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Development of a selective electrodialysis for nutrient recovery and desalination during secondary effluent treatment

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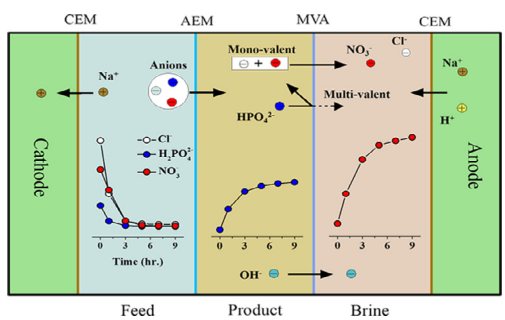
HIGHLIGHTS

- A selective electrodialysis reactor was developed for nutrients recovery and desalination.
- HPO_4^{2-} and NO_3^- were separated and concentrated in different compartments of the SED system.
- The simultaneous removal of Cl^-, NO_3^- and HPO_4^{2-} indicated a well desalination performance.
- A mathematics model was developed to simulate the variation of current.

GRAPHICAL ABSTRACT



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ABSTRACT

Recovering resources, especially nutrients and water, from biologically treated secondary effluent, which in line with the concept of zero liquid discharge, has attracted increasing interests. In this study, a selective electrodialysis (SED) was developed to separate and recover the nitrogen and phosphorus nutrients and enforce desalination during secondary effluents treatment under low applied voltages. The SED system performance as well as current efficiency and energy consumption were investigated under different number of ion exchange membrane trios, applied voltages and flow rates. Nitrate could be reconcentrated to 40.64 mg-N L^{-1} in brine compartments while the phosphate was retained by a monovalent anion exchange membrane and concentrated to 21.2 mg-P L^{-1} in product compartments. The conductivities of feed compartments were all below 2 μS/cm after treatment, indicating a well desalination performance of the SED system. The current efficiency was obtained to be lower under a higher voltage, and a mathematical fitting of current was developed to confirm the existence of water dissociation under higher voltages. The SED with more ion exchange membrane trios proved to be able to perform an effective desalination under advantageous electricity consumption conditions. With the capability to reconcentrate nutrients and simultaneously realize zero liquid discharge of secondary wastewaters, the examined SED treatment technology has a potential for practical nutrient recovery and sustainable water reuse.

1. Introduction

The biologically treated secondary effluent from existing wastewater treatment plants still contain a certain amount of nutrients (such as NO_3^- and HPO_4^{2-}) [1] and salinity (such as Na^+, Ca^{2+}, K^+, Mg^{2+} and Cl^-). The insufficient treatment could lead to eutrophication [2] and influence the reuse of reclaimed water [3]. Moreover, the phosphorous is an important mineable resource [4], recovering P from wastewater streams for reuse can alleviate the problem of limited phosphate resource supply [5]. However the zero discharge of N and P remains to be a tough problem with the currently used techniques, such as activated sludge and anaer-

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obic/anoxic/oxic processes, especially along with the increasingly stringent effluent standards. Moreover, these biological treatment technologies are less effective to reduce salinity [1]. In light of these problems, novel wastewater treatment processes capable of removing and recovering N and P resources as well as reducing salinity to realize the zero liquid discharge (ZLD) of secondary effluents are necessary to develop to satisfy the increasing need of environment protection [1,6,7].

In recent years, ZLD technology has been utilized in wastewater treatment to eliminate liquid waste and maximize water usage efficiency [8]. Several techniques are available to remove and recover nutrients from secondary wastewaters, such as chemical precipitation, adsorption and membrane filtration [9]. Among these technologies, the chemical precipitation is applied as an efficient process by using Fe or Al salts [10]. However the generated residues need further disposal [11] and this method is less effective to reduce salinity. The high salinity in wastewater as well as high regeneration costs would limit the widely application of adsorption.

Recently, membrane filtration technologies, such as reserve osmosis (RO), nanofiltration (NF) and electrodialysis (ED), have drawn much attention to desalinize and recover useful materials in wastewater treatment [12–14]. Pressure membrane processes like RO and NF need a quite complex pretreatment to alleviate the membrane fouling [15,16], resulting in needless capital cost and energy consumption. Furthermore, the RO is ion uncontrollable and highly relying on the size of molecules [17]. However, as an electrochemical membrane separation process [18,19], ED is capable of separating undesired ions from wastewaters more energy-efficient [18,21] with an applied electric filed [20,21] as the driving force [22] to get a higher water recovery [17]. ED would be an alternative technique in an environmental and economical manner to realize the ZLD and nutrients recovery during secondary effluent treatment.

