range
Temperature, °C	19.4–31.1 with an average of 27.0
pH level in the reactor	6.62~7.45 with a mean of 6.98
Dissolved oxygen (DO), mg/L	2.43–4.35 with a mean of 2.90
Initial membrane permeability at 20°C and 0.15 bar, L/(m^2.h.bar)	706
Draft tube diameter, mm	235
Permeate flux, L/(m^2.h)	45.3
Aeration rate, m^3/h	3.4
Solids retention time (SRT), d	30
Hydraulic retention time (HRT), h	≈5
Backwash regime	5 min filtration/15 s backwash

The experiment was carried out continuously without additional cleaning during a period of 114 days.

The experiments were conducted under ambient conditions in J. Blaustein Institutes for Desert Research, Kiryat Sde-Boker, Israel. Domestic wastewater was taken from the residential caravan area, and fed into the bioreactor through a 0.8 mm screen filter after preliminary settling. During the operating period, the excess sludge was discarded daily to maintain an SRT of 30 days. The average hydraulic retention time (HRT) was around 5 h. The permeate was extracted intermittently with a suction device in a cycle of 5 minutes extraction and 15 s backwash. The temperature in the bioreactor during the operating period was in the range of 19.4°C to 31.1°C with a mean of 27.0°C. Influent, mixed liquor in the bioreactor and effluent qualities were monitored twice a week. All analytical parameters including pH, turbidity, electrical conductivity (EC), TSS, COD, BOD_5, NH_4-N, NO_2-N, NO_3-N, PO_4-P, and fecal coliforms (FC) were determined according to Standard Methods [12].

3. Results and discussion

3.1. Removal efficiency of organic matter

At the beginning of the study chicken manure solution was added to the wastewater to increase the organic load and to accelerate biomass growth. During the extended application period, mean concentration of the mixed liquor suspended solids (MLSS) was around 4,850 mg/L, with a minimum of 3,210 mg/L at the beginning and maximum of 5,910 mg/L towards the end of the experimental period. The pH level in the rector varied from 6.62 to 7.45 with a mean of 6.98, while the dissolved oxygen (DO) concentration fluctuated from 2.43 to 4.35 with a mean of 2.90 mg/L which was sufficient for both oxidation and nitrification processes. Variations of organic matter in the influent and effluent were monitored during the extended period (Fig. 2). High removal efficiency was obtained, especially for the biodegradable compounds (expressed by BOD_5). Total COD and BOD_5 removal efficiencies were 94% and 99%, resulting in mean effluent concentrations of 17.7 mg/L and 1.02 mg/L, respectively. These results are superior to the ones disclosed in other reports [13], and could be achieved probably due to the low organic strength feed.

The average organic load (F/M) was 0.34 g COD/g MLVSS/d, or 0.13 g BOD_5/g MLVSS/d (Fig. 3), which is typical for the extended aeration activated sludge processes. Churchouse et al. [14] reported that the oldest full scale sMBR plant for municipal sewage treatment in Europe, located at Porlock, UK, has been operated continuously and stably for 10 years at a low TMP (maximum 0.1 bar), extended sludge age (30–90 days) and low F_{BOD}/M ratios (0.02–0.07), requiring cleaning every 8 months.

