Integrated anaerobic fixed-film MBR-reverse osmosis-chlorination process: An environmentally sustainable approach for reclamation of municipal used water to NEWater-like product water

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SUMMARY

Nowadays, the reclamation of municipal used water to high-grade water (e.g. NEWater) has been widely accepted as a feasible alternative to achieve water sustainability. However, there may be some room to further improve the current NEWater production line in terms of energy consumption and excess sludge production. To address these emerging issues, an integrated anaerobic fixed-film MBR (AnfMBR), reverse osmosis (RO) and chlorination process was developed for producing high-grade product water from municipal used water. It turned out that the product water could meet typical NEWater quality in terms of TOC, ammonium, phosphorous, chlorine and other major ions, with net energy consumption estimated to be 0.30 kWh per m^3 product water. Consequently, this study may open a new window for reclamation of municipal used water to high-grade product water with reduced energy consumption and negligible excess sludge production.

KEYWORDS

AnfMBR, Municipal used water, NEWater, Reverse osmosis.

1. INTRODUCTION

The water shortage is becoming a pressing issue in highly urbanized countries. However, water reuse and recycle have not yet been practiced in most of current biological processes for treating municipal used water. The total global water demand has been projected to be about 6,906 km^3, whereas only 60% of which would be met by the time of 2060 (Boccaletti et al. 2009). This in turn suggests an urgent need for exploiting unconventional water sources. Most recently, the mayor of Los Angeles announced the target of recycling 100% of municipal used water by the end of 2035 (LAMayor 2019). Thus, it appears necessary to explore novel process configurations for reclamation of used water to high-grade product water at an affordable cost. Facing to such a situation, this study aims to develop an innovative integrated process for producing high-grade product water from municipal used water, which is a synergetic combination of anaerobic MBR, RO and chlorination. It can be expected that the proposed process may offer an alternative solution for water recycle and reuse with remarkable technological feasibility and economic viability.

2. METHODS

The AnfMBR was operated at the temperature of 30±1°C and a HRT of 7.5 hours, and polyvinylidene fluoride (PVDF) hollow fibre membranes with a nominal pore size of 0.02 μm were employed in the MF unit. The permeate flux of AnfMBR was controlled at 10 L/m^2 h. Synthetic wastewater mainly containing 400 mg/L COD, 45 mg/L NH_4^+-N and 5 mg/L PO_4^{3-}-P was prepared to simulate typical municipal used water. The AnfMBR permeate was fed to a RO unit, where the permeate flux was maintained at 20 L/m^2 h. Breakpoint chlorination with sodium hypochlorite (Sigma-Aldrich, USA) was applied to further polish part of the RO permeate in case the ammonia concentration in the RO permeate exceeded 1 mg/ L of nitrogen (Figure 1). After stirred at 80 rpm for 30 min, the concentrations of free chlorine, total chlorine, NH_4^+-N and TN were measured immediately.

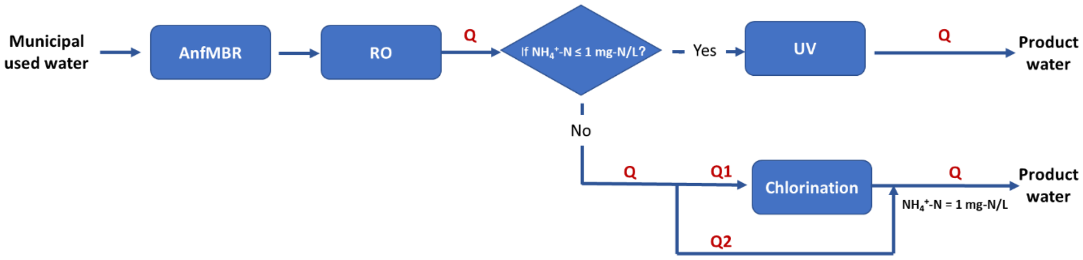

Figure 1 Illustration of the integrated AnfMBR-RO-Chlorination process.

3. RESULTS AND DISCUSSION

3.1 Process performance

In the AnfMBR-RO-Chlorination process, 96% of COD was captured in AnfMBR with a methane yield of 0.28 L/g COD, while NH_4^+-N concentration was slightly reduced from 43.9 to 41.9 mg/L. MF membrane fouling was well controlled by means of biogas sparging and membrane relaxation, evidenced by a low dTMP/dt value of 0.029 bar/d. 96.4% of TOC, 95% of NH_4^+-N and 99.3% of PO_4^{3-}-P were removed in the subsequent RO unit. In case where NH_4^+-N concentration exceeded 1 mg/L, part of RO permeate was subjected to chlorination with hypochlorite at a Cl_2:NH_4^+-N ratio of 9 by weight. As can be seen in Table 1, the NH_4^+-N concentration in the part of RO permeate subjected to chlorination was reduced to 0.11 mg/L, with 0.13 mg/L of TN and 0.98 mg/L of chlorine.

