Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2017.20982

78 (2017) 19–23
June

Performance of external membrane bioreactor for wastewater treatment and irrigation reuse

Sarra Kitanou*, Hajar Qabli, Abdelali Zdeg, Mohamed Taky, Azzedine Elmidaoui*

Laboratory of Separation Processes, Department of Chemistry, Faculty of Sciences, Ibn Tofail University, P.O. Box 1246, Kenitra 14000, Morocco, emails: sarra.kitanou@gmail.com (S. Kitanou), elmidaouiazzedine@hotmail.com, elmidaouiazzedine@yahoo.fr (A. Elmidaoui)

Received 26 January 2017; Accepted 3 May 2017

ABSTRACT

The performance of an external membrane bioreactor in treating domestic wastewater was investigated with laboratory experimental pilot scale. The results showed that the rate of the chemical oxygen demand in the permeate could be reduced up to 27 mg/L and the biological oxygen demand concentrations of 5–8.5 mg O_2/L and total suspended solid concentration of 5.7 mg/L. In the same way, the rate of total nitrogen and total phosphorus were reduced, respectively, to 8.7 mg/L and 0.4 mg/L. Globally, the results of the investigation revealed that the external membrane bioreactor presents several advantages in terms of water resource protection because of the great quality of the treated water that can be reused for irrigation.

Keywords: External membrane bioreactor; Domestic wastewater; Ultrafiltration treatment; Irrigation reuse

1. Introduction

Domestic wastewater, municipal and industrial, contains significant amounts of organic contaminants, inorganic and microbial. These wastewaters are one of the main sources of contamination of surface water and groundwater [1]. The main aim of wastewater treatment is to decrease the danger to public health and without polluting watercourses or causing other nuisances [2].

In fact, in order to overcome the growing shortage of water resources for human consumption, the wastewater is increasingly subject to treatments for reuse. The treatment levels will vary of effluent quality required for the end use [3]. This reuse should always be performed with the aim of providing water with a specific quality linked to the intended use [4]. Therefore, conventional methods cannot be adapted, because of their lack of reliability in the quality of treated water and the risk of microbiological contamination [5]. To resolve this important issue, membrane technologies, including membrane bioreactors (MBR) may be a potential avenue for treatment and reuse of wastewater.

The advantage of these methods lies in their non-polluting aspect. It facilitates their automation and their ability to simultaneously remove various pollutants in a single processing step. These technologies provide the opportunity to clarify and simultaneously disinfect water without the risk of organo-halogen compounds formation [6].

The MBR is a hybrid technology that combines a biological system and a separation step on porous membrane. This technology is an improvement in the biological system activated sludge, almost 100 years old, which is characterized by replacing the traditional secondary clarifier by membrane filtration unit, whose remarkable selectivity represents an insurmountable barrier by purifying species, regardless of their state of flocculation [7]. The MBR technology was introduced for the first time in the 1960s, but the growing interest in its application for wastewater treatment really appeared few years later. The first marketed facilities emerged in the 1970s and 1980s for markets atypical [8]. The development has led to two types of configurations: external membrane bioreactor (EMBR) and submerged membrane bioreactor.

* Corresponding author.

The outer membrane of bioreactors is also called "recirculation system" since the mixed liquor is pumped from the aeration tank to the filtration module placed outside the bioreactor. The retentate which contains the molecules or retained particles is returned to the aeration tank. EMBR is normally operated for high concentration of inorganic compounds such as high salinity and extreme pH value that might inhibit the biodegradation process. EMBR selectively extracts specific organic pollutants that can be degraded in separated bioreactor [9].

The present study is focused on the performance of the EMBR for domestic wastewater treatment using a pilot-scale ultrafiltration (UF) membrane. The impact of operational parameters, such as chemical oxygen demand (COD), biological oxygen demand (BOD_5), total suspended solids (TSSs), total nitrogen (TN) and total phosphorus (TP), on effluent quality was evaluated. Contributions of the bioreactor and membrane module to the removal efficiency were examined. Moreover, the reuse potential of treated water was discussed by comparing with current water quality standards.

