Journal of Environmental Management 187 (2017) 393–400

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Performance of electrodialysis reversal and reverse osmosis for reclaiming wastewater from high-tech industrial parks in Taiwan: A pilot-scale study

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ARTICLE INFO

Article history:
Received 5 May 2016
Received in revised form
20 October 2016
Accepted 1 November 2016
Available online 9 November 2016

Keywords:
Wastewater reclamation
Ultrafiltration
Electrodialysis reversal
Reverse osmosis
Fiber filtration

ABSTRACT

Wastewater reclamation is considered an absolute necessity in Taiwan, as numerous industrial parks experience water shortage. However, the water quality of secondary treated effluents from sewage treatment plants generally does not meet the requirements of industrial water use because of the high inorganic constituents. This paper reports experimental data from a pilot-plant study of two treatment processes—(i) fiber filtration (FF)-ultrafiltration (UF)-reverse osmosis (RO) and (ii) sand filtration (SF)—electrodialysis reversal (EDR)—for treating industrial high conductivity effluents from the Xianxi wastewater treatment plant in Taiwan. The results demonstrated that FF-UF was excellent for turbidity removal and it was a suitable pretreatment process for RO. The influence of two membrane materials on the operating characteristics and process stability of the UF process was determined. The treatment performance of FF-UF-RO was higher than that of SF-EDR with an average desalination rate of 97%, a permeate conductivity of 272.7 ± 32.0, turbidity of 0.183 ± 0.02 NTU and a chemical oxigen demand of <4.5 mg/L. The cost analysis for both processes in a water reclamation plant of 4000 m^3/d capacity revealed that using FF-UF-RO had a lower treatment cost than using SF-EDR, which required activated carbon filtration as a post treatment process. On the basis of the results in this study, the FF-UF-RO system is recommended as a potential process for additional applications.

1. Introduction

Fresh and clean water is becoming scarce in many countries as a consequence of rapid urbanization in conjunction with poor water management practices and climate change. Approximately one-fifth of the world's population faces water scarcity. By 2030, half of the world is predicted to be under water-stress conditions (United Nations, 2007). To overcome this crisis, alternative water sources i.e, seawater and wastewater have been explored (Mohammadi and Kaviani, 2003; Chuang et al., 2005; You et al., 2008; Chang and Ma, 2012).

Compared with seawater desalination, reusing and recycling sewage from wastewater treatment plants (WWTPs) are more technically and economically feasible. In addition, water reuse helps in reducing emissions of pollutants into the environment, as well as in reducing consumption of natural water resources. Influents in wastewater reclamation plants often require at least a secondary treatment, which is followed by various methods of water reclamation. According to United States Environmental Protection Agency wastewater effluent discharge standards, the quality of wastewater effluent from secondary WWTPs is usually sufficient for dust control, toilet flushing, landscaping and crop irrigation (Chang and Ma, 2012). However, these effluents requires additional advanced purification processes for industrial process water and cooling use.

In general, high conductivity wastewater is a key parameter for industrial water reuse as it contains high salt concentrations; thus, utilization of this water can easily lead to the information of scales and corrode the surface of the system pipeline or vessel. Several studies have shown that reverse osmosis (RO) and electrodialysis reversal (EDR) are promising treatment processes for removing

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Abbreviations: CIP, Cleaning in place; CEB, Chemically enhanced backwash; UF, Ultrafiltration; RO, Reverse osmosis; FF, Fiber filter; EDR, Electrodialysis reversal; CA, Cellulose acetate; PVC, Polyvinyl chloride; SF, Sand filtration; COD, Chemical oxygen demand; TDS, Total dissolved solids; SDI, Silk density index.

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http://dx.doi.org/10.1016/j.jenvman.2016.11.001

dissolved organic compounds and ionic pollutants (Wilf and Alt, 2000; Xing et al., 2000; Petala et al., 2006; Hsu et al., 2012; Chon et al., 2013a,b).

RO is a wastewater purification process that separates the solvent from the solutes through pressure differences. RO has been extremely effective in removing dissolved matter in municipal wastewater (Tang et al., 2016) and in the wastewater from various industries such as pulp and paper (Gönder et al., 2011), pharmaceutical (Ravikumar et al., 2014), dairy and food (Salehi, 2014), textile (Kim et al., 2005; Li et al., 2014; Holkar et al., 2016), and steel (Colla et al., 2016).

EDR is a process where electric current causes the dissolved ions, to migrate through an electrodialysis stack comprising alternating layers of cationic and anionic ion exchange membranes. EDR has been utilized for treating various industrial wastewater (Chao and Liang, 2008; Hsu et al., 2012; Scialdone et al., 2013, 2014a,b,c). The EDR process has also been used to produce renewable energies (Turek and Bandura, 2007; Cusick et al., 2012). Scialdone et al. (2014a,b,c) produced the electricity used to treat wastewater containing chromium pollutants through the EDR process. The same group generated the electric energy used to treat contaminated by the organic pollutant Acid Orange 7 (Scialdone et al., 2015).

Both RO and EDR treatment processes are extremely sensitive to membrane fouling; thus, an adequate pretreatment for RO and EDR processes must be provided to produce high quality of feed water for a stable process operation.

