Integrated and Hybrid Process Technology for Water and Wastewater Treatment

Edited by
Abdul Wahab Mohammad
Wei Lun Ang

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CHAPTER

22

Municipal wastewater treatment processes for sustainable development

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22.1 Municipal wastewater

Municipal wastewater is wastewater from households or a mixture of wastewater from households and industry (Malik et al., 2015). The pollutants present in wastewater include organic compounds, nutrients, and micropollutants from plastics and pharmaceuticals. As a result, wastewater, if improperly treated, poses a serious threat to freshwater aquifers and human health. In 2015 the United Nations (UN) announced a collection of 17 interlinked microalgae-based nutrient recovery and coproducts., which are a blueprint to achieve a better and more sustainable future for all and are intended to be achieved by the year 2030. The UN's sustainable development goal (SDG) 6 is concerned with clean water and sanitation for all. Specifically, the aim of SDG 6 is to ensure availability and sustainable management of water and sanitation for all.

Since micropollutants in municipal wastewater can pose a serious risk to human health and the environment, governments around the world have increasingly attached greater importance to the issue (Berendonk et al., 2015; WHO, 2015, 2017). The micropollutants commonly present in municipal wastewater include bisphenol A, phthalates,

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pharmaceuticals, aromatic compounds, and nonmetabolized compounds in human waste (Gurung, Ncibi, & Sillanpaa, 2019; Lei et al., 2018; M. et al., 2020; Rizzo et al., 2013; Wang & Wang, 2018, 2019).

The World Health Organization and the US Environmental Protection Agency classify phenols and phthalates as endocrine disrupting chemicals because of their harmful effects on the reproductive system, neural development, and immune system (Boonnorat et al., 2018). The micropollutants in municipal wastewater come from various sources, including households, hospitals, crop plantations, and industry (Clara et al., 2005). Several micropollutants are degradation-resistant compounds, rendering conventional biological wastewater treatment systems, for example, activated sludge (AS), less effective in removing the compounds, when compared with membrane bioreactor (Gurung et al., 2019; Kanyatrakul et al., 2020; M. et al., 2020).

In view of the UN's SDG 6 on clean water and sanitation for all, this article investigates the current wastewater treatment technology for removal of micropollutants in municipal wastewater and water reclamation and reuse. The aim of wastewater reclamation and reuse is to ensure availability and sustainable management of water and sanitation for all.

22.2 Membrane bioreactor for removal of micropollutants in municipal wastewater and technology development

Membrane bioreactor (MBR) is an advanced wastewater treatment technology that integrates membrane filtration with AS technology. The treatment performance is dependent on classes of membrane filtration, and there are four classes of membrane filtration: microfiltration, ultrafiltration, nanofiltration, and reverse osmosis.

Microfiltration is the membrane class of largest pore size. Microfiltration membranes can filter suspended particles of 0.1−10 μm in diameter. Ultrafiltration membranes can filter macromolecules with molecular weight of 1000−5000,000 Da. Nanofiltration membranes can filter molecules with 100−1000 Da in molecule weight (Cheryan, 1998). Besides, nanofiltration membranes can remove contaminants as small as 0.001 μm (Taylor & Jacobs, 1996). Reverse osmosis membranes are capable of filtering the particles with a diameter as small as 0.0001 μm (Taylor & Jacobs, 1996).

The advantages of MBR include process stability, compact operation, high throughput, and high removal efficiency (Sanguanpak, Chiemchaisri, & Chiemchaisri, 2019). MBR is thus operationally ideal for municipal wastewater treatment, given the scarcity of space in urban areas and large daily volumes of municipal wastewater generated by urban residents. Fig. 22.1 shows the MBR treatment technology, MBR removal mechanisms, and filtration capability of the four classes of membrane filtration.

The micropollutant removal of MBR entails three mechanisms: adsorption, biodegradation by microorganisms, and membrane filtration (Boonyaroj et al., 2017). The adsorption efficiency is a function of the octanol−water partition coefficients (K_{ow}) of micropollutants. A micropollutant with high K_{ow} is readily adsorbed onto the membrane surface and microbial sludge, while that with low K_{ow} is removed in aqueous form and biodegraded by microorganisms (Boonyaroj et al., 2017). Meanwhile, the performance of membrane filtration is closely related to membrane pore size. Gurung et al. (2019) investigated the