2. Materials and methods

2.1. Pilot plant configuration

The EMBR pilot plant used is manufactured by Cossimi in France. A schematic of the EMBR is shown in Fig. 1. The bioreactor is composed of an anoxic tank of 20 L and an aeration tank of 40 L. The flow is regulated grocers (between a high level and a low level of the tank anoxia) with two level sensors (rod) to maintain a constant volume of liquid in the reactor. A peristaltic pump controlled by these levels feeds the pilot in wastewater from a common tank.

A sequenced aeration is done by four diffusers placed at the bottom of the aeration reactor, providing the necessary oxygen for good treatment. The aeration cycles were fixed by the oxygen or redox transmitters which control the air blowing. The concentration of dissolved oxygen, temperature, pH and the redox in the two reactors (anoxia/aeration) can be followed by transmitter electrodes.

The UF membrane employed in the study is ceramic tubular (Membralox®) allowing the separation of the treated effluent and the purifying biomass, it is placed outside the bioreactor. Ceramic UF membranes are by far widely used for physical removal of particles from liquid in the size range of 0.01–10 µm, because of their potential advantages including chemical and thermal stability, physical strength and a longer operational life [10]. The membrane has a great chemical stability in a wide range of pH and temperature [11]. The characteristics of the membranes are listed in Table 1. The cleaning of membrane is easy and convenient in situ because these inorganic membranes possess take a high degree of resistance to chemical abrasion and biological degradation [12].

At the EMBR, the mixed liquor is circulated outside of the bioreactor to the membrane module, where pressure drives the separation of water from the sludge. The concentrated sludge is then recycled back into the aeration tank.

2.2. Inoculum and supply of wastewater

The bioreactor was inoculated with 15 L of sludge from a mesophilic (35°C) anaerobic sludge pilot digester without previous acclimatization to psychrophilic conditions. The initial concentration of sludge in the bioreactor was around 10 g/L of TSS. The pilot plant is continuously fed with the raw domestic wastewater. The wastewater sampling was done two times per week at the outlet of the sanitary sewer network of the city of Kenitra.

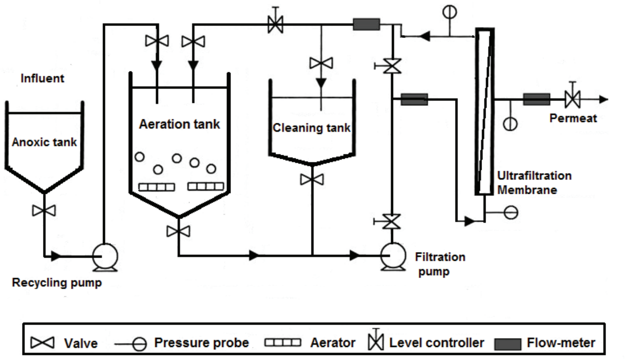

Fig. 1. Schematic of EMBR pilot plant.

Table 1
Characteristics of the membranes used. Ref: KB6L 03XU1-E (Kleansep)

Membrane material	Ceramic
Module	Tubular type P10
Filter area	0.45 m²
Cut-off	15 kD/10–20 nm
Provider	Pall Exekia
Membrane length	1,178 cm
Diameter of the channels	6 mm

2.3. Chemical assays and sampling

The supply of wastewater and permeate of the MBR are characterized daily: COD (Hach DR2800 Spectrophotometer) and suspended solids are determined following sample filtration through 0.45 µm. Biochemical oxygen demand (BOD) was estimated by 5-d BOD test (standard method) [13]. Three times per week, the concentration of mixed liquor volatile suspended solids of the sludge is also ascertained. The TN and TP were analyzed with reagent kits (HACH DR4000, USA) and estimated by standard methods. Also, the disinfectant efficacy of EMBR was evaluated, analyses of total coliforms were carried out in the bacteriology laboratory using the filter membrane method. The analysis of heavy metals (zinc, iron and copper) concentration was made by inductively coupled plasma mass spectrometry method. The sampling and all analyses are determined according to the standard methods for examination of water and wastewater [14,15].

3. Results and discussion

3.1. Analysis of domestic wastewater before treatment

The quality of domestic wastewater was examined every day during the period of study. Apparently, it was grey in color with mordant smell. Parameters of the domestic wastewater are listed in Table 2, were within the standard limits of World Health Organization (WHO) and US-EPA [16,17]. However, TSS (379.60 mg/L), BOD_5 (400 mg/L) and COD (531 mg/L) were considerably deviated from their prescribed limits, indicating the high level of contamination. Pollution loads are assumed to be all of domestic origin. As shown, the wastewater characteristics can represent the medium-strength urban wastewater seen in Morocco and in most cities around the world [18,19].