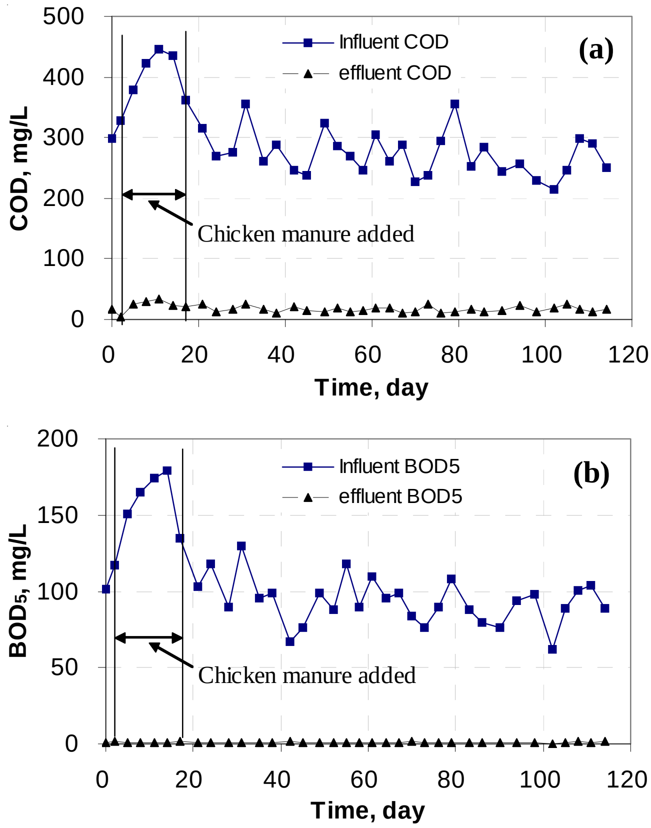

Fig. 2. Variations of organic matter concentrations during the long-term study: (a) COD; (b) BOD_5.

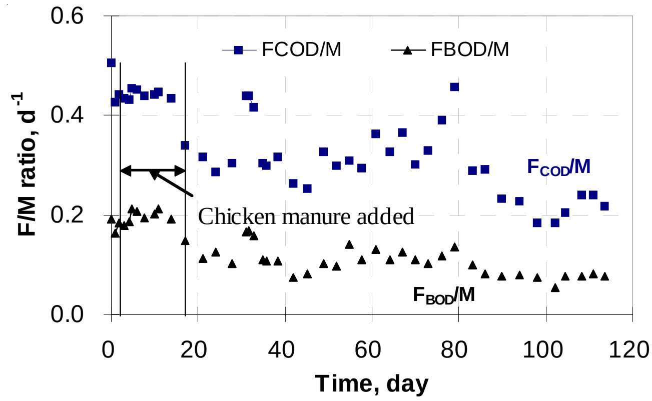

Fig. 3. Variations of F/M ratios during the long-term study.

3.2. Removal efficiency of nitrogen and phosphorus

The system exhibited high efficient nitrification (94%) (Fig. 4). Mean ammonia concentration in the effluent was only 0.99 mg/L, while the mean nitrate concentration in the effluent was around 12.8 mg/L. The mean nitrite concentrations in the reactor and effluent were 1.01 mg/L and 0.11 mg/L, respectively, which confirmed the oxidation of nitrite to nitrate during the filtration process. It is probably due to the extended SRT and efficient aeration

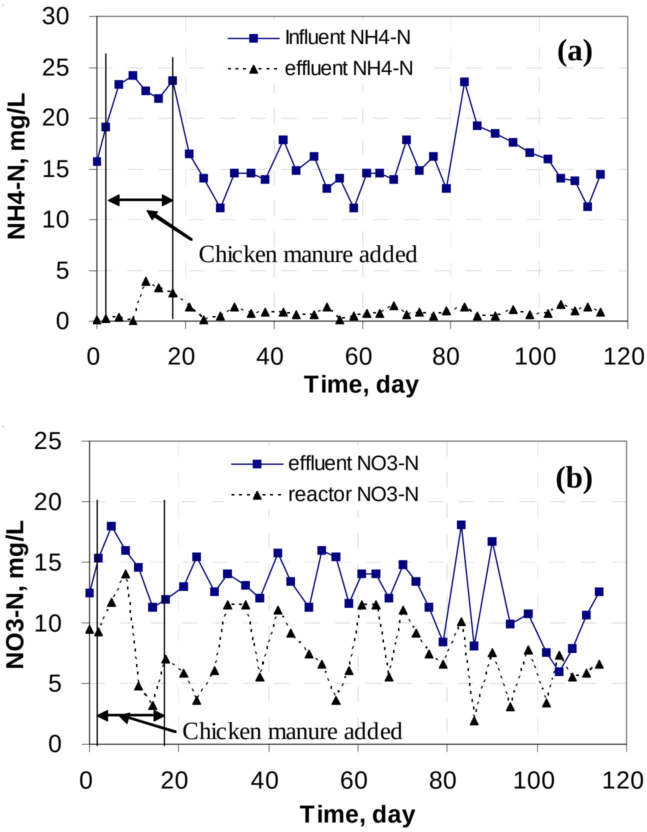

Fig. 4. Variations of ammonia and nitrate concentrations during the long-term study: (a) NH_4-N; (b) NO_3-N.

