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Short communication

Energy-neutral sustainable nutrient recovery incorporated with the wastewater purification process in an enlarged microbial nutrient recovery cell

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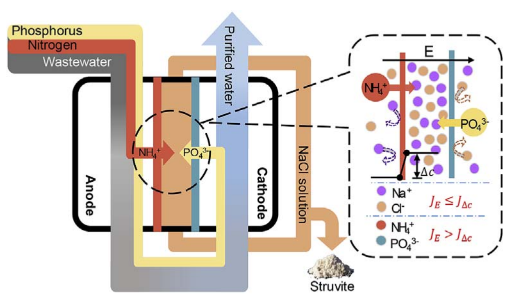
HIGHLIGHTS

- The energy-neutral wastewater treatment powered the nutrient recovery in EMNRC.
- The best nutrient recovery result was achieved using 3 g/L NaCl recovery solution.
- Nutrient was continuously recovered during 12 cycles of raw wastewater treatment.
- > 89% of P and > 62% of N were fixed into struvite from the recyclable NaCl solution.
- The EMNRC system was proved a promising process toward practical application.

GRAPHICAL ABSTRACT



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ABSTRACT

Recovery of nutrient resources from the wastewater is now an inevitable strategy to maintain the supply of both nutrient and water for our huge population. While the intensive energy consumption in conventional nutrient recovery technologies still remained as the bottleneck towards the sustainable nutrient recycle. This study proposed an enlarged microbial nutrient recovery cell (EMNRC) which was powered by the energy contained in wastewater and achieved multi-cycle nutrient recovery incorporated with *in situ* wastewater treatment. With the optimal recovery solution of 3 g/L NaCl and the optimal volume ratio of wastewater to recovery solution of 10:1, > 89% of phosphorus and > 62% of ammonium nitrogen were recovered into struvite. An extremely low water input ratio of < 1% was required to obtain the recovered fertilizer and the purified water. It was proved the EMNRC system was a promising technology which could utilize the chemical energy contained in wastewater itself and energy-neutrally recover nutrient during the continuous wastewater purification process.

1. Introduction

Water shortage and resource scarcity had already been crucial issues surrounding human society for decades. By the year of 2050, the consumption for clean water resource is estimated to increase by over 40% from now on [1]. Meanwhile the demand for nutrient fertilizer will

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annually increase by 4% to grow enough crops for the additional population [2]. Simply conserving water and resources can't fundamentally maintain supply, treating and reusing the vast wastewater and also recovering the abundant nutrient (especially N and P) from it are the inevitable paths toward supply-demand balance. However the conventional wastewater treatment technologies are energy intensive [3], otherwise perform weakly on recovering the nutrient resources [4]. Owing to the irreproducibility of P, the sustainable conversion of "wasted" P from the drainage to reusable resource is the only approach to avoid the massive consumption of phosphate rock [5–8]. Therefore, new wastewater treatment technologies that can energy-neutrally recover the nutrient are urgently required.

Bioelectrochemical systems (BESs) which utilizeing electrochemically active bacteria to extract electrons from the organics can achieve wastewater purification [9–12], valuable substances producing [13,14] and/or saline water desalination, accompanying the output of electricity [15–19]. In a concept named microbial desalination cell, the internal electrical field of a BES was proved capable of directionally driving ion migration with the cooperation of ion exchange membranes [15,20]. From then on, abundant of researches had emerged to remove, recover or produce ionic substances from different kinds of solutions [21–28], among which the attempts aiming at removing and recovering ammonium and phosphate ions from wastewater enabled people to solve the critical nutrient recovery issue in an integrated energy-economical way [29,30]. A device termed R^2-BES successfully removed nutrient from wastewater, while the efficiency of phosphate recovery was limited owing to the movement of ions inverse to electrical field [31]. Later the concept of microbial nutrient recovery cell (MNRC) was proposed [32], in which the migrations of ammonium and phosphate both were consistent to that of the inner electrical potential and thus presented better recovery effect of concentrating PO_4^{3-}-P and NH_4^+-N to ~37 mg/L and ~15 mg/L, respectively. However in the study of MNRC, recovery extent of nutrient was not satisfactory considering the small portion of current attributed to nutrient ions among all species of ions, and the long-term operation of real wastewater treatment was still waiting for investigation.

In the present study, an enlarged microbial nutrient recovery cell (EMNRC) was designed to not only improve nutrient recovery effect by optimizing operational conditions but also test the feasibility of utilizing raw wastewater to operate the EMNRC in a practical long-run operation. The concentration of NaCl recovery solution and the volume ratio between wastewater and recovery solution were hypothesized affecting the competitive migrations of nutrient ions and other species in wastewater and thus would result in different concentrating extents of recovered nutrient ions. Thereafter the long-term recovery operation of EMNRC was conducted with optimal conditions achieved, utilizing a recycled small volume of recovery solution to purify multiple batches of real wastewater, and timely fixing the recovered ammonium and phosphate into struvite fertilizer. Both the wastewater purification and nutrient recovery results were tracked via the analysis of organic and ion concentrations in wastewater and recovery solution.