3.2. Variation of pH, temperature and conductivity in the EMBR

The results in Table 3 show a means of temperature in the influent 20°C, while it is substantially constant in the bioreactor and the permeate. These are favorable values for the operation of bioreactors and acceptable for irrigation reuse. The pH influent is stable with an average value of 7.5 indicating a low alkalinity [20], this average is in the range of Moroccan standards. The pH in the bioreactor is almost constant. The conductivity of the influent varies between 1,332 and 1,997 μS/cm with an average of about 1,688 μS/cm. A reduction in the conductivity was recorded in the bioreactor and the permeate, the respective averages are 1,094 and 931 μS/cm. This decrease is attributed to the natural water mineralization [21]. The averages are near of Moroccan water quality standards for irrigation [22].

3.3. Removal of COD, BOD_5, TSS, nitrogen and phosphorus

The removal efficiency of COD, BOD_5 and suspended solids in the samples is shown in Fig. 2. The mean concentration of COD, BOD_5 and suspended solids in the effluent were, respectively, 531.04, 400.04 and 397.60 mg/L. It should be noted that more than 94.91%, 98.36% and 98.58% of COD, BOD_5 and TSSs were removed (Table 4).

During the days of operation, the COD concentration in the effluent was maintained at 531.04 mg/L. The chemical oxygen demand on average eliminated in the bioreactor was 70.86%. In the permeate, 94.91% of COD was eliminated. The average value of COD in the permeate is about 27 mg/L. This parameter measures the oxidized material in concentration of suspended and dissolved organic origin without distinction or inorganic [14].

In the same way, 89.27% of biological oxygen demand was eliminated in the aeration tank and 98.37% in the permeate. This indicator used to measure the biochemical oxygen demand for the natural destruction of the organic matter present in water [14].

Also, the average of suspended solids eliminated in the bioreactor was 80.35% and in the permeate was 98.65%. Suspended solids represent solids (small particles of solid pollutants) contained in the waste water [23]. They may be retained by filtration or centrifugation [14]. These results demonstrate that the UF treatment is more effective in treating wastewater [23].

Fig. 3 shows the mean values of TN and TP present in the influent, in the bioreactor and in the permeate (effluent from the membrane). Most of the TN in domestic sewage were present as NNH_4^+ [24]. However, the mean concentration of TN in influent is 52.75 mg/L and decreases to 25.4 mg/L in the bioreactor and to 8.7 mg/L in the permeate. This decrease of the nitrogen content throughout the operation of the EMBR could be due to both the hydrolysis of the accumulated particulate organic matter and the cell disintegration. The removal efficiency of TN was 83.51%.

The phosphorus concentration has undergone a similar evolution, a significant difference in the average was between the TP concentration in the influent and the permeate. The mean value of TP elimination at the outlet of membrane treatment is 0.4 mg/L. Also, a significant decrease of TP concentration was recorded within the bioreactor. The removal efficiency of the TP was 93.75%. In this regard, a decrease of TN and the concentration of TP in the permeate was observed by Chen et al. [25], in which an MBR was used to treat wastewater, achieving almost 100% removal of TP and 62% removal on nitrogen.

Table 2
Characteristics of domestic wastewater

Parameter	Influent concentration	Moroccans standards[a]	International standards[b]
Temperature, °C	16–20	<30	25–35
pH value	7–8.5	5.5–9.5	6.5–8
Turbidity, NTU[c]	300–650	–	50–100
COD, mg/L	365–746	500	250–400
BOD_5, mg/L	236–611	100	130–180
TSS, mg/L	235–569	100	80–160
TN, mg/L	40.5–60	40	3–5
TP, mg/L	7.5–8.5	15	1–3

[a]Moroccan pollution standards – limits rejection to abide by spills.
[b]The American National Standards help in evaluating and approving water reuse treatment technologies. The New NSF 35.
[c]Nephelometric Turbidity Unit.