that enhanced nitrifiers' growth in the system. It was observed that nitrate concentrations in the reactor (measured in the filtrate obtained in MLSS analysis) were lower than those in the effluent (permeate), around 60% of the effluent nitrate values in average (Fig. 4b). In another research study of our group [21]. *Nitrospira* related bacteria were identified to be part of the prominent species on the UF membrane biofilm in the MBR. The *Nitrospira* bacteria attached to the membrane biofilm could thus convert nitrite to nitrate during the filtration process, resulting in an increase of nitrate in the effluent. This finding is in contrast to the observation of Kang et al. [4] that found an opposite phenomenon in an intermittently aerated MBR system. A track study confirmed that a denitrification process occurred inside the membrane-attached biofilm. These experiments revealed that nitrification/denitrification processes can occur within the biofilm which is developed on membrane surface, depending on operational conditions such as dissolved oxygen. This should be further investigated.

Total nitrogen removal efficiency was relatively poor, and only 23% of total nitrogen was removed. Phosphorus removal was also insufficient with a mean efficiency of 35.3%. These two (anoxic and anaerobic-dependent) processes were probabely suppressed by the high oxygen operation regime. It indicates that nutrients removal in sMBR systems needs to be improved by optimizing the aeration mode.

3.3. Removal efficiency of other contaminants

Complete removal of suspended solids and fecal coliforms were obtained subject to nominal pore size of 0.04 μm (data not shown), as well as very low turbidity values in the effluent (mean value of 0.18 NTU). The results indicate that no further disinfection of the treated wastewater is required prior to disposal or reuse. However, almost no dissolved solutes removal was obtained as EC values in the influent and effluent were almost equal, indicating a reverse osmosis (RO) stage is needed for efficient dissolved solutes removal.

3.4. Filtration efficiency of the airlift sMBR

The system was operated under a constant flux mode with an initial flux of 45.3 L/(m^2.h). Consequently, the TMP increase could serve as a good indication for membrane fouling development. The permeate fluxes at different temperatures were normalized to 20°C according to Eq. (1) [15]:

$$J_{20} = J_t \cdot \mu_t / \mu_{20} = J_t \cdot e^{-0.0239(T-20)} \tag{1}$$

where J_t is the permeate flux at time t, L/(m^2.h); J_{20} is the normalized permeate flux (at 20°C), L/(m^2.h); μ_t and μ_{20} are the viscosities of the permeate at time t and 20°C, mPa.s, respectively; and T is the temperature at time t, °C.

The increase of TMP over time (Fig. 5) displays a slightly exponential trend, until reaching the maximum limitation (0.55 bar in this system) according to the manufacturer guidelines. Although the system was operated under a constant flux mode, 14% decline of the permeate flux (30% decline expressed as the normalized flux) was observed towards the end of the experiment (Fig. 5). Actually, the flux decreased from 45.3 to 38.7 L/(m^2.h), while the normalized flux decreased from 42.4 to 29.7 L/(m^2.h) (Fig. 5). Total filtration resistance increased exponentially from 0.5×10^{12} to 6.58×10^{12} m^{-1} during the entire experimental period (Fig. 6) in complience with the increase of the TMP. The inherent membrane resistance was the dominant one during the first 16 days, while the fouling resistance dominated during the rest experimental period. It indicates that the membrane fouling is the main factor affecting the filtration process during a long-term application period. A fast decrease of the permeability was observed from an initial value of 706 to 478 L/(m^2.h.bar) in the first 3 days. Overall, the membrane permeability decreased exponentially from 706 to 54 L/(m^2.h.bar) (7.5% of the initial value at the final stage) during the 114 days of operation. The fast decline of the permeability is probably due to pore block-

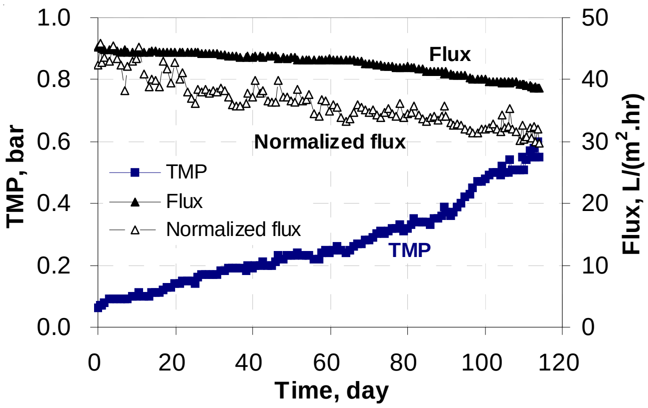

Fig. 5. Variations of TMP, flux, and normalized flux during the long-term study.

