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Effects of electron beam irradiation and temperature on the treatment of swine wastewater using an ion exchange biological reactor

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HIGHLIGHTS

- The optimal dose for solubilization of organic matter ranged from 20 kGy to 75 kGy.
- Ammonia removal was significantly impacted at low temperatures.
- Phosphorus removal was mainly caused by precipitation in the IEBR.

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ABSTRACT

Swine wastewater was treated using an ion exchange biological reactor (IEBR). Organic matter and nutrient in swine wastewater were pre-treated by electron beam irradiation. The optimal dose for solubilization of organic matter in swine wastewater ranged from 20 kGy to 75 kGy. The carbohydrates, proteins, and lipids were investigated as proteins and lipids mainly contained the solubilized organic matter. The solubilization of organic matter in swine wastewater was affected by the combination effects of temperature and dose. The maximum chemical oxygen demand (COD) and ammonia removal efficiencies were 74.4% and 76.7% at a dose of 0 kGy under room temperatures (23.0 °C). The removal of ammonia was significantly affected by low temperature (15.3 °C). On the other hand, the removal of phosphorus was not a function of electron beam irradiation or temperature because struvite is one of the main removal mechanisms under anoxic conditions.

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1. Introduction

Swine production has increased upon robust global demand with accordance to the intensive growth of husbandry industry. Specifically, the increase of swine production has been obvious in Asia. For instance, China consumes one half of pigs generated in the world. South Asia has become one of the biggest exporters owing to a continuous demand for red meat in developed countries. According to the Food and Agricultural Organization (FAO), the number of swine produced in Korea was 9,880,630 heads in 2010 (FAO, 2010). Considering that the population in Korea as of 2010 was approximately 49,000,000, swine wastewater has already been highlighted as one of high-strength organic wastewaters in Korea (Statics Korea, 2010). It is necessary that organic matter and nutrient be treated before being released into water systems because of ammonia toxicity and a deterioration of the environmental quality caused by high organic loading (Park et al., 2011). Several investigators stated that biological processes can be feasible for treating swine wastes. However, swine manure requires a long hydraulic retention time (HRT) to stabilize organic matter using a continuous stirred-tank reactor because of the high-strength of organic loading and solids (Chynoweth et al., 1999). Andreadakis (1992) stated that approximately 40% of total organic matter in swine manure is composed of non-biodegradable fraction. Nonetheless, several investigators showed that swine wastewater can be successfully treated using high-rate anaerobic processes such as an anaerobic filter, an upflow anaerobic sludge blanket, an anaerobic baffled reactor, and a static granule bed reactor (Lim and Fox, 2011a,b; Lo et al., 1994; Yang and Chou, 1985). Ammonia in swine wastewater commonly exists as ammonium because the ionic fraction of ammonia is predominant at pH 7. Although ammonium is less toxic than free ammonia in an aqueous phase, it must be removed to prevent a detriment to human health or the ecosystems. In addition, phosphorus contained in swine wastewater effluent should be stringently controlled. Among the fraction of effluent in wastewater, phosphorus

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mainly causes eutrophication in fresh/coastal waters (Luo et al., 2002). The actual nutrient concentration in swine wastewater is highly dependent upon a particular operation of manure collection, housing, and/or humidity. For instance, there is a considerable loss of nitrogen to air, a potential run-off, or leaching into ground water when manure is exposed to an open lot (Zhang and Felmann, 1997).

On the other hand, advanced oxidation processes (AOPs) using free radicals, ozone, and/or UV can be an alternative solution for mineralizing refractory substances (Auslender et al., 2002; Kim et al., 2007; Lucas et al., 2010). Ye et al. (2009) reported the deodorization of swine wastewater using horseradish peroxidase and peroxides. Getoff (2002) stated that "The radiation chemistry helps to solve environmental problems very efficiently, especially in the degradation of water pollutants". Several investigators reported that the solubility and biodegradability of organic matter were enhanced after electron beam irradiation. Park et al. (2009a) showed the enhancement of gas production and biodegradability of sewage sludge by electron beam irradiation. The biodegradability of textile wastewater was enhanced by electron beam irradiation (Kim et al., 2007). The objective of this study was to investigate the effects of pre-treatment by an electron beam on simultaneous removal of organic matter and nutrient in swine wastewater using an ion exchange biological reactor (IEBR), which was developed by Park et al. (2011). Swine wastewater was biologically treated after pre-treatment by electron beam irradiation. In addition, the effects of temperature on solubilization of organic matter and nutrient removal were investigated. The temperature was decreased from room temperature conditions to psychrophilic temperature conditions during the study period.

