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# Removal of organic matter and nitrogen in swine wastewater using an integrated ion exchange and bioelectrochemical system

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## HIGHLIGHTS

- Swine wastewater was treated using an ion exchange and bioelectrochemical system.
- The average organic matter removal was 80.6% at the applied voltage of 3 V.
- The average total nitrogen removal was 70.5% at the applied voltage of 3 V.

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## ABSTRACT

Swine wastewater was treated using an integrated ion exchange and bioelectrochemical system. This system contains three chambers separated by a cation exchange membrane (CEM) and an anion exchange membrane (AEM). Each chamber acted as a bioanode chamber, an aerated biocathode chamber, and a denitrification chamber. To accelerate the ammonium transportation through CEM, a bioelectrochemical system was installed between bioanode and aerated biocathode. The current was provided by a programmable DC power supply. The average chemical oxygen demand (COD) removal efficiencies at applied voltages of 0, 1 and 3 V were 65.6%, 75.4% and 80.6%, respectively. Unlike the COD removal, the total nitrogen removal was proportional to the ammonium flux through the CEM. The average total nitrogen removal efficiencies at the applied voltages of 0, 1 and 3 V were 37.0%, 63.1% and 70.5%, respectively.



## 1. Introduction

A tremendous amount of swine wastewater has been generated since the intensive growth of the husbandry industry. The amount of swine wastewater has been consistently increased owing to the demand of red meat in developing countries. As of 2010, China covered almost half of the world's pig production (50 million metric tons) (Oh and Whitley, 2011). Among Asian countries, pork consumption has sharply increased in South Korea ever since the Free Trade Agreement between Korea and the United States in 2005. Swine head increased from 8.2 million in 2000 to 9.6 million in 2009. As swine wastewater consists of high-strength organic matter, nutrient and pathogenic organisms, it is necessary that swine wastewater be treated to prevent from surface/ground water contamination, eutrophication and pathogenic problems before discharging into rivers or the environment. According to statistics, the production of swine wastewater in South Korea (1040 thousand metric tons) is the 11th highest in the world (Korea Swine Association, 2014).

Several investigators showed various processes for the treatment of swine wastewater. Anaerobic digestion is commonly used to control organic matter, and reduce volatile solids and pathogens in swine wastewater. Anaerobic processes used to treat swine wastewater are exemplified by a continuous stirred tank reactor (CSTR), an upflow anaerobic sludge blanket (UASB), an anaerobic sequencing batch reactor (ASBR), and an anaerobic baffled reactor (ABR) (Sánchez et al., 2005; Hernández and Rodríguez, 2013; Kim et al., 2013; Wu et al., 2013). Since the 1990s, bioelectrochemical systems (BESs) have been one alternative to treat various wastewaters. BESs involve direct production of electricity and versatility or chemical compounds (e.g. hydrogen) by means of electrochemically active organisms. These systems are considered promising due to their high efficiency. The best BES known so far is a microbial fuel cell (MFC), in which electric energy is obtained from the exergonic conversion of chemical energy, through a process known as electrogenesis. Organic matter oxidation at the anode is carried out by microorganisms that liberate protons

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towards the cathode: electrons are transferred to the latter through an external circuit for completing oxygen reduction and the production of clean water. More recently, a similar process has been developed, known as electrohydrogenesis. In this process, oxygen is not provided to the cathodic compartment. Since the overall reaction is endergonic and the metabolic production of hydrogen using acetate as substrate is not thermodynamically possible, a low potential (0.2 V) needs to be applied to the circuit. As a result of these modifications, hydrogen gas is produced at the cathode. This process is carried out in microbial electrolysis cells (MEC). In the case of a MEC, only the anodic reaction is catalyzed by microorganisms and cathodic reactions (reduction) remain abiotic. Compared to classical water electrolysis technologies, MEC work at lower potential (5–10 times) reducing the energy costs proportionally (Logan et al., 2008; Pant et al., 2010). Min et al. (2005) reported that swine wastewater can be treated using an air cathode microbial fuel cell (MFC). Several investigators showed the plausible treatability of some synthetic organic matter. Nonetheless, to date, BESs have many practical challenges in treating real wastewaters in wastewater treatment facilities, as investigators have focused on interactions between microorganisms and electrodes (Wagner et al., 2009; Omidi and Sathasivan, 2013).

The objective of this study was to evaluate the performance of organic matter and nutrient removal in swine wastewater using an integrated ion exchange and BES. In addition, it was shown that the effect of calcium ions on forming crystals to remove phosphorus in the integrated ion exchange and BES.