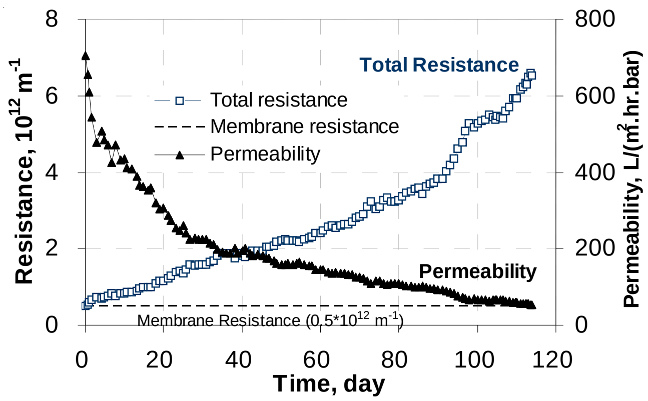

Fig. 6. Variations of membrane permeability and filtration resistance during the long-term study.

ing by rapid entrapement of colloids and solutes during the initial stage of the MBR operation. This phenomenon was observed also by many other researchers [16,17].

High quality effluents from MBRs can be produced for unrestricted and environmentally friendly reuse purposes such as unrestricted irrigation, aquifer recharge, and other industrial applications including complementary RO processes [2,5,8,18]. Qin et al. [19] concluded that the MBR process was capable of producing water suitable for industrial use from a mixed sewage consisting of 60% industrial waste and 40% domestic waste. Kimura et al. [20] showed that the airlift MBR could be modified to a baffled MBR (BMBR) for the enhancements of nitrogen and phosphorus removal, by generating anoxic conditions without mixed liquor circulation. Furthermore, Shannon et al. [5] pointed out that future direct reuse systems may involve only two stages: a single-stage MBR with an immersed nanofiltration membrane (obviating the need for RO stage), followed by a photocatalytic reactor to provide an absolute barrier for pathogens and to destroy low molecular-weight organic contaminants that may pass the nanofiltration barrier. This vision indicates a potential and promising extension of MBR's applications.

4. Conclusions

An airlift submerged MBR has been used for the treatment of domestic wastewater using a hollow fibre membrane module of ZW-10 under ambient desert conditions. The process proved to be stable and efficient without a need for external chemical cleaning during the extended experimental period. The system produced high quality permeate, and the removal efficiencies of COD and BOD_5 were around 94% and 99%, respectively. Nitrate concentration in the effluent (permeate) was higher (by 40%) than that in the reactor mixed liquor, probably due to extra nitrification taking place by *Nitrospira* bacteria in the membrane biofilm. Further studies referring to nitrification/denitrification in the membrane biofilm are required. Membrane permeability decreased exponentially during the long term experiment indicating that fouling is the main factor affecting the filtration process.

The advantages of MBRs display potential and promising directions for improving and replacement of conventional wastewater systems, primarily for localized, decentralized sewage treatment facilities such as small communities and resorts.

Acknowledgments

This work was supported partially by the SMART (Sustainable Management of Available Water Resources with Innovative Technologies) project financed by the Ministry of Science of the German government [Projektantrag zum BMBF-Förderschwerpunkt, Integriertes Wasserressourcen-Management (IWRM)], by The Beracha Foundation, The Stephen and Nancy Grand Water Research Institute, The Technion, Haifa Israel, The Palestinian-Jordanian-Israeli Project (PJIP) (1996), on Membrane Technology for Secondary Effluent Polishing: From Raw Sewage to Valuable Waters and Other By-Products, and by The Levin Family Foundation, Dayton, Ohio, USA, on Membrane Use for Wastewater Reclamation, Research Authority of Jerusalem College of Technology (JCT), Israel.

References

[1] A. Bick, G. Oron, L. Gillerman and Y. Manor, Data envelopment analysis for assessing optimal operation of ultra-filtration systems for effluent polishing, Water Sci. Technol.: Water Supply, 3(5) (2003) 379–384.

[2] G. Oron, A. Bick, L. Gillerman and Y. Manor, Hybrid membrane systems for secondary effluent polishing for unrestricted reuse for agricultural irrigation, Water Sci. Technol., 50(6) (2004) 305–312.