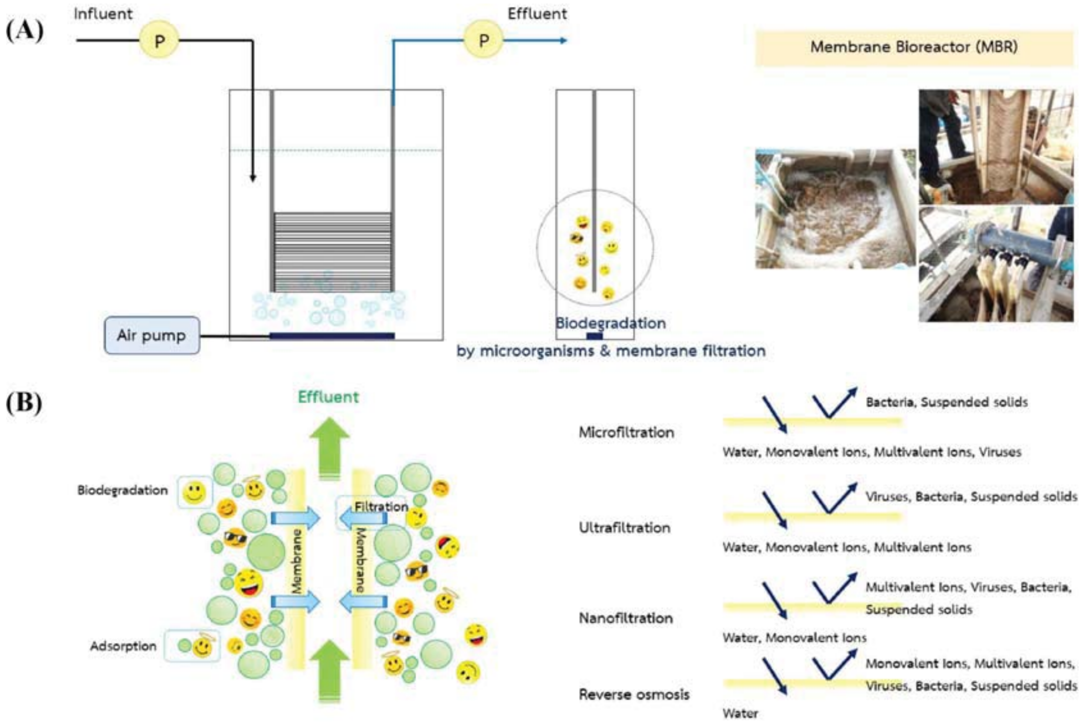

FIGURE 22.1 Membrane bioreactor technology and mechanisms and filtration capability of four membrane classes. Source: *Modified from* Honda et al. (2012) *and* Sanguanpak et al. (2019)

removal efficiency of 23 micropollutants in municipal wastewater using pilot-scale MBR under two solid retention time (SRT) conditions: 60 and 21 days. The micropollutants under study were pharmaceuticals and steroid hormones. The result showed that the micropollutant removal efficiency was positively correlated to SRT.

Furthermore, Tadkaew et al. (2011) documented that the determinants of micropollutant removal efficiency are the hydrophobicity, molecular weight, and chemical structure of micropollutants. Hydrophobic micropollutants are mostly removed by adsorption. Meanwhile, the removal efficiency of micropollutant is positively correlated with the molecular weight of the compound.

In addition, micropollutants can be classified into three groups by function and removal efficiency: electron-withdrawing (EWG) micropollutants with low removal efficiency; electron-donating (EDG) micropollutants with high removal efficiency; and EDG/EWG or EDG micropollutants with low removal efficiency. Fig. 22.2 shows, as an example, the chemical structure of EWG and EDG micropollutants.

The bacterial species reported in previous research that can degrade micropollutants in municipal wastewater including *Agrobacterium* sp. H13-3 (Wu et al., 2011), *Pseudomonas* sp. UW6, *Nitrosococcus* sp., *Nitrosomonas* sp., and *Nitrospira* sp. (Boonnorat et al., 2018; Fernandez-Fontaina et al., 2012).

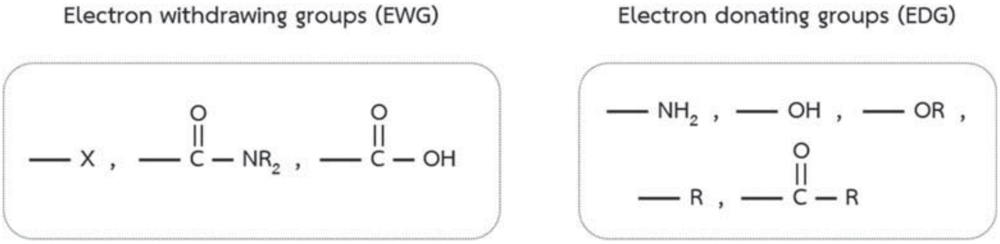

FIGURE 22.2 The chemical structure of EWG and EDG micropollutants. Source: *From Tadkaew, N. et al. (2011). Removal of trace organics by MBR treatment: The role of molecular properties. Water Research. Australia: Elsevier Ltd, 45(8), 2439–2451. https://doi.org/10.1016/j.watres.2011.01.023.*

Reclaimed wastewater is reused for various purposes, including irrigation of gardens and agricultural fields or replenishing surface water and groundwater. However, evidence shows that reuse of improperly treated wastewater (i.e., containing micropollutant residues) could result in stunted crop growth and poor seed germination (Wu et al., 2015). In addition, concerns exist over translocation of micropollutants to the crops and pose serious health risks to consumers (Christou et al., 2017; Hurtado et al., 2016; Wu et al., 2015).

Furthermore, certain antibiotic-resistant bacteria remain in effluent treated by conventional biological wastewater treatment systems due to limited capability of the biological treatment technology in removing the microbes (Christou et al., 2017; Tijani, Fatoba, & Petrik, 2013). As a result, a more effective wastewater treatment technology, specifically MBR, should be adopted to treat municipal wastewater to minimize the micropollutant residues and antibiotic-resistant bacteria in treated wastewater. M. et al. (2020) proposed MBR with nanofiltration/reverse osmosis system for municipal wastewater reclamation because of high micropollutant removal efficiency.

MBR was mostly use for municipal wastewater for responsible to water reclamation and reuse. However, conventional activated sludge-based MBRs pose operational problems such as membrane fouling, high energy consumption, and limited nutrient removal capability (Nguyen et al., 2012). One problem of MBR is membrane fouling, which operators have to clean membrane and it can be the cost in system operation. The development of MBR to overcome these problems (Nguyen et al., 2015) focused a novel osmotic membrane bioreactor (OsMBR) with the following unique features was developed: (1) osmotic pressure is used as the driving force instead of hydraulic pressure; (2) forward osmosis membranes show high rejection for a wide range of contaminants; and (3) the membranes have a low fouling tendency. Nevertheless, a major technical challenge to OsMBR application was the lack of appropriate draw solutions that could reduce salt accumulation and membrane fouling during long-term operation (Ge et al., 2012; Kim, 2014).