Numerous treatment processes are widely used to remove colloids and dissolved organic matter in secondary treated effluents. These processes include coagulation, sand filtration (SF), activated carbonfiltratio (Freeman et al., 2001; Muñoz et al., 2008) microfiltration (MF) and ultrafiltration (UF). With regard to the pretreated water quality, MF and UF are the preferred options to conventional media filtration (Qin et al., 2002; Bohdziewicz et al., 2003; Tomaszewska et al., 2005; Petrinic et al., 2015). The performance of these treatment systems is influenced by the characteristics of raw wastewater, the membrane materials, and other operating parameters such as feed flow rate. Yamato et al (2006) observed the membrane fouling in membrane bioreactor (MBR) system that used two different polymeric. They found that or MBRs used for treating municipal wastewater, polyvinylidene fluoride (PVDF) could prevent irreversible membrane fouling to a greater extent compared with polyethylene. They explained that the reversible fouling for the PVDF membrane might be related to an increase in the submicron size of organic matter composed mainly of carbohydrates, whereas dissolved organic matters may be responsible for the irreversible fouling.

In the present study, we evaluated two processes for reclaiming wastewater from industrial parks: (i) fiber filtration (FF) UF RO and (ii) SF EDR. Several experiments were conducted to indentify which process delivered higher performance in terms of the process stability and removal efficiency. On the basis of the filtrate quality and cost analysis, a suitable wastewater reclamation system was suggested for additional applications.

2. Materials and methods

2.1. Xianxi wastewater treatment plant

Fifty-five industrial (WWTPs) operated in Taiwan. One of them is Xianxi WWTP, which is located in Changhua coastal industrial park in northern Taiwan. This WWTP applies activated sludge process to treat both rainwater and industrial wastewater from spinning processes, chemical industries, and metal processors. After the chlorine disinfection process, part of the treated wastewater is reused within the industrial park as low quality reclaimed water and the rest is discharged to the environment. However, water utilization from this source has become problematic because of the high concentration of salts and ions. This high concentration may be ascribed to the presence of sodium chloride in the wastewater. In addition, a long-term disposal may cause environmental impacts on the receiving water bodies, ground water, and soil. The average electrical conductivity of the industrial effluent was 7.3 mS/cm (Table 1) which is higher that reported in the literature (Chuang et al., 2005; López-Ramírez et al., 2006; Chao and Liang, 2008). Bauder et al. (2014) reported that irrigation water with conductivity greater than 0.75 mS/cm had potential to reduce crop yield.

2.2. Wastewater reclamation process: pilot-scale test

Two wastewater reclamation processes based on different treatment technologies of RO and EDR were examined. These processes can remove organic ions and improve the quality of the reclaimed water for sustainable water reuse within the industrialpark. The treatment performance and operating stability of both processes were compared under various operating conditions. Fig. 1 diagrams a flow schematic of a pilot-plant study for two treatment processes. Table S1 (supplementary information) indicates the characteristics and design control parameters for each treatment unit.

2.2.1. Operation of the fiber filtration-ultrafiltration- reverse osmosis process

Secondary effluent typically contains a wide variety of particulates that are responsible for membrane fouling. To minimize this effect, three filtration processes SF, FF and hollow-fiber ultrafiltration UF were tested for turbidity removal. Influent and effluent turbidity concentrations, water flow, and the operating pressure were monitored during the experiment, to determine a suitable pretreatment process for RO. When the turbidity removal decreased considerably or the operating pressure drop reached 2 kg/cm^2, the treatment systems were automatically backwashed with water and air. An additional step of chemical cleaning using 100 mg/L sodium hypochlorite (NaOCl) and 0.05% w/v sodium hydroxide (NaOH) was applied for the UF membrane after the backwash process.

The next step was to assess the influence of membrane materials and process operations (e.g. operating flux and cleaning frequency) on the water filtrate produced from the UF process. Two types of membranes (supplied by China) were used: (i) polyvinyl chloride

Table 1
Quality of the effluent water from the Xianxi WWTP (number of samples = 7).

Parameters	Min–max	Avg ± SD
pH	7.7–8.2	7.9 ± 0.20
Conductivity (mS/cm)	5.9–8.1	7.3 ± 0.83
Turbidity (NTU)	1.0–8.5	4.7 ± 2.87
TDS (g/L)	3.6–4.6	4.2 ± 0.39
COD (mg/L)	22.1–63.1	41.5 ± 15.40
TOC (mg/L)	3.7–7.1	5.5 ± 1.29
NH_4^+-N (mg/L)	0.05–0.16	0.1 ± 0.05
NO_3^- (mg/L)	1.0–52.4	21.3 ± 17.07
PO_4^{3-} (mg/L)	1.2–30.3	15.9 ± 10.26
Cl^- (mg/L)	1610–2210	2010 ± 224.05
Al (mg/L)	0.07–0.15	0.1 ± 0.03
Ca (mg/L)	57.2–72.5	63.9 ± 5.25
Fe (mg/L)	0.08–0.34	0.2 ± 0.13
Mg (mg/L)	103–129	118 ± 8.82
SiO_2 (mg/L)	13.4–20.0	16.8 ± 2.30
B (mg/L)	1.12–1.41	1.26 ± 0.12
SO_4^{2-} (mg/L)	60.3–579.0	435 ± 190.37