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Enhanced treatment of swine wastewater by electron beam irradiation and ion-exchange biological reactor

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ABSTRACT

Organic matter and nutrient in the pre-treated swine wastewater by electron beam irradiation was treated using an ion-exchange biological reactor (IEBR). To evaluate the solubilization of organic matter by electron beam irradiation, carbohydrates, proteins and lipids were analyzed. The optimal dose for the solubilization of organic matter in swine wastewater ranged **20–75 kGy**. Most of solubilized organic fractions were proteins and lipids. The solubilized proteins and lipids were effectively used as electron donors for denitrification. **The maximum chemical oxygen demand (COD) removal efficiency was 85.1% at an organic loading rate of 1.4 kg/m^3·day and electron beam irradiation dose of 75 kGy**. For nitrogen, the nitrogen removal was highly dependent upon the current density. The maximum total nitrogen removal efficiency was 75.0% at 1.09 A/m^2. Amorphous phosphorus precipitation was formed in the IEBR, because calcium ions outcompeted magnesium.

1. Introduction

According to the Food and Agricultural Organization (FAO), the total amount of swine in the world was 977,273,246 head in 2013. One half of the swine was produced in China (475,922,000 head; 48.7%), while the European Union (EU) and America accounted for 18.8% and 16.6%, respectively. The swine production in Asia including China (589,902,648 head; 60.4%) sharply increased as compared to the last few decades. The top five swine producers in the world were as consecutive of China (482,398,000 head), China, mainland (475,922,000 head), U.S. (64,775,000 head), Brazil (36,743,593 head) and Germany (27,690,100 head) [1]. Specifically, South Asia became one of the biggest exporters because of the continuous demand for red meat in developed countries [2]. The swine produced in Korea was 9,912,204 head in 2013 [1]. Considering that the population in Korea, as of 2013, was approx. 50,220,000, swine wastewater has been already highlighted as one of the notorious high-strength organic wastewaters in Korea [3]. Raw swine manure was usually used as fertilizers for organic farms or soil conditioners in the past. Specifically, many developing countries spread compost based on manure onto soils, resulting in sufficient nutrient for crops. Investigators have continuously been reporting the values of swine manure as fertilizers and/or soil conditioners [4]. However, many countries have paid attention to the pollution originating from livestock farms. Animal production including swine has shifted toward large confinement in recent decades. The intensive growth of the husbandry industry is highly associated with the global demand for red meat. The mass production of animals sufficient for the demand of developed countries including China has led to the large-scale operation of farms. However, many agro-industries, researchers, and even governments have missed adverse influences on human health and the ecosystems caused by the tremendous amount of disposed animal wastes. Swine wastewater should be treated before discharging into rivers/water systems owing to its high-strength organics and nutrient. Nutrient in swine wastewater should be stringently controlled because eutrophication is mainly caused by ammonia and/or phosphorus in fresh/coastal waters. In addition, livestock wastewater poses some difficult problem issues including the intensive odor and the possibility of pathogen. Several investigators reported that various antimicrobial resistant microorganisms and pathogens exist in swine wastewater [5,6]. Otte et al. [5] warned about the emergence of human disease networks resulting from animal populations such as Nipha virus and H5N1. Swine manure commonly requires a long hydraulic retention time (HRT) to stabilize organic matter using a continuously stirred tank reactor (CSTR) due to the high-strength of organic and solids loading [7]. Approximately 40% of total organic matter in swine wastewater is usually composed of a non-biodegradable fraction. Nonetheless, several investigators reported that swine wastewater can be successfully treated using high-rate anaerobic processes

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such as an anaerobic filter, an upflow anaerobic sludge blanket and an anaerobic baffled reactor [8,9].

Refractory organic matter in swine wastewater can be effectively solubilized using advanced oxidation processes (AOPs). Several investigators reported that biological processes combined of AOPs showed excellent degradation of refractory organic matter. Lim et al. [10] showed the effects of oxidation and temperature on treating of swine wastewater by electron beam irradiation. Park et al. [11] stated that the gas production and the biodegradability of sewage sludge in an anaerobic bioreactor were enhanced after electron beam irradiation. The biodegradability of textile wastewater was enhanced by electron beam irradiation [12]. Ye et al. [13] reported the deodorization of swine wastewater using horseradish peroxidase and peroxides. Winery wastewater was successfully treated by ozone, ozone/UV, and ozone/UV/peroxide [14]. Specifically, radicals originated from an irradiation technology strongly/fast attack refractory organic matter because the reaction rate constants by water radiolysis are extremely high [15]. Getoff [16] stated that "The radiation chemistry helps to solve environmental problems very efficiently, especially in the degradation of water pollutants." After electron beam irradiation, the solubility and the biodegradability of organic matter are usually enhanced. In addition, several investigators reported degradation of persistent organic matter by electron beam irradiation. Chung et al. [17] showed that tetracycline in an aqueous phase was completely oxidized at an applied dose of 5 kGy. Oller et al. [18] well reviewed several advantages when refractory industrial wastewaters were treated by the combined AOPs and biological processes. According to their research, metabolites by AOPs can be readily biodegradable.