The use of sponge-based moving bed in membrane bioreactor was the one innovation in wastewater treatment for enhance nutrients removal by nitrification/denitrification and include reduction of membrane osmotic pressure during operations (Nguyen et al., 2016) (Fig. 22.3). The innovative concept of combining sponge-based moving based and osmotic membrane bioreactor (SMB-OsMBR) hybrid system was investigated using Triton X-114 surfactant couple with MgCl2 salt as the draw solution. This solution can reduce salt accumulation, low fouling, and high nutrients removal efficiency.

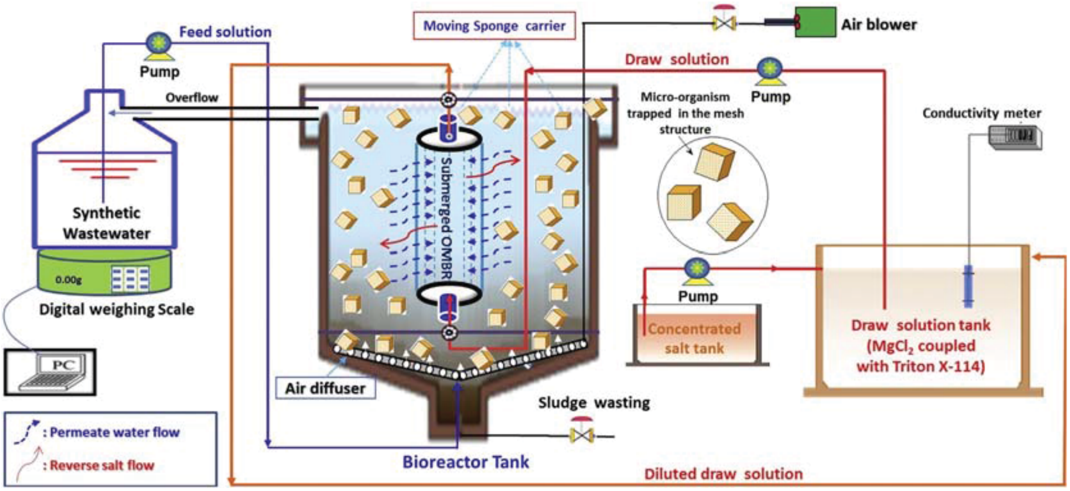

FIGURE 22.3 The sponge-based moving based and osmotic membrane bioreactor. Source: *From Nguyen, N.C. et al. (2016). Innovative sponge-based moving bed-osmotic membrane bioreactor hybrid system using a new class of draw solution for municipal wastewater treatment. Water Research. Taiwan: Elsevier Ltd, 91, 305–313. https://doi.org/10.1016/j.watres.2016.01.024.*

The variation of the water flux and amount of salt accumulation with the operating duration was examined using synthetic wastewater as the feed solution. The nutrient removal efficiency was then determined in the SMB-OsMBR hybrid system for the proposed draw solution. Finally, the membrane fouling characteristics were analyzed using scanning electron microscopy and energy dispersive x-ray spectroscopy (SEM-EDS), and fluorescence excitation-emission matrix spectrophotometry.

Fig. 22.4 showed most of the microorganisms were attached to the sponge carriers rather than the membrane, which prevented membrane fouling. Hence, the moderate decrease in the water flux suggested that membrane fouling in the SMB-OsMBR. The SMB-OsMBR system was able to remove more nutrients due to the thick-biofilm layer on sponge carriers. Subsequently less membrane fouling was observed during the wastewater treatment process. A water flux of 11.38 L/(m^2 h) and a negligible reverse salt flux were documented when deionized water served as the feed solution and a mixture of 1.5 M $MgCl_2$ and 1.5 mM Triton X-114 was used as the draw solution. The SMB-OsMBR hybrid system indicated that a stable water flux of 10.5 L/(m^2 h) and low salt accumulation were achieved in a 90-day operation. Moreover, the nutrient removal efficiency of the proposed system was close to 100%, confirming the effectiveness of simultaneous nitrification and denitrification in the biofilm layer on sponge carriers. The overall performance of the SMB-OsMBR hybrid system using $MgCl_2$ coupled with Triton X-114 as the draw solution demonstrates its potential application in wastewater treatment.

In Singapore, NEWater is produced from the secondary effluent of the conventional biological treatment with membrane technology included microfiltration, reverse osmosis (RO) followed by UV disinfection. In water treatment system with multistage processes