Table 3
Mean value of pH, temperature and conductivity in samples

Parameter	Influent	Bioreactor	Permeate	Reuse standards
T (°C)	20	25	17.5	35
pH	7.5	7.4	8.6	8.4
Conductivity (μS/cm)	1,688	1,093.8	930.4	1,200

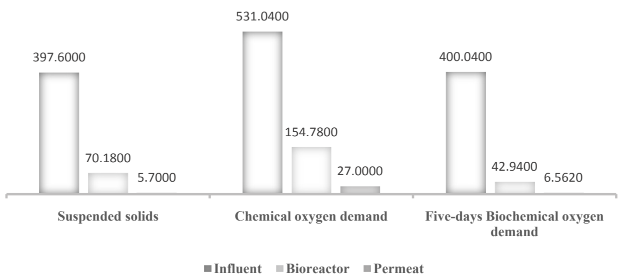

Fig. 2. Average of removal COD, BOD_5 and suspended solids.

Table 4
Percentage of the reduction of physicochemical parameters (pollution) of treated wastewater by EMBR

Parameters	Influent	Bioreactor	Abatement rate (%)	Permeate	Abatement rate (%)
TSS, mg/L	397.6	70.18	82.35	5.7	98.56
COD, mg/L	531	154,5	70.90	27	94.91
BOD_5, mg/L	400	42.94	89.25	6.56	98.36
TN, mg/L	52.75	25.4	51.85	8.7	83.51
TP, mg/L	8	2.75	65.63	0.5	93.75

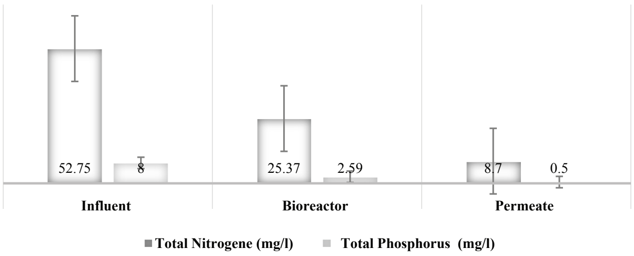

Fig. 3. Total nitrogen and phosphorus concentration in the sample (mean values) during the entire period of operation.

3.4. Quality of EMBR effluent and irrigation water standards

In regulating the reuse of treated wastewater, chemical parameters must be considered alongside the biological parameters. These settings are also related to the protection of health and the environment (soil, water, etc.). The important chemical parameters to consider are the following: pH, electrical conductivity, TSSs, biodegradable organic compounds (COD and BOD), nutrients (TN and TP), bacteriological test (total coliforms), and elements metal traces or heavy metals [26]. The effluent quality of the EMBR is listed in Table 5.

As shown, the COD value in the permeate was 27 mg/L, it is less than 100 mg/L value of Moroccan irrigation stands [22]. Regarding BOD_5, it was in range of 6,056 mg/L, which is less than 20 mg/L value of Moroccan irrigation reuse standards [20]. For the TSS, the concentration in the permeate was 5.7 mg/L which is less than 50 mg/L limit value for irrigation reuse in Morocco [22]. The observation of TP was above <2 mg taken as the threshold value for Moroccan standards irrigation [26]. This predictable removal of nitrogen and phosphorus in the EMBR could be beneficial if the effluent will be used for agriculture or irrigation [27].

Also, the results of the bacteriological analysis show an absence of the total coliforms at the exit of the EMBR (permeate), while an important value was detected at the influent [26]. These results confirm those of the literature, obtained for processing by MBR located in Perthes-en-Gatinais [24], which reveal that the application of MBR allows an efficient elimination of pathogenic indicators (total and fecal coliforms), viruses and bacteria. Indeed, the small size of the pores of the UF membrane makes it possible to block all the bacterial species.

Concerning the removal of heavy metals from wastewaters, in our study, we made analyses of three main heavy metals (zinc, iron and copper), the results are listed in Table 5. The analyses show that the concentration of the three heavy metals present in the permeate conforms with the irrigation reuse standards. Also, these results are consistent with those indicate

Table 5
Permeate quality and irrigation water standards

Parameter	EMBR effluent	Water irrigation reuse[a]
pH value	8.6	6.5–8.4
Temperature, °C	17.5	35
Conductivity, µS/cm	930.5	1,200
COD, mg/L	27	100
Five-day BOD, mg/L	6.6	20
TSS, mg/L	5.7	<50
Total nitrogen, mg/L	8.7	<5
Total phosphorus, mg/L	0.4	<2
Iron (Fe), mg/L	2.5	5
Copper (Cu), mg/L	0.2	0.2
Zinc (Zn), mg/L	1.7	2
Total coliformes, FCU/100 mL	ND[b]	<1,000/100 mL