2. Methods

2.1. Configuration of the IEBR

A schematic diagram of the IEBR used in this study is shown in Fig. 1. This system consisted of three chambers, separated by a cation exchange membrane (CEM; ASTOM Co., Tokyo, Japan) and an anion exchange membrane (AEM; ASTOM Co., Tokyo, Japan). The active volume of each chamber was 2 L. The dimensions of each membrane installed in this system were 100 mm × 120 mm. A CEM and an AEM used in this study were specified to design the exchange of monovalent cations or monovalent anions. The influent flowed into chamber A followed by chamber C, whereas chamber B was hydraulically closed. While both chambers A and C were stirred using magnetic bars, chamber B was continuously aerated. The string speed was 450 rpm and the air flow rate maintained at 5 L/min. Each chamber was considered as a continuous stirred-tank reactor owing to the completely mixing conditions. Cations including ammonium in swine wastewater were ion-exchanged between chambers A and B via a CEM. The ion-exchanged ammonium was nitrified to nitrate in chamber B. The ammonium transportation between chambers A and B via a CEM was determined by the ammonium flux, and the nitrate transportation was caused by the concentration gradient between chambers B and C via an AEM (Park et al., 2009b, 2011). The inoculated activated sludge for chamber B was taken from a livestock wastewater treatment plant (WWTP) located at Gongju, Korea. Activated sludge was washed three times with purified water. The washed activated sludge with 50 mM phosphate buffer solution was inoculated to chamber B. The average concentration of inoculated activated sludge in chamber B was 3040 ± 20 mg/L. The pH of chamber B was adjusted to between 7.0 and 7.5 using 1.0 N NaOH or 1.0 N H_2SO_4. Monovalent anions such as nitrite and nitrate in chamber B were ion-exchanged between chambers B and C via an AEM due to the concentration gradient. $NaHCO_3$ was added to study nitrification (2.0 g/L). In addition, the concentration of dissolved oxygen (DO) was monitored. Organic matter (electron donor) in swine wastewater flowed into chamber C and was used for denitrification.

2.2. Characteristics of swine wastewater

Chynoweth et al. (1999) reported that the characteristics of swine manure are highly affected by dilution, storage, and separation. Since the characteristics of swine wastewater are highly dependent upon several parameters, it is very important to obtain the representative sample. Swine wastewater is solid waste that has some liquid, while municipal or industrial wastewater is usually liquid waste that has some solids (Andreadakis, 1992). Total solids (TS) of swine excrete is approximately 10%, and is usually diluted with urine. For the case of livestock wastewater, swine manure is collected from many swine farms and mingled with one another. This implies that it is possible to obtain the representative swine wastewater from a livestock WWTP. The swine wastewater investigated in this study was collected from a livestock WWTP located at Gongju, Korea. The collected sample was stored at 4 °C until use. The characteristics of swine wastewater used in this study are shown in Table 1. The chemical oxygen demand/nitrogen (COD/N) ratio of swine wastewater was 6.5. US EPA (1993)

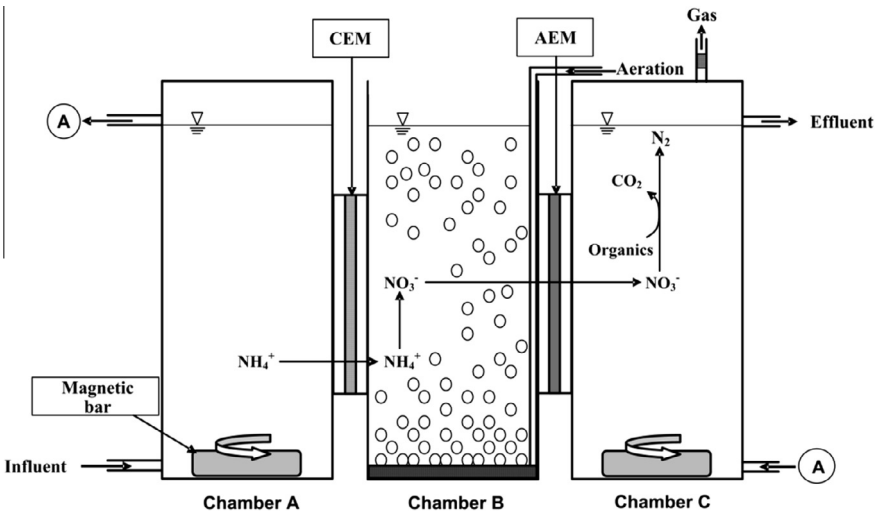

Fig. 1. A schematic diagram of the IEBR.