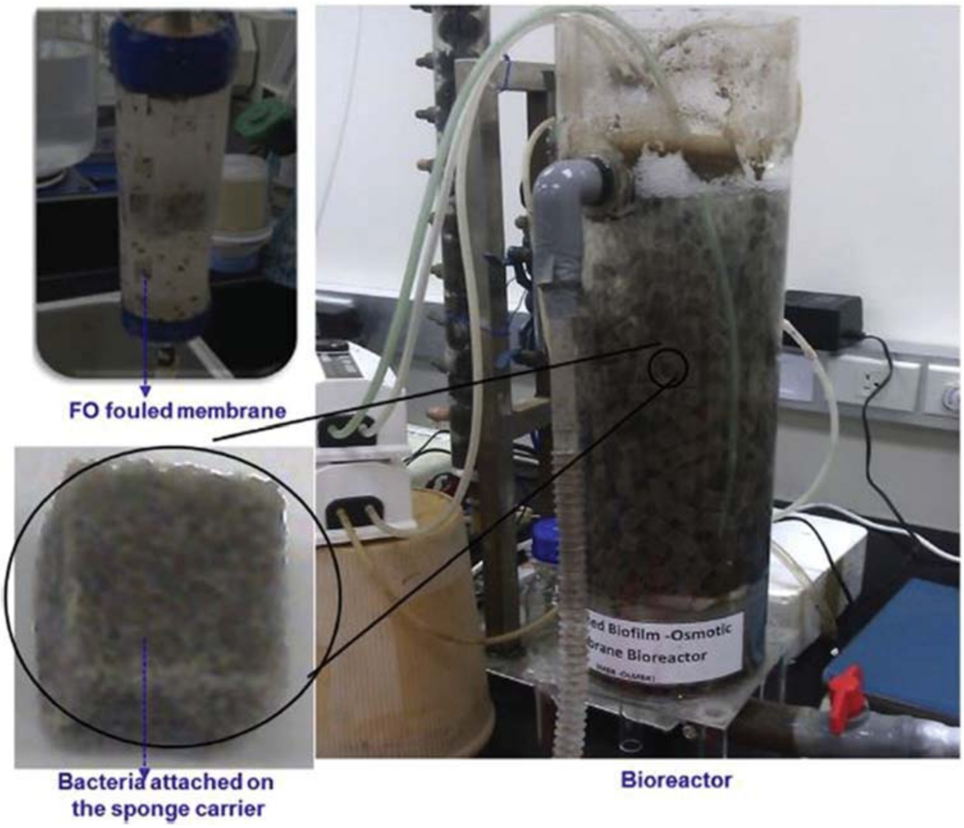

FIGURE 22.4 The microorganisms attached to the sponge media and membrane during system operation. Source: *From Nguyen, N.C. et al. (2016). Innovative sponge-based moving bed-osmotic membrane bioreactor hybrid system using a new class of draw solution for municipal wastewater treatment. Water Research. Taiwan: Elsevier Ltd, 91, 305–313. https://doi.org/10.1016/j.watres.2016.01.024.*

have been criticized due to the high process complexity, intensive energy consumption, and large footprint (Cornejo, Zhang, & Mihelcic, 2016). In recent years, the integration of aerobic MBR and RO has been applied for high-grade reclaimed water production from wastewater in pilot-scale and further progressed to full-scale implementation with the advantage of process robustness and compact footprint (Lay et al., 2017). However, the core of these processes is greatly built on the principle of biooxidation, in which COD is converted to carbon dioxide with a huge amount of excess sludge production, while nitrogen is removed through nitrification-denitrification at the expense of high energy consumption. About 50% of the in-plant energy was consumed by aeration for the purpose of biooxidation (Panepinto et al., 2016), and proper handling of waste sludge produced has become a great challenge in many countries (Michał, Jacek, & Piotr, 2015). Therefore, the treatment processes and water reclamation are needed toward improved energy efficiency and environmental sustainability.

The anaerobic membrane bioreactor (AnMBR) has received great attention due to the advantages of high-quality effluent with neglectable solids and short start-up period (Ozgun et al., 2013). Previously, its application in municipal wastewater treatment was challenged due to the dilute nature of municipal wastewater (Song et al., 2018). In recent years, studies have proved the feasibility of AnMBR for municipal wastewater treatment (Wu et al., 2017). However, it should be noted that AnMBR is ineffective for nutrients (N, P) removals (Pretel et al., 2016), which require further treatment. In addition, the RO has been widely used to reclaim municipal wastewater treated with conventional processes, while it can remove nutrients from effluent.

Gu et al. (2019) studied the improvement of energy efficiency and sustainability with process design, treatment performance, energy recovery, and consumption for recommendation the rearrangement of NEWater treatment process. These factors were calculated by the experimental results and membrane trans pressure between the integrated AnMBR-RO-IE and NEWater production process. The energy consumption and mass flows of carbon and nitrogen of both processes were showed in Fig. 22.5 and the effluent characteristics of integrated process compared to NEWater process was showed in Table 22.1.

This study evaluated the feasibility of an innovative integrated anaerobic membrane bioreactor—reverse osmosis—ion exchange (AnMBR-RO-IE) process for municipal wastewater treatment. The objective of this innovation is to upgrade water reclamation with high energy efficiency and low waste sludge production. In this integrated process, an AnMBR was employed as the lead for energy recovery through direct COD capture, and AnMBR effluent was subsequently reclaimed to NEWater-like product through combined RO and IE. Results showed that nearly 76.8% of influent COD was converted to methane (CH_4) in AnMBR equivalent to 0.41 kWh/m^3 wastewater treated, while more than 95% of organic carbon, ammonium, phosphate, major ions, and cations in AnMBR effluent were rejected by RO after further polishing by IE. The treated water quality appeared to be comparable or even better than the typical NEWater quality in Singapore. This study showed that the integrated AnMBR-RO-IE process could produce NEWater-like product water with compact footprint, near-zero sludge production, high operation stability, maximized energy recovery and reduced energy consumption compared to the current process for NEWater production from municipal wastewater. It is expected that the proposed process can offer new insights into the direction of future wastewater reclamation.

22.3 A case study of municipal wastewater reclamation and reuse in Thailand

22.3.1 The environmental education and conservation center

The *Bang Sue* Environmental Education and Conservation Center (EECC) in Thailand's capital Bangkok is a two-story administrative building with a submerged municipal wastewater treatment facility using MBR and membrane filtration. The EECC project is the first pilot project in Southeast Asia for submerged wastewater treatment system. The façade of the administrative building facing the park showcases a 100-meter-long curvaceous cascading waterfall. The waterfall utilizes recycled water from the submerged treatment facility.