Table 1 Performances of integrated AnfMBR-RO-Chlorination process

Parameter (mg/L)	Integrated process				Typical NEWater quality[a] (Singapore)
	After AnfMBR	After RO	RO permeate subjected to chlorination	Product water	
NH_4^+-N	41.90	2.10	0.11	1.00	<1.00
TN	41.90	2.10	0.13	1.02	-
TP	4.41	0.03	0.03	0.03	-
TOC	3.60	0.13	-	0.06	<0.50
Sodium	132.7	3.20	14.57	9.45	<20.00
Potassium	10.18	0.08	0.08	0.08	-
Calcium	31.20	0.05	0.05	0.05	4.00-20.00
Chloride	157.80	4.70	22.30	14.38	<20.00
Sulphate	31.90	0.50	0.50	0.50	<5.00
Chlorine	-	-	0.98	0.54	<2.00
Conductivity (μS/cm)	1127.00	47.00	98.50	73.32	<250.00

[a]. Data from PUB (2017)

3.2 Engineering implications

It has been reported that the influent ammonium concentration in real municipal used water could fluctuate from 16 to 50 mg N/L (Malovanyy et al. 2015). The ammonium rejection by RO was determined to be 95% in this study which was close to that reported in large-scale operations (Bellona et al. 2008). In this study, the NH_4^+-N concentration in RO permeate was 2.1 mg N/L, which could not meet the typical NEWater quality (i.e. 1 mg N/L). As illustrated in Figure 1, with online sensing system, it is possible to monitor the NH_4^+-N concentration in RO permeate. The RO permeate with NH_4^+-N concentration below 1 mg/L could be directly channeled to UV unit. Otherwise, a portion of RO permeate was chlorinated, while blended with non-chlorinated portion to make up a NH_4^+-N concentration of 1 mg/l or less (Figure 1). For example, in this study the RO permeate contained 2.1 mg/L of NH_4^+-N, thus the ratio of Q_1/Q_2 could be calculated as 2.1 mg N/L × Q_1 +0.11 mg N/L × Q_2 = 1 mg N/L, i.e. about 55% of RO permeate should undergo chlorination. As shown in Table 1, all the parameters investigated could meet typical NEWater quality, i.e. the product water could be supplied for non-potable and indirect potable uses. According to a survey of 127 used water treatment plants in China, the influent NH_4^+-N concentration in municipal used water was averaged at 22.83 mg/L (Guo et al. 2018). In this case, only 28.8% of RO permeate will be needed for chlorination in order to make up the NH_4^+-N concentration of 1 mg/L in the product water. It should be realized that the bypass fraction of RO permeate for chlorination is determined by feed ammonium concentration and ammonium rejection rate by RO.

3.3 Technology feasibility and economic viability analysis

In this study, 105.6 L of methane was generated from AnfMBR when treating 1 m^3 of used water, indicating that the recoverable energy could be estimated as (0.1056 m^3 CH_4 per m^3 used water treated × 40 MJ/m^3 methane × 35% × 0.28) = 0.41 kWh per m^3 used water treated. The respective energy consumptions associated with AnfMBR and RO were estimated to be 0.21 kWh per m^3 used water treated and 0.57 kWh per m^3 water produced (Gu et al. 2019), while the energy consumption for chlorination could be negligible (Cao 2011). As such, the net energy demand of the proposed AnfMBR-RO-Chlorination process could be calculated as (0.21 kWh per m^3 used water treated/0.75 + 0.57 kWh per m^3 water produced – 0.41 kWh per m^3 used water treated/0.75) = 0.30 kWh per m^3 product water with the RO recovery rate of 75%. Compared to the conventional biological treatment process with an average sludge yield of 0.4 g dry biomass/g COD (Gu et al. 2019), the sludge yield in the proposed process was negligible due to direct conversion of influent COD into biogas. These clearly show environmental sustainability of the proposed integrated process.

4. CONCLUSIONS

The feasibility of an integrated AnfMBR-RO-Chlorination process for producing high-grade water from municipal used water was demonstrated in this study. The product water from the proposed process could meet typical NEWater quality in terms of TOC, ammonium, phosphorous, chlorine and other major ions tested, while the net energy consumption was estimated to be 0.30 kWh per m^3 product water. This process may offer an alternative to the current NEWater production technology.

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