Previous studies of ED were focused on the treatment of wastewaters for demineralization and water reclamation [20,21]. As the ions migrated through the ion exchange membranes (IEMs) to concentrate in another compartment of ED, the unique ion separation mechanism provided a selective method for nutrient recovery [22,23]. ED could selectively generate high quality nutrient products [24], like ammonia and phosphorus enrichment were observed from urine and other wastewaters [25–27]. Simultaneous recovery of ammonia and phosphorus was achieved via the integration of ED with struvite reactor [2], and ED was also integrated with bio-electrochemical system to recover resources [28]. In desalination often multi ionic compositions are encountered, but the conventional ED could not separate ions of the same charge but different valence. The use of selective IEMs brought appreciable separation efficiencies between different valent ions [29]. Simultaneous phosphate removal and separately reconcentration against chloride were achieved by using the selective IEMs [30,31]. ED also enjoys the important advantage for small to medium sized applications where high quality product is required [32]. Although substantial researches have been published on the subject of electrodialysis over the past decades, little information is available about the application of ED in nutrients separation and recovery from low concentration wastewaters like biological treated secondary effluent.

In this study, by integrating monovalent anion exchange membrane (MVA) into a conventional ED, a novel selective electrodialysis (SED) reactor was developed for secondary effluent desalination and nutrient recovery. As an alternative of ZLD procedure, the potential application of this technology in N and P resource removal and separately recovery was evaluated. The performances of SED in terms of nitrate and phosphate separation and recovery as well as desalination were studied under different IEM trios, flow rates and voltages. The selectivity of MVA, the current efficiencies of different ions and the variation of pH in different compartments were evaluated under different voltages. A mathematical fitting of current was developed to compare with the monitored current, which verify the water dissociation under higher voltages. The results of this study would provide a novel process for resources recovery during secondary effluent treatment.

2. Materials and methods

2.1. Reactor construction

The assembled ED reactor was constructed as shown in Fig. 1. Two electrodes were titanium electrodes coated ruthenium (Dexin Taiye, China). A stack of IEMs (Neosepta, Astom Co., Japan) were placed between the anode and the cathode compartments, and their properties were listed in Table 1. From anode to cathode, a cation exchange membrane (CEM), an anion exchange membrane (AEM), a MVA and an extra CEM were placed in order. The effective area of an IEM was 25 cm^2. The neighboring membranes were separated with a thickness of 1 mm by using the plastic gaskets, creating three compartments, which were denoted as feed, product and brine compartment, respectively. An electrochemical worksta-

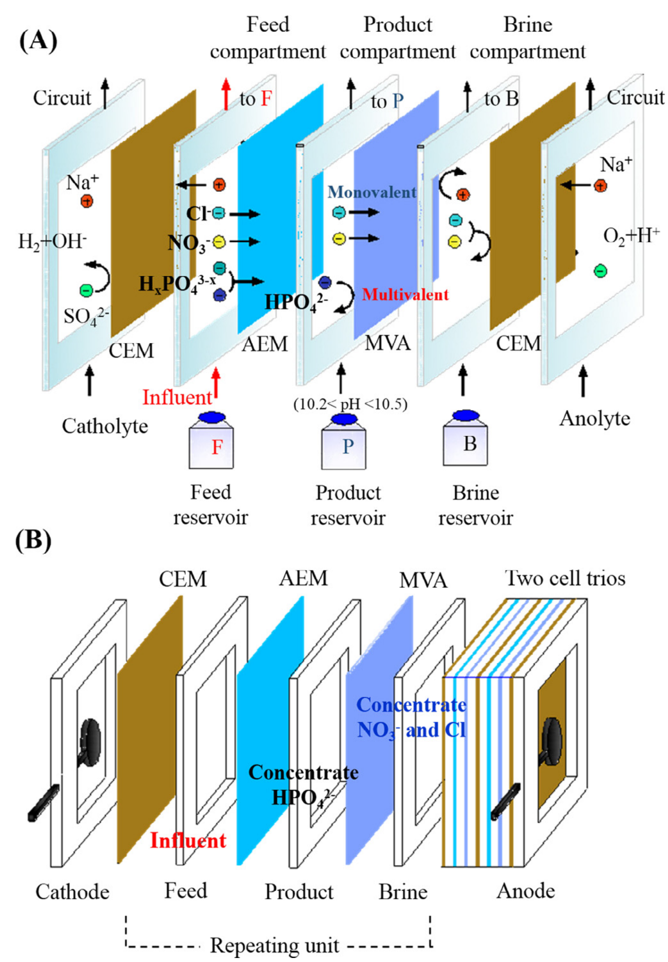

Fig. 1. (A) Single membrane-trio ED reactor schematic design for treatment of secondary effluent. (CEM: cation exchange membrane; AEM: anion exchange membrane; MVA: monovalent anion exchange membrane.) The experiment was ran in a batch mode, and the three different streams are pumped from the reservoirs. The shown arrows indicate the migrating direction of different ions (B) 3 membrane-trios schematic design. The electrodes are two titanium electrodes coated with a ruthenium mixed metal oxide.