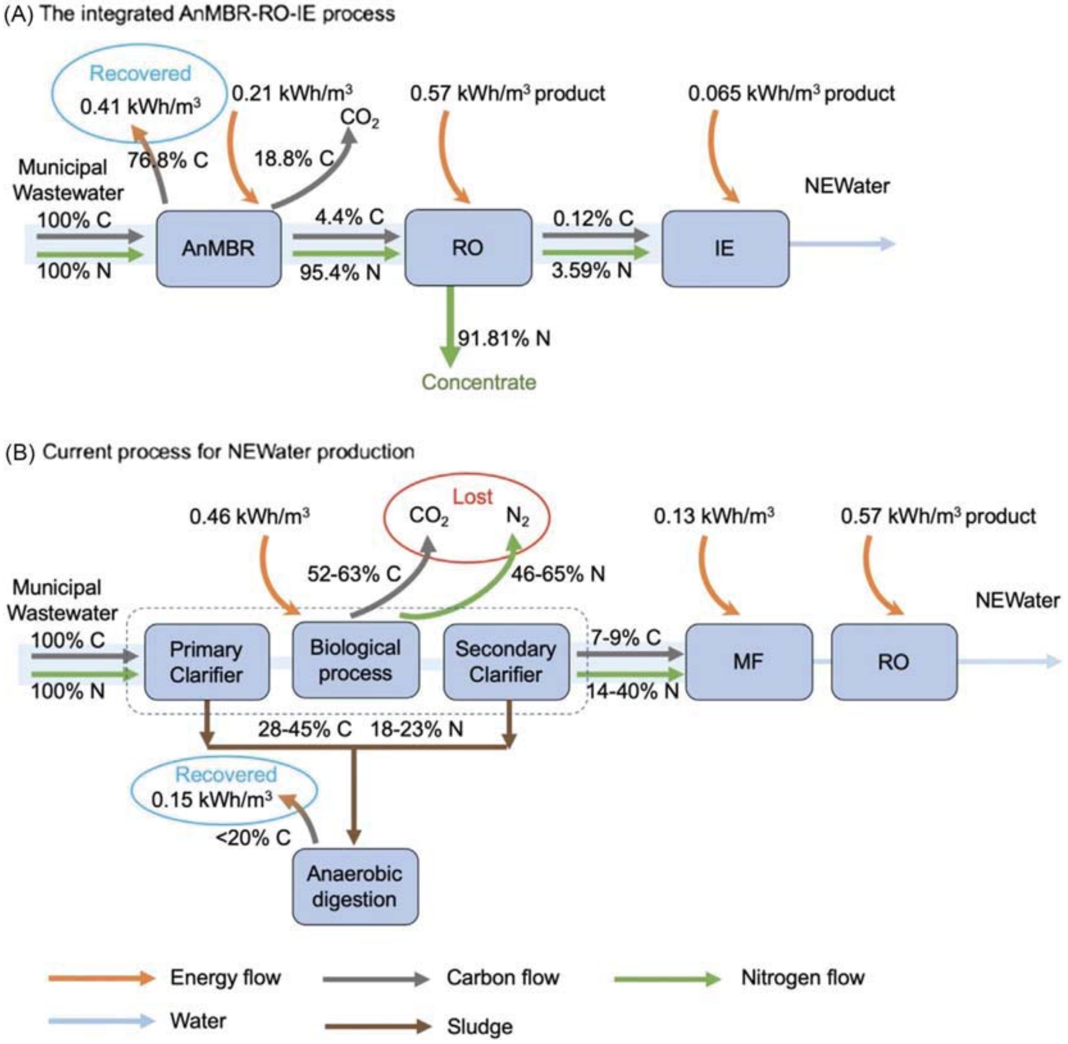

FIGURE 22.5 Energy consumption and mass flows of carbon and nitrogen in (A) the integrated AnMBR-RO-IE and (B) the present NEWater production process. Source: *From Gu, J. et al. (2019). An innovative anaerobic MBR-reverse osmosis-ion exchange process for energy-efficient reclamation of municipal wastewater to NEWater-like product water. Journal of Cleaner Production. Singapore: Elsevier Ltd, 230, 1287–1293. https://doi.org/10.1016/j.jclepro.2019.05.198.*

The EECC administrative building also houses the Ecology Conservation Center and a learning center for indigenous plants and aquatic plants. The aims of the centers are to increase awareness and educate visitors about the importance of the environment and natural resources. Surrounding the EECC building is the recreational park irrigated by reclaimed wastewater from the underground treatment facility. Inside the park is a well-designed and elaborate nexus of bicycle lanes, paved walkways, and jogging routes.

TABLE 22.1 Effluent characteristics of integrated process compared to NEWater process.

Parameters (mg/L)	After AnMBR	After RO	After IE	NEWater[a]
NH_4^+-N	41.90	2.10	<1.00	1.00
PO_4^{3-}-P	4.41	0.03	0.03	not specific
TOC	3.60	0.13	0.13	0.50
Na	132.70	3.20	3.50−6.60	20.00
K	10.18	0.084	<0.01	not specific
Ca	31.20	0.05	<0.01	1.00
Fe	0.33	<0.005	<0.005	0.04
Cl	157.80	4.70	4.70	20.00
SO_4^{2-}	31.90	0.50	0.50	5.00
Conductivity (μS/cm)	1127.00	47.00	<39.00	100.00

[a] *Information from PUB (2017).*

From Gu, J. et al. (2019). An innovative anaerobic MBR-reverse osmosis-ion exchange process for energy-efficient reclamation of municipal wastewater to NEWater-like product water. Journal of Cleaner Production. Singapore: Elsevier Ltd, 230, 1287−1293. https://doi.org/10.1016/j.jclepro.2019.05.198.

The landscaped area of the park, partially covering a treated wastewater reservoir and linked by wooden boardwalks, is an open water garden showcasing aquatic plants of diverse botanical varieties. The water garden also provides ample space for sports, outdoor activities, and live musical miniconcerts. The landscape, in the ripple pattern, blends the facility (i.e., building and underground wastewater treatment plant) and lush urban environment with human needs (Fig. 22.6).

22.3.2 Srinakharinwirot University, Thailand

Srinakharinwirot University has the opportunity to create cultures of sustainability for students. Recently, the university enforced the green university policy. The project has implemented at Ongkharak campus (Nakhon Nayok, Thailand), initialed the treatment of wastewater from the residential area (e.g., dormitory), and reused in various sectors. Kalayanamit building is a dormitory for the university's staff, located in Ongkharak campus area. This building has eight floors with 64 rooms, 48 single rooms, and 16 family rooms. The building sanitary separated blackwater from toilet to septic tank while greywater from rooms' showers, hand-wash basins, kitchen, and laundry. This water was collected and taken to the lagoon without treatment.