The objective of this study was to investigate the combined effects of electron beam irradiation and an ion-exchange biological reactor (IEBR) on treating of swine wastewater. Swine wastewater was irradiated by electron beam irradiation with various doses. The organic matter and nutrient in the pre-treated/solubilized swine wastewater was treated using the IEBR, which was developed by Park et al. [19]. To evaluate the combined effects of electron beam irradiation and the IEBR on the treatment of swine wastewater, statistical analysis was performed using SPSS (ver. 17).

2. Material and methods

2.1. Ion-exchange biological reactor

A schematic diagram of the IEBR used in this study is shown in Fig. 1. This system consists 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 dimension of each membrane was 100 mm × 120 mm. The active volume of each chamber was 2 L. Each membrane was to design exchanging from monovalent cations or anions to polyvalent. The influent flowed into chamber A, followed by chamber C. Meanwhile, chamber B was hydraulically closed between two ion-exchange membranes. Cations in swine wastewater were ion-exchanged between **chambers A and B** through a CEM. The ion-exchanged ammonium was biologically nitrified to nitrate at chamber B. The ammonium transportation between **chambers A and B** through a CEM was determined by the ammonium flux, and the nitrate transportation was performed by the concentration gradient between **chambers B and C** through an AEM. The ammonium flux was accelerated by a DC power supply. The current was provided by a programmable DC power supply (OPM-501T, ODA, Korea). Carbon graphite (dimension: 8 mm × 150 mm × 100 mm), installed at chamber A, was used as an anode. Stainless steel (dimension: 2 mm × 150 mm × 100 mm), installed at chamber B, was used as a cathode. Each electrode was immersed to a 5 cm depth. While both **chambers A and C** were continuously stirred using magnetic bars, chamber B was continuously aerated. The string speed was 450 rpm, and the air flow rate was maintained at 5 L/min. Each chamber was considered as a CSTR due to the completely mixed conditions.

2.2. Characteristics of swine wastewater

Dilution, storage and separation in swine farms significantly affect the characteristics of swine manure [20,21]. In addition, the characteristics of swine wastewater are very different from those of usual municipal thickened sludge. Andreadakis [20] stated that swine manure is solid wastes that have some liquid, while municipal or industrial wastewater is usually liquid waste that has some solids. Total solids of swine excretion are approximately 10% and are usually diluted with urine. This implies that swine wastewater should be sampled at a livestock wastewater treatment plant (WWTP) to obtain a representative sample. The swine wastewater investigated in this study was collected from a livestock WWTP located in Gongju, Korea. The collected sample was stored at 4 °C until use. The characteristics of swine wastewater investigated in this study are shown in Table 1.

2.3. Batch experimental conditions for ammonium flux evaluation

The batch experimental conditions for ammonium flux evaluation are shown in Table 2. As the ammonium flux was accelerated by a power supply, it is very important to know the flux for each ion transformed through a CEM/an AEM. The configuration of the batch reactor used in this study was the same as the combination of **chambers A and B**. The volume of each chamber was 2 L and was separated by a CEM. A CEM was used to evaluate the ammonium flux between two chambers at each applied voltage. Carbon graphite (dimension: 8 mm × 150 mm × 100 mm) was used as an anode, while stainless steel was used as a cathode (dimension: 3 mm × 150 mm × 100 mm). Each electrode was immersed to a 5 cm depth. The current was provided by a programmable DC power supply (OPM-501T, ODA, Korea). To investigate the ammonium transportation through a CEM, the initial ammonium concentration of approximately at chamber A was 1400 mg/L. Meanwhile, chamber B was filled with the washed activated sludge with a 50 mM phosphate buffer solution (pH 7.0). The inoculated activated sludge was taken from a livestock WWTP located in Gongju, Korea. The concentration of MLSS at chamber B was 3250 ± 30 mg/L. Activated sludge was washed three times with purified water. The washed activated sludge with a 50 mM phosphate buffer solution was inoculated to chamber B. The medium composition for ammonium flux batch experiment in this study is shown in Table 3. The medium contains macro- or micro-nutrient for biological nitrification. The medium was buffered at pH 7.2 with a 50 mM phosphate buffer. $NaHCO_3$ was added to study the nitrification. The pH of chamber B was adjusted to 7.0–7.5 using 1.0 N NaOH or 1.0 N H_2SO_4. To investigate the effects of each applied voltage on the ammonium flux between two chambers, the driving force of one batch set was caused by the ammonium concentration gradient (0 V) or the small voltage (1 or 3 V) added. Samples were periodically collected and measured at **0, 0.5, 1, 2, 3, 4, 7, 15, 20, 25, 45, 67, 80 and 122 h** after blending ammonium with a buffer/medium. Each batch test was carried out at room temperature (24.3 °C).

2.4. Continuous operating conditions of the IEBR

The IEBR was continuously operated for 90 days at room temperature (25.0 °C). The continuous operating conditions in the IEBR