## 2. Methods

### 2.1. Configuration of an integrated ion exchange and BES

A schematic diagram of an integrated ion exchange and BES is described in Fig. 1. The system consists of three chambers separated by a CEM and an anion exchange membrane (AEM). The active volume of each chamber was 2 L. The dimensions of a CEM (CMX, ASTOM Co., Tokyo, Japan) and an AEM (AMX, ASTOM Co., Tokyo, Japan) were 100 mm × 120 mm. Influent flowed into chamber A followed by chamber C, whereas chamber B was hydraulically closed. As shown in Fig. 1, organic matter in swine wastewater was fermented in chamber A and cations including ammonium were ion-exchanged between chambers A and B through a CEM. In chamber B, activated sludge (nitrifying bacteria) was continuously/vigorously aerated with the air flow rate of 5 L/min. This implies that electrons can be sufficiently oxidized using oxygen onto the cathode installed in a hydraulically closed chamber B. On the other hand, ammonium ion-exchanged between chambers A and B through a CEM was oxidized to nitrate, and electrons onto stainless steel were oxidized into water. Nitrate/nitrite in chamber B was ion-exchanged between chambers B and C through an AEM due to the concentration gradient. Nitrate ion-exchanged between chambers B and C through an AEM was denitrified with fermented organic matter in chamber C.

According to Lim et al. (2012) results, the ammonium flux between chambers A and B was the rate-limiting step in an integrated ion exchange and BES. To accelerate the ammonium transportation, a BES system was installed between chambers A and B. An anode was installed in chamber A and a cathode was installed in chamber B. Carbon graphite (8 mm × 150 mm × 100 mm) was used as a bioanode in chamber A, while stainless steel (3 mm × 150 mm × 100 mm) was used as a biocathode in chamber B. Each electrode was immersed to a 5 cm depth. The current was provided by a programmable DC power supply (OPM-501T, ODA, Korea). Both chambers A and C were continuously stirred using magnetic bars (450 rpm), whereas chamber B was aerated with micro bubbles. The air flow rate was 5 L/min. Each chamber was considered a CSTR owing to the completely mixing conditions.

### 2.2. Characteristics of swine wastewater

The characteristics of swine wastewater are usually determined by many parameters such as hog age, diet of hog, temperature and

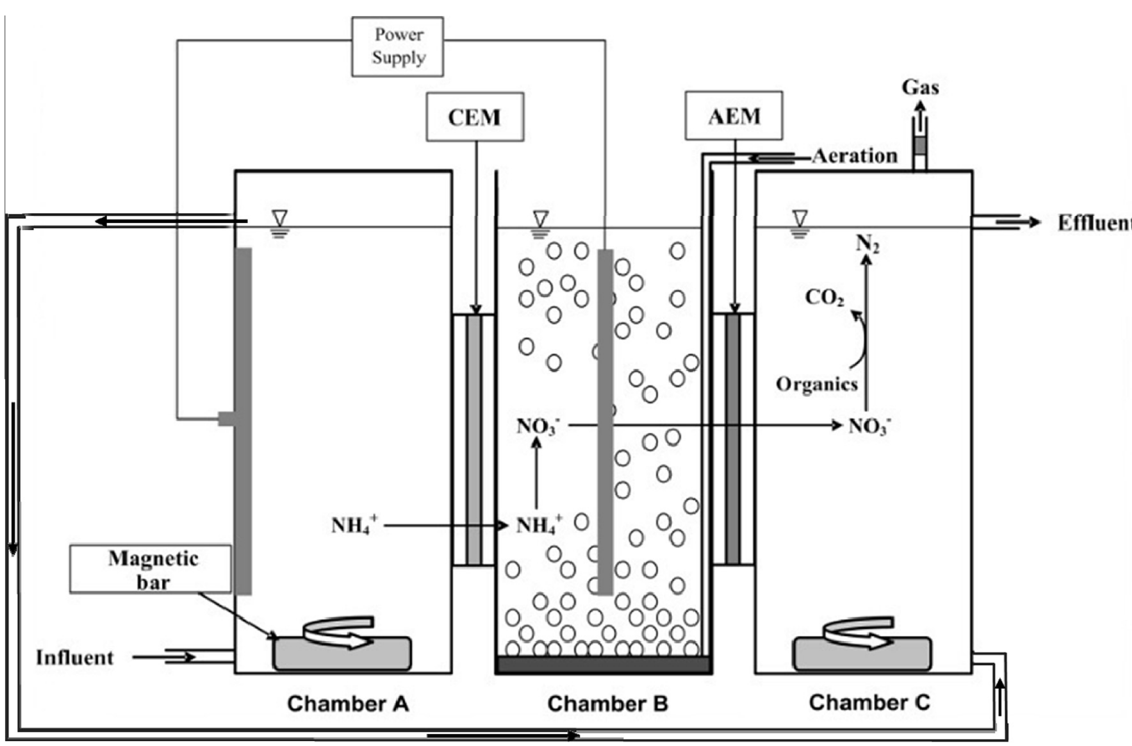


**Fig. 1.** A schematic diagram of the integrated ion exchange and BES.