A demonstration MBR was installed and operated to treat up to 10 m^3/day of greywater with an HRT of 12 h. Fig. 22.7 and Fig. 22.8 show the schematic diagram of the MBR pilot plant, which consists of an entrance tank (12 m^3), a membrane compartment, an aerobic tank, an automatic cleaning system, permeate tank, and several pumps. The membrane was a PTFE submerged ultrafiltration hollow fiber (UF-HF) membrane module (POREFLON SPMW-12B6) with a nominal pore size of 0.1 microns Sumitomo Electric

FIGURE 22.6 The Bang Sue Environmental Education and Conservation Center in the capital Bangkok, Thailand. Source*: From Jarungwit Boonnorat.*

FIGURE 22.7 The MBR pilot plant for greywater treatment at Srinakharinwirot University. Source*: From Suthida Theepharaksapan.*

Company, Japan. The total membrane area of each membrane was 6 m^2, and six membrane units were installed. The pilot plant was equipped with programmable logic controller (PLC) system, the transmembrane pressure (TMP) values, and levels of the reactor were monitored to regulate all pumps and air blowers.

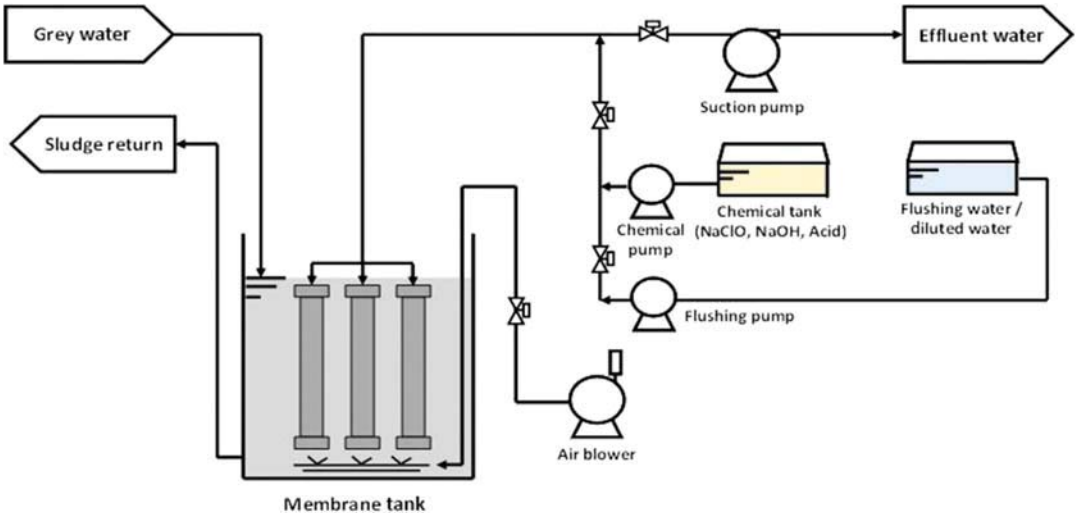

FIGURE 22.8 Schematic diagram of the MBR pilot plant. Source: *From Suthida Theepharaksapan.*

The MBR has been operated to minimize its energy consumption while assuring high-quality effluent. A regular sampling biweekly was performed for offline analysis at the inflow and the MBR outflow in terms of chemical water quality parameters. The MBR could be proven to be efficient in greywater treatment, as shown in Table 22.2. The results indicated that the reclaimed effluent could meet international guidelines/regulations for nonpotable reuse, save for the presence of the possible microorganism. The tread greywater has been used for toilet flushing on the first floor of the building. A total of 90 liters of freshwater could be saved daily, and the remaining could be used for garden watering with the high freshwater demands of these daily activities. In addition, the evaluation of long-term effects of treated greywater reuse on vegetable crop irrigation (i.e., butterhead lettuce and melon crops) intended for human consumption was performed with an experimental site near the pilot-plant, as shown in Fig. 22.9. Irrigation water and vegetable samples were collected during the cropping seasons and evaluated for fecal coliform, which did not find microbial contamination in both samples. The vegetable crops were successfully grown on treated water supplied plots based on the production and quality components, with no statistical difference yields compared to plots supplied with fresh water.

This research demonstrated the appropriateness, and the economic feasibility of MBR-based GW systems in university facilities, offering a good opportunity for a high-quality alternative water source. However, the latter stage involves justifying the practicality of the greywater recycling systems through the implementation of engineering tools, such as environmental risk assessment (ERA), material flow analysis (MFA), and economic worthiness.

22.3.3 Thailand's Eastern Economic Corridor

The Eastern Economic Corridor (EEC) is a pilot project for Thailand's Eastern Seaboard's economic development. The project covers three eastern provinces: Chachoengsao, Chonburi,

TABLE 22.2 Influent and effluent characteristics.

