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Electrodialysis on RO concentrate to improve water recovery in wastewater reclamation

Yang Zhang[a], Karel Ghyselbrecht[b], Boudewijn Meesschaert[b,d], Luc Pinoy[c,d], Bart Van der Bruggen[a,*]

[a] Department of Chemical Engineering, Laboratory for Applied Physical Chemistry and Environmental Technology, K.U. Leuven, W. de Croylaan 46, B-3001 Leuven, Belgium
[b] Department of Industrial Sciences and Technology, Katholieke Hogeschool Brugge-Oostende, Associated to the K.U. Leuven as Faculty of Industrial Sciences, Zeedijk 101, B-8400 Oostende, Belgium
[c] Department of Industrial Engineering, Laboratory for Chemical Process Technology, KaHo St.-Lieven, Associated to the K.U. Leuven as Faculty of Industrial Sciences, Technologie Campus, Gebroeders Desmetstraat 1, B-9000 Gent, Belgium
[d] Department of Microbial and Molecular Systems, Centre for Surface Chemistry and Catalysis, K.U. Leuven, Kasteelpark Arenberg 23, B-3001 Leuven, Belgium

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ABSTRACT

Over-consumption of groundwater in coastal areas causes seawater intrusion and soil salinization, which is a threat to residents, to agricultural activity and to the ecological system. In this study, a more sustainable approach is investigated based on groundwater recharge of the unconfined aquifer in the dune water catchment area in the western part of the Flemish coast. Ultrafiltration (UF) followed by reverse osmosis (RO) is currently applied to treat the secondary effluent from a wastewater treatment plant (WWTP) for infiltration (groundwater recharge). This paper investigates the feasibility of electrodialysis (ED) on the RO concentrate to reduce the volume of salty water discharge and to improve the overall water recovery to produce infiltration water for groundwater recharge. In the pilot system, the decarbonation process was used to reduce scaling potential of the feed or the concentrate stream of the ED. Based on various experiments in batch and in feed-and-bleed mode, ion transport mechanisms were studied to monitor the effluent water compositions. Meanwhile, a factor named critical scaling concentration (CSC) was established to predict the potential occurrence of scaling. Ozonation was used to improve the biodegradability of the ED effluent hence to reduce the potential of organic compounds accumulation in the recirculation system. Thus, ED was found to be a good option to treat RO concentrates.

1. Introduction

Nowadays, water shortage has become a global issue [1]. Water reuse, wastewater reclamation and desalination of saline water are crucial strategies to generate water needed for economical development [2–4]. It is recognized that water supply and sanitation in developing countries is even more important, in view of the Millennium Development Goals (MDG) [5]. Thus, water and wastewater treatment technologies are to be developed and applied to fulfill the higher requirements on water quantities and quality. Apart from being the fastest growing process for desalination, reverse osmosis (RO) now also increasingly used in other applications [6,7] due to the high and stable quality of the water produced and the relatively low cost.

However, there are still some drawbacks for RO application. One of the most important issues is the treatment of the concentrated waste drain from RO due to the high salinity of this RO concentrate. Traditionally, the RO concentrate is discharged into the natural water body (with or without dilution, depending on the local discharge regulations to avoid degradation of the water body) or treated by evaporation. The former method is not environmentally friendly and the latter process is very costly (when conventional energy is used for evaporation, potentially even less environmentally friendly). In the mid-1990s, a survey of membrane drinking water plant disposal methods in the United States was conducted [8] for plants with a capacity above 25,000 gal/day (95 m^3/day). In this survey, 78% of the 137 installations were RO, 11% were NF (nanofiltration) and the rest 11% were electrodialysis. The survey showed that roughly half (48%) of the 137 installations chose to discharge their concentrate directly in surface water; in 23% of the cases, the concentrate was mixed with sewage wastewater effluent and discharged in the water body; only in 6% of them it was chosen to discharge the concentrate to evaporation ponds. In 1999, a follow-up survey [9] showed that 60% of the installations discharged their concentrate directly into surface water. However, investigation shows that the standard limit for surface water discharge require that the salinity difference should be less than 10% [10].

* Corresponding author. Tel.: +32 16 322340/322726; fax: +32 16 322991.
E-mail address: bart.vanderbruggen@cit.kuleuven.be (B. Van der Bruggen).

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More recently, new processes have been developed for treating and recycling the brine from the RO process. Van der Bruggen et al. [11] reviewed the possibilities to treat or to discharge the pressure-driven membrane concentrates and pointed out that distillation, electrodialysis, or an integrated membrane operation can be applied to minimize the waste fraction from the brine. Greenlee et al. [12] concluded that zero liquid discharge processes (including thermal evaporators, crystallizers, brine concentrators, and spray dryers) for RO concentrate recovery are technically feasible but more efforts have to be done to reduce the capital and operational cost.