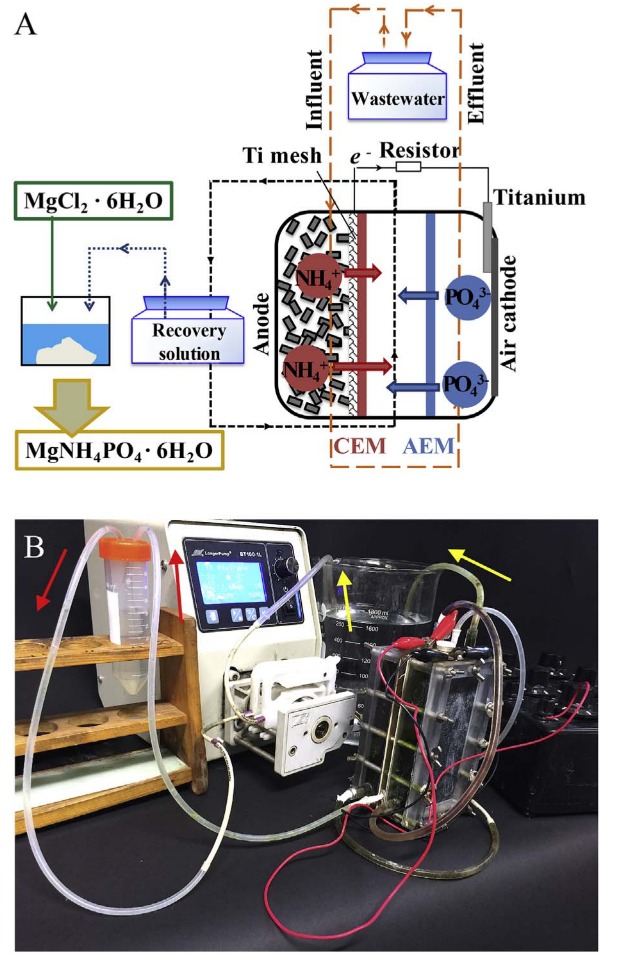

Fig. 1. Schematic (A) and photograph (B) of the enlarged microbial nutrient recovery cell (EMNRC).

2. Materials and methods

2.1. EMNRC construction

Each of the duplicated EMNRC reactors consisted of an anode chamber (50 × 110 × 20 mm), a middle recovery chamber (50 × 110 × 5 mm) and a cathode chamber (50 × 110 × 20 mm) (Fig. 1A). The recovery chamber was isolated by a pair of ion exchange membranes of which the cation exchange membrane (CEM, Ultrex CMI7000, Membrane International Inc.) adjoined the anode and the anion exchange membrane (AEM, Ultrex AMI-7001, Membrane International Inc.) was against the cathode, with a surface area of 55 cm^2. The anode chamber was packed with granular activated carbon (~1 mm in diameter, ~2-5 mm in length, Beijing Chunqiudingsheng Environmental Science and Technology Co. Ltd., China) [33,34] to immobilize microorganisms. A piece of titanium mesh was squeezed in between the anode chamber (tightly contacting granular activated carbons) and the CEM to collect and conduct electrons produced in the anode. The air cathode was fabricated on 30% wet-proofing carbon cloth (Clean Fuel Cell Energy, LLC, USA) with a platinum loading of 0.5 mg/cm^2 and four diffusion layers of polytetrafluoroethylene [35,36]. The external circuit was connected via a 5.8 Ω resistance to obtain the maximum current production. The anode chamber and cathode chamber were linked through a polyvinyl chloride tube of 20 cm in length and 3 mm in inner diameter [32,37]. Wastewater which was circulated in the anode and cathode chambers and the recovery solution which was independently circulated in the recovery chamber were contained in additional containers, respectively.

2.2. Experimental operation

The EMNRCs were inoculated with the effluent of a BES (which had already performed for over one year) and operated at a steady current for over one month before conducting any experiments. Raw domestic wastewater (Beixiaohe wastewater treatment plant, Beijing, chemical oxygen demand (COD) = 463 mg/L, PO_4^{3-}-P = 7.6 mg/L, NH_4^+-N = 47.4 mg/L) was utilized to investigate EMNRC's performance in both of the optimizing test and long-term nutrient recovery test.

During optimizing test, the concentration of NaCl recovery solution and the volume ratio of wastewater to recovery solution (referred to as w/r volume ratio) were investigated to achieve the optimal nutrient recovery results. NaCl solutions with concentrations of 1, 2, 3 and 4 g/L