		Water samples		Guidelines and regulations		
Parameters	**Unit**	**Greywater**	**Effluent**	**USA**[b]	**Canada**[c]	**Japan**[d]
pH	–	7.0 ± 0.3	7.1 ± 0.4	6–9	–	5.8–8.6
Dissolved Oxygen (DO)	mg/L	1.1 ± 0.5	6.4 ± 1.2	–	–	–
Biochemical oxygen demand (BOD_5)	mg/L	74.4 ± 18.7	0.7 ± 0.5	<10	<20	<20
Chemical oxygen demand (COD)	mg/L	123.1 ± 33.2	5.0 ± 6.5	-	-	-
Suspended solids (SS)	mg/L	27.7 ± 11.3	0.6 ± 0.8	-	<20	-
Total dissolved solids (TDS)	mg/L	289 ± 90	335 ± 130	-	-	-
Ammonium nitrogen (NH_4^+-N)	mg/L	5.0 ± 2.6	0.3 ± 0.7	-	-	-
Nitrate nitrogen (NO_3^--N)	mg/L	0.2 ± 0.1	5.9 ± 1.3	–	–	–
Total phosphorus (TP)	mg/L	1.8 ± 0.6	0.7 ± 0.4	–	–	–
Total coliform[a]	CFU/100 mL	1.2×10^7	346 ± 314	Not detected	–	<50
E.coli[a]	CFU/100 mL	4.1×10^4	Not detected	–	<200	–

[a] *total plate count (CFU/100 mL).*

[b] *Guidelines for unrestricted urban reuse of USA, USEPA (2012).*

[c] *water regulation for a toilet and urinal flushing in Canada, Health Canada (2010).*

[d] *water regulation for landscape irrigation in Japan.*

FIGURE 22.9 The wastewater treatment and water reuse project at Srinakharinwirot University, Thailand. Source*: From Jarungwit Boonnorat.*

and Rayong provinces, with approximately 13,000 km^2. The EEC will serve as a hub of trade and investment, a center of regional transportation and logistics, and a gateway to Southeast Asia. The rising demand for water in the EEC area, which is forecast to reach 3.09 billion cubic meters in 2037, will lead to conflicts and confrontations over limited resources. Environmental agencies have warned that the conflicts might spill over to nearby provinces, as the Eastern Economic Corridor Office (EECO) seeks more water resources. This comes when many parts of Thailand are suffering from a drop in rainfall due to climate change. Wastewater treatment for water reuse (circular economy) is a solution to mitigate problems that may have an impact as a guideline for sustainable water and wastewater management.

Several industrial estates are located in the EEC development zone, including *Map Ta Phut* Industrial Estate and *Laem Chabang* Industrial Estate, which is the country's largest industrial port. The wastewater management in the industrial estates emphasizes the reduction of wastewater at point sources via online monitoring, in addition to a permit system for pollutant loading. The pollution control agency is also updating the standards of treated wastewater to minimize discharge of substandard treated wastewater into natural waterways.

In municipal wastewater management, the three provinces in the EEC development zone have adopted an action plan with four key goals: (1) wastewater reduction at point sources; (2) public participation; (3) effective law enforcement; and (4) renovation and construction of wastewater treatment facilities with an emphasis on water reclamation and reuse.

The vast amount of wastewater discharge and low reclaimed water production means that wastewater reuse still has a great potential in the EEC area. In 2020, there are 13 wastewater treatment systems in the EEC area, with 9 in Chonburi Province, Chachoengsao Province, and 2 in Rayong Province with a total treatment capacity of 221,780 m^3/day, as shown in Table 22.3. The technologies mostly used in wastewater treatment systems are AS and oxidation ditch, which account for over 50% of the existing wastewater treatment systems.

According to statistics from the Environment Agency Region 13 (Chonburi), the estimated amount of wastewater in Chonburi Province is 230,317 m^3/day (base on the wastewater production rate of 150 liters/person/day), Rayong Province and Chachoengsao Province are 107,251, and 108,497 m^3/day, respectively. On the other hand, Chonburi Province have an average treatment rate of 70% of the municipal wastewater (160,829 m^3/day) while Chachoengsao and Rayong provinces have an average treatment rate of 16% and 2.5% of municipal wastewater for treatment (17,124 and 2687 m^3/day). The major difference in treatment rates across the country may be due to the wastewater network connection, which was a total of 42% of total wastewater.

Approximately 80% of the water consumed in the urban area ends up in the wastewater stream and 70% of which may be reclaimed if the wastewater is collected and treated. If the reclaimed water is fully utilized, the available water supply will increase by 56%. In the literature, it is a promising source of stable and reliable water supply. It could resolve 50% plus of the urban water shortages if on the average 20% of reclaimed water is used nationwide (Zhou, 2006).

TABLE 22.3 Characteristics of municipal wastewater treatment systems in the Eastern Economic Corridor (EEC) area.

Administrative area	Types	Capacity (m^3/day)	Wastewater inflow (m^3/day)	Year of operation
EEC Area		*221,780*	*180,640*	
Chonburi Province		*169,780*	*160,829*	
Chonburi Provincial Administrative Organization	AS	22,500	7,605	2001
Pattaya City (Soi Wat Nong Yai)	AS	65,000	75,570	2000
Pattaya City (Wat Bun Kanjanaram)	AS (SBR)	23,000	23,000	1994
Laem Chabang City Municipality	AL	7,500	1,000	2009
Phanat Nikhom Municipality	SP	5,380	24,000	1997/2019
Saen Suk Municipality (North)	AS (OD)	14,000	10,353	1994
Saen Suk Municipality (South)	AS (OD)	9,000	5,522	1994
Sriracha Municipality	AS (OD)	18,000	9,779	1997
Bang Saray Subdistrict Municipality	AL	5,400	4,000	2011
Chachoengsao Province		*29,000*	*17,124*	
Chachoengsao Municipality	AS (OD)	24,000	15,124	1998/2005
Bang Khla Subdistrict Municipality	SP	5,000	2,000	2008
Rayong Province		*23,000*	*2,687*	
Map Ta Phut Municipality	AL	15,000	1,764	2001
Ban Phe Municipality	AS (OD)	8,000	923	1998/2013

Operation year: phase1/phase2.
AL, Aerated lagoon; *AS*, activated sludge; *OD*, oxidation ditch; *SBR*, sequencing batch reactor; *SP*, stabilization pond.
From Environment Agency Region 13 (Chonburi), 2019.