On the other hand, rather than considering to minimize RO concentrate waste disposal, an integrated system allows to reclaim the RO concentrate with the aim of: (i) producing chemicals from the solutes and (ii) water reclamation or recycle to the treatment system. Some investigations had been carried out to make the RO concentrate "valuable". Electrodialysis (ED) or electrodialysis reversal (EDR) has been proposed as part of such system. Mavrov et al. [13] treated RO/EDR/ion exchanger concentrates from a surface water desalination plant by electrodialysis with bipolar membranes (EDBMs) to produce mixed acid and mixed base for regeneration of the ion exchangers in the plant. Badruzzaman et al. [14] investigated the feasibility to produce mixed acid and mixed base by EDBM process from an RO concentrate stream from the wastewater treatment plant in Rio Rancho, U.S. After 10 h operation of the EDBM stack (PCCell GmbH, Germany), the production (mixed acid and mixed base) quality was comparable with technical grade and the NF (US National Formulary) grade acids and bases. Thus, it was proved that the use of EDBM to treat and produce mixed acid and mixed base is technically feasible. Xu and Huang [15] reviewed ED-based separation processes and concluded the applications of ED/EDBM integrated RO/NF process for brine minimization and chemical production. Furthermore, a novel type of electrodialysis, named electrostatic shielding electrodialysis (ESE) can be a promising option to minimize RO concentrate and to produce acids and bases without chemical and thermo sensitive polymeric ion-exchange membranes or bipolar membranes [16–19]. The ESE stack has proven to treat electroplating rinse waters [17], brackish water [18,19] and to produce acid and base [19]. Further investigation on treating RO concentrate should be interesting since membrane fouling and scaling can be eliminated [16].

Reahl [20] reported the design and the operation of an UF–RO–EDR system to reinsert 85% of the RO concentrate to the UF–RO system and to improve the overall water recovery to 97%. Similarly, an RO–EDR system was applied to treat the brackish water with high scaling potential from the Sahel region in Tunisia; the system overall water recovery reached 91.6% [21]. Korngold et al. [22,23] investigated the treatment of the concentrate from an RO unit fed by brackish water, by a pilot ED installation with a separated gypsum precipitator to reduce the scaling problem in ED. The salts in the RO concentrate were partially removed by the ED and the produced water was mixed together with the RO permeate, thus, the overall recovery of the RO unit was improved; furthermore, the volume of brine in the combined process was reduced, at the same time increasing its salt concentration. The salt concentration in the brine increased from 1.5% to 10% and the RO unit overall recovery increased to 97–98% [23]. More recently, Oren et al. [24] investigated a pilot study on an RO–EDR process with a side loop crystallizer to improve water recovery and produce mineral byproducts on brackish groundwater from the Negev Highland, Israel. It is reported that the overall water recovery reached over 98% and the treatment cost was significantly less than the Israel water tariff and competitive with the cost of conventional RO [24].

In conclusion, ED (or EDR) shows remarkable advantages technically and economically on treating RO concentrate streams.

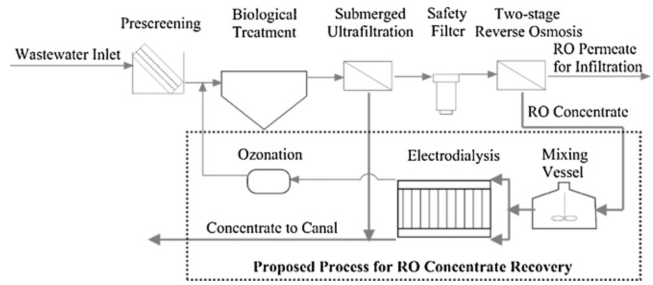

Fig. 1. Schematic diagram of I.W.V.A. wastewater treatment process.

Although some investigations on the treatment of RO concentrate by ED have been done, further study on the details of the process is needed, in view of fully understanding the influence of operational parameters and transport of the inorganic and the organic compounds through the membranes. Furthermore, scaling on the membranes and fouling remain potential hurdles.

In July 2002 the Intermunicipal Water Company of the Veurne region (I.W.V.A., Wulpen, Belgium) has started to treat wastewater for producing infiltration water for groundwater recharge of the dune water catchment 'St-André'. As this water is recharged in a dune area, which is of high ecological value, the infiltration water must have low levels of salts and nutrients. Based upon the quality parameters set for the infiltration water, a combination of membrane filtration (UF and RO) was chosen to treat the (mainly domestic) wastewater effluent. The schematic diagram of the wastewater treatment process is shown in Fig. 1. The intake of the wastewater first passes a mechanical screen with 1 mm openings to remove all larger particles. After conventional biological (anaerobic–aerobic) treatment, the water is clarified and flows to the submerged hollow fiber UF units. From the UF filtrate reservoir the water first passes the cartridge safety filters with pore sizes of 15 μm, and is then pumped to the RO system. The recovery of the RO system is around 75% and is varied according to the feed water conductivity. Finally, the RO product (permeate) is pumped for infiltration; the RO brine (concentrate) is mixed with the UF concentrate and discharged to the canal.

To improve the overall water recovery of the RO process for producing infiltration water, an ED installation is proposed to treat the RO concentrate and to re-insert the product, i.e., the diluate of the ED, into the biological treatment process. The proposed procedure is shown in Fig. 1: RO concentrate flows into a mixing vessel with acid to reduce the scaling potential, then it is pumped to the ED installation for desalting. The ED product (diluate) is ozonated prior to be re-inserted into the biological treatment process. The ED brine (concentrate) is mixed with the UF concentrate to meet regulations and is discharged to the canal.

In this work, a systematic investigation was done to study a pilot scale ED installation to treat RO concentrate with high scaling potential form a WWTP, in view of improving the overall water recovery of the system. As proposed, the ED product (effluent) will be recycled into the biological treatment unit of the WWTP and the RO overall water recovery can be improved from 75% to around 95%. To achieve this, some basic requirements have to be fulfilled:

1. the pilot system can be long-term operating in a stable way;
2. the salt removal should be around 75% and the ED effluent conductivity should be similar as the influent of the biological treatment unit;
3. besides conductivity, the ED effluent quality should be similar as the influent of the biological treatment unit, i.e., concentration of different cations and anions, pH, biodegradability of organic compounds.