[a]These are the maximum permissible values according to Directive FAO and Water reuse standard for irrigation, land watering, Morocco [28].
[b]ND, not detected. The bacteriological test was negative. The ultrafiltration membrane could effectively retain the bacteria (size from 0.5 to 5 mm).

the maximum concentration of trace elements in irrigation water (Table 5) by FAO [28]. However, membrane processes such as UF, nanofiltration and reverse osmosis have proven their competitiveness in removal of metals from wastewater because of their low energy requirement, small volume of retentate, and high selectivity [29]. The removal of toxic metals makes wastewater safe for reuse and contribute to water sustainability [28]. These, when present, can cause health risks by transfer and accumulation from water, via plants, to humans.

These results comply with Moroccan irrigation norms, which has enacted Ordinance No. 1276-1201 establishing the water quality standards for irrigation. Besides, the conductivity rate in the permeate has to decrease further, to get, a reverse osmosis or nanofiltration should be considered. However, the EMBR system can provide a good-quality effluent that is completely acceptable for reuse in irrigation [22,30]. Therefore, lots of urban wastewater can be effectively harnessed, and moreover, large quantities of water could be saved [27].

4. Conclusion

Today, the MBR is in full-swing optimization and their future looks very promising in application fields varied as the food, irrigation or the urban wastewater treatment.

The association of a biological reaction and separation by porous membrane displays several advantages compared with the traditional activated sludge process, such as high effluent quality and space requirement. In addition, it presents several advantages in terms of water resource protection because of the great quality of the treated water that can be reused for irrigation. However, the quality of the water, notably the absence of solids in suspension and turbidity, allows considering the EMBR as a perfect tool for pre-treatment before desalination or preparation of water of very high quality. Moreover, because of its modular property, the EMBR may also be favorable for developing a new wastewater network configuration in an urban area.

The high quality of effluent, free from solids and germs, meets many of the current quality standards throughout the world and will meet the increasingly stringent standards of tomorrow. The results of the investigation revealed that external membrane bioreactors are potential alternative wastewater treatment processes, particularly, when the reuse of wastewater is considered as a vital option. The removal efficiency of COD was on the average as high as 94.91%, in which 70.9% was attributed to the bioreactor and the residual 24% resulted from membrane separation. However, other contaminants present in the sludge such as TN and TP should be further investigated to improve their removal efficiencies. Finally, the EMBR is a potential alternative to treat wastewater, especially, for the reuse of wastewater for irrigation.

References

[1] W. Lukenga, Water Resource Management, 1st ed., Bookboon, London, UK, 2015, pp. 12–48.

[2] M. Templeton, D. Bultler, An Introduction to Wastewater Treatment, Bookboon, London, UK, 2011, pp. 8–16.

[3] S. Vigneswaran, M. Sundaravadivel, Recycle and Reuse of Domestic Wastewater, Wastewater Recycle, Reuse and Reclamation, Encyclopedia of Life Support Systems, UNESCO, Oxford, UK, 2004, pp. 1–29.

[4] J. Wood, Water Quality and Public Health: Risks and Prevention in Health Assessments and Global Potable Use Case Studies, A Report of a Study Funded by the Australian Water Recycling Center of Excellence, New South Wales, 2015.

[5] F.I. Hai, T. Riley, S. Shawkat, S.F. Magram, K. Yamamoto, Removal of pathogens by membrane bioreactors: a review of the mechanisms, influencing factors and reduction in chemical disinfectant dosing, Water, 6 (2014) 3603–3630.

[6] B. Seyhi, P. Droguil, G. Buelna, J.F. Blais, M. Heran, State of the art of the membrane bioreactor processes for urban and industrial wastewater treatment and reuse, Water Sci., 24 (2011) 283–310.

[7] R. Bourrier, M. Satin, B. Selmi, Guide technique de l'assainissement, Le Moniteur (Ed.), 4th ed., Paris, 2010, pp. 409–486.

[8] J. Yang, Membrane Bioreactor for Wastewater Treatment, 1st ed., Bookboon, China, 2013, pp. 18–62.