22.4 Nutrients recovery by microalgae in municipal wastewater treatment

Municipal wastewater normally contains high concentrations of nitrogen and phosphorus. Nitrogen and phosphorus in household wastewater come from human waste and personal care and cleaning products (Beler-Baykal, Allar, & Bayram, 2011). The nutrients (i.e., nitrogen and phosphorus) in wastewater can be harvested and used to fertilize agricultural crops (J.R. et al., 2017). However, conventional municipal wastewater treatment systems, for example, AS, are less effective in removing nitrogen and phosphorus in wastewater, resulting in high concentrations of the nutrients in treated wastewater (Honda et al., 2012).

As a result, microalgae cultivation is employed to remove and recover the nutrients in municipal wastewater. The nutrient recovery efficiency varies by microalgae species, effluent characteristics, and environmental conditions. In addition, microalgae can be used for removal of several micropollutants such as hormones (Ruksrithong & Phattarapattamawong, 2019), pharmaceuticals (de Wilt et al., 2016; Escapa et al., 2016), and antibiotics (Leng et al., 2020). The recovered microalgae can be used as fertilizers, animal feed, and raw materials for cosmetic products and biofuels (Mehta et al., 2015). Table 22.4 summarizes previous research on microalgae-based recovery of nutrients in municipal wastewater and the reference number 1 denotes (Li et al., 2019), 2 denotes (Naaz et al., 2019), 3 denotes (Rani et al., 2019), 4 denotes (Tao et al., 2017), and 5 denotes (Gao et al., 2014).

The advantages of microalgae-based nutrient recovery include: (1) the recovered microalgae can be used as the raw material for biofuel production (Roostaei & Zhang, 2017); (2) the energy consumption is considerably lower, vis-a-vis the AS technology (Fernandez, Gomez-Serrano, & Fernandez-Sevvila, 2018); (3) unlike the AS system in which nitrogen and phosphorus dissipate into the atmosphere, the nutrients are recovered and deposited in biomass under the microalgae-based nutrient recovery scheme (Fernandez, Gomez-Serrano, & Fernandez-Sevvila, 2018); (4) atmospheric carbon dioxide (CO_2) captured and oxygen (O_2) generated during microalgae photosynthesis help mitigate the effects of global warming (Honda et al., 2012); and (5) microalgae biomass can be used for animal feed and biofuel (Catarina et al., 2019; Sofie et al., 2016).

TABLE 22.4 Summary of existing research on microalgae-based recovery of nutrients in municipal wastewater.

Wastewater characteristics	Microalgae	Effluent characteristics or treatment efficiency (%)	References
BOD 112 mg/L, NH_4^+-N 22.7–29.2 mg/L, PO_4^{3-} 2.1–3.9 mg/L	*Galdieria sulphuraria*	BOD 30 mg/L, NH_4^+-N 19.5–19.9 mg/L, PO_4^{3-} <1 mg/L	(Li et al., 2019)
COD 153.7 ± 6.0 mg/L, NH_4^+-N 27.3 ± 2.01 mg/L, NO_3^--N 11.16 ± 0.75 mg/L, TP 21 ± 0.5 mg/L	PA6 *Phormidium* and *Chlorella pyrenoidosa*	COD 53%, NH_4^+-N 81%, NO_3^--N 81%, TP 75%	(Naaz et al., 2019)
COD 250 ± 20 mg/L, BOD 35 ± 2 mg/L, NO_3^--N 2.5 mg/L, PO_4^{3-} 3.4	*Chlorella sorokiniana*	COD 17–47%, BOD 60–80%, NO_3^--N 53–96%, PO_4^{3-} 59–92%	(Rani et al., 2019)
COD 21.26 ± 4.84 mg/L, total nitrogen (TN) 16.43 ± 3.12 mg/L, total phosphorus (TP) 3.25 ± 0.71 mg/L	*Chlorella vulgaris*	Nitrogen 61%, Phosphorus 71%	(Tao et al., 2017)
COD 55.6 ± 10.9 mg/L, NH_4^+-N 11.26 ± 0.82 mg/L, NO_3^--N 7.06 ± 0.56 mg/L, NO_2^--N 0.15 ± 0.03 mg/L, total nitrogen (TN) 19.12 ± 0.52 mg/L, total phosphorus (TP) 1.24 ± 0.12 mg/L	*Chlorella vulgaris*	Nitrogen 56%, Phosphorus 82%	(Gao et al., 2014)

22.5 Conclusion

In view of the UN's SDG 6 on clean water and sanitation that aims to ensure availability and sustainable management of water and sanitation for all, this article investigates the current municipal wastewater treatment technology and water reclamation and reuse. The wastewater treatment technology under study is MBR since the technology is operationally ideal for removal of micropollutants in municipal wastewater, especially in urban areas where space is scarce. In addition, MBR is effective in removing biodegradation-resistant micropollutants, with high daily throughput of treated wastewater. The MBR effluent can also be reused to irrigate agricultural crops due to low micropollutant residues. However, in areas where municipal wastewater is predominantly treated by conventional biological AS systems, high concentrations of nitrogen and phosphorus that remain in treated wastewater can be further removed and recovered by microalgae cultivation. The recovered microalgae can be used as fertilizers, animal feed, and raw materials for cosmetic products and biofuels. Essentially, to attain goal 6 of the UN's SDGs on clean water and sanitation for all, collaboration among stakeholders, that is, both public and private sectors, is of vital importance.

Credit authorship contribution statement

Suthida Theepharaksapan: Conceptualization, Data curation, Writing – original draft. Suda Ittisupornrat: Data curation, Writing – review & editing. Kanjana Ketbubpha: Data curation, Writing – original draft. Songkeart Phattarapattamawong: Data curation, Writing – review & editing. Jarungwit Boonnorat: Conceptualization, Data curation, Writing – review & editing.

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