[3] T. Melin, B. Jefferson, D. Bixio, C. Thoeye, W. De Wilde, J. De Koning, J. van der Graaf and T. Wintgens, Membrane bioreactor

technology for wastewater treatment and reuse, Desalination, 187 (2006) 271–282.
[4] S. Kang, W. Lee, S. Chae and H. Shin, Positive roles of biofilm during the operation of membrane bioreactor for water reuse, Desalination, 202 (2007) 129–134.
[5] M.A. Shannon, P.W. Bohn, M. Elimelech, J.G. Georgiadis, B.J. Mariñas and A.M. Mayes, Science and technology for water purification in the coming decades, Nature, 452 (2008) 301–310.
[6] M. Galloway, Small communities turn to membrane technology to meet water and wastewater discharge standards, J. AWWA, 95(12) (2003) 30–33.
[7] A. Bick, J.G. Plazas and G. Oron, Immersed membrane bioreactor (IMBR) for treatment of combined domestic and dairy wastewater in an isolated farm. Water Sci. Technol., 51(10) (2005) 327–334.
[8] L. Gillerman, A. Bick, N. Buriakovsky and G. Oron, Secondary wastewater polishing with ultrafiltration membranes for unrestricted reuse: Fouling and flushing modelling, Environ. Sci. Technol., 40 (2006) 6830–6836.
[9] R. Liu, X. Huang, C.W. Wang, L.J. Chen and Y. Qian, Study on hydraulic characteristics in a submerged membrane bioreactor process, Process Biochem., 36 (2000) 249–256.
[10] A. Sofia, W.J. Ng and S.L. Ong, Engineering design approaches for minimum fouling in submerged MBR, Desalination, 160 (2004) 67–74.
[11] F. Yang, A. Bick, S. Shandalov and G. Oron, Optimal performance of an immersed membrane bioreactor equipped with a draft tube for domestic wastewater reclamation, Water Sci. Technol., 54(10) (2006) 155–162.
[12] American Public Health Association, American Water Works Association and Water Pollution Federation (APHA), Standard Methods for the Examination of Water and Wastewater, 20th ed., Washington DC, 1998.
[13] T. Stephenson, S. Judd, B. Jefferson and K. Brindle, Membrane Bioreactors for Wastewater Treatment. IWA Publishing, London, 2000.
[14] S. Churchouse, S. Warren and M. Floyd, Feedback from the Porlock MBR plant in its 10th year of operation: an analysis of the flux, effluent quality and membrane lifetime data to date, Proc. 7th Aachen Conference, Water and Membranes, Aachen, Germany, 30–31 October 2007.
[15] J. Bersillon and M. A. Thompson, In Situ Evaluation and Operation in Water Treatment Membrane Processes, McGraw-Hill, Madrid, 1998.
[16] S.P. Hong, T.H. Bae, T.M. Tak, S. Hongb and A. Randallb, Fouling control in activated sludge submerged hollow fibber membrane bioreactors, Desalination, 143 (2002) 219–228.
[17] H. Choi, K. Zhang, D.D. Dionysiou, D.B. Oerther and G.A. Sorial, Influence of cross-flow velocity on membrane performance during filtration of biological suspension, J. Membr. Sci., 248 (2004) 189–199.
[18] J.-J. Qin, K.A. Kekre, G. Tao, M.H. Oo, M.N. Wai, T.C. Lee, B. Vswanath and H. Seah, New option of MBR–RO process for production of NEWater from domestic sewage, J. Membr. Sci., 272 (2006) 70–77.
[19] J.-J. Qin, M.N. Wai, G. Tao, K.A. Kekre and H. Seah, Membrane bioreactor study for reclamation of mixed sewage mostly from industrial sources, Separ. Purif. Technol., 53 (2007) 296–300.
[20] K. Kimura, R. Nishisako, T. Miyoshi, R. Shimada and Y. Watanabe, Baffled membrane bioreactor (BMBR) for efficient nutrient removal from municipal wastewater, Water Res., 42 (2008) 625–632.
[21] E. Ben-David, A. Nejidat and G. Oron, Combined PLFA-DGGE analysis of diversity, biomass and physiological status of microbial communities responsible for biofouling in wastewater membrane bioreactors. Final Report for the period September 2005–August 2007, submitted to the Ministry of Absorption of the State of Israel by The Department of Environmental Hydrology and Microbiology, Zuckerberg Institute for Water Science and Technology, The Jacob Blaustein Institutes for Desert Research, Kiryat Sde-Boker 84990, Israel, 21 p.