[9] N.S. Ahmad Mutamim, Z.Z. Noor, M.A. Abu Hassan, A. Yuniarto, G. Olsson, Membrane bioreactor: applications and limitations in treating high strength industrial wastewater, Chem. Eng. J., 225 (2013) 109–119.

[10] N.L. Le, S.P. Nunes, Materials and membrane technologies for water and energy sustainability, Sustain. Mater. Technol., 7 (2016) 1–28.

[11] N. Yin, Z. Zhong, W. Xing, Ceramic membrane fouling and cleaning in ultrafiltration of desulfurization wastewater, Desalination, 319 (2013) 92–98.

[12] E. Mancha, W.S. Walker, J. Sutherland, T.F. Seacord, D. Hugaboom, Texas Water Development Board, Alternatives to Pilot Plant Studies for Membrane Technologies, 2014.

[13] C. Bliefert, R. Perraud, Chimie de l'environnement, De Boeck (Ed.), 2nd ed., 2009, pp. 317–330.

[14] J. Rodier, B. Legube, N. Merlet, L'analyse de l'eau, 9th ed., Paris, 2009.

[15] S. Lenore, E. Arnold, D. Andrew, Standard Methods for the Examination of Water and Wastewater, 21th ed., American Public Health Association (APHA), American Water Works Association (AWWA), Water Pollution Control Federation (WPCF), Washington, D.C., 2005.

[16] Anonymous, Guidelines for Drinking Water Quality: Recommendations, World Health Organization (WHO), 3rd ed., Geneva, 2004.

[17] Anonymous, EPA, Wastewater Technology: Fact Sheet Trickling Filter Nitrification, U.S. Environmental Protection Agency (USEPA), Washington, D.C., 2006.

[18] Anonymous, Préservation de la qualité des ressources en eau et lutte contre la pollution, Valeurs Limites de Rejet à respecter par les déversements (Normes de pollution), Rabat, 2014.

[19] T. Bruursema, The American National Standards Help in Evaluating and Approving Water Reuse Treatment Technologies, The New NSF 350 and 350–1, Plumbing Systems & Design Magazine, 2011.

[20] M.L. Salazar Pelaez, J.M. Morgan Sagastume, A. Noyola, Influence of hydraulic retention time on fouling in a UASB coupled with an external ultrafiltration membrane treating synthetic municipal wastewater, Desalination, 277 (2011) 164–170.

[21] E. Shakir, Z. Zahraw, A.H.M.J. Al-Obaidy, Environmental and health risks associated with reuse of wastewater for irrigation, Egypt. J. Pet., 26 (2016) 95–102.

[22] Anonymous, Normes de qualité des eaux destinées à l'irrigation, Secrétariat d'Etat auprès du Ministère de l'Energie, des Mines, de l'Eau et de l'Environnement, chargé de l'Eau et de l'Environnement, Rabat, 2007.

[23] J. Gagnaire, P. Moulin, B. Marrot, Bioréacteurs à membranes; un intérêt grandissant, Département de Procédés Propres et Environnement, Revue E.I. N, 314 (2008) 64–74.

[24] J. Baudart, N. Paniel, Sources and fate of pathogenic microorganisms in aquatic environments, Revue Francophone des Laboratoires, 495 (2014) 29–39.

[25] L. Chen, Y. Gu, C. Cao, J. Zhang, J.W. Ng, C. Tang., Performance of a submerged anaerobic membrane bioreactor with forward osmosis membrane for low-strength wastewater treatment, Water Res., 50 (2014) 114–123.

[26] Anonymous, Water Resources Sustainability Project (WRS), United States Agency for International Development (USAID), Rabat, 2004.

[27] DAI, Compétitivité économique du Maroc, Ebauche de révision des normes de qualité des eaux usées traitées destinées à l'irrigation des cultures et a l'arrosage des espaces verts, USAID, Rabat, 2013.

[28] M. Barakat, New trends in removing heavy metals from industrial wastewater, Arab. J. Chem., 4 (2011) 361–377.

[29] R. Abhanga, K. Wanib, V. Patilc, B. Pangarkara, S. Parjanea, Nanofiltration for recovery of heavy metal ions from waste water – a review, Liver, 1 (2013) 29–34.

[30] G. Tchobanoglous, F.L. Burton, Wastewater Engineering: Treatment and Reuse, 4th ed., Metcalf & Eddy, Singapore, 2003.