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Effects of electric voltage and sodium chloride level on electrolysis of swine wastewater

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ABSTRACT

The effects of electric voltage and NaCl concentration on the removal of pollutants in swine wastewater were investigated to determine the optimum operation conditions for a designed electrolysis process. An up-flow electrolytic reactor was fabricated from Plexiglas, and one titanium anode coated with iridium oxide (IrO_2) and two stainless steel cathodes were installed in it. The anode surface area was 80 cm^2/L and the hydraulic retention time (HRT) was 6 h. The results indicated that the pollutant removal was highly proportional to the electric voltage and removal could be enhanced by adding NaCl. The removal efficiencies of NH_4-N, soluble nitrogen (NH_4-N plus NO_x-N), soluble total organic carbon (STOC), and color were proportional to the NaCl level up to 0.05% NaCl level, beyond which no further enhancement in removal was observed. However, such a tendency was not observed in the case of PO_4-P removal. The obtained results indicate that 7 V and 0.05% (8.56 mM) NaCl level would be the optimum conditions for the designed electrolysis process. Under these conditions, the average removal efficiencies of NH_4-N, soluble nitrogen, PO_4-P, STOC, and color were 99%, 94%, 59%, 64%, and 93%, respectively.

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1. Introduction

Swine wastewater contains a large amount of nitrogen, phosphorus, and suspended and dissolved solids that cause water pollution. These contaminants lead to eutrophication of surface water bodies and cause severe environmental problems [1] affecting both aquatic life and human health. Therefore, it is essential to remove these pollutants from swine wastewater before discharging it into soil or any water body. Several studies have already investigated the removal of pollutants from wastewater [2–5].

Wastewater treatment by electrolysis is a modern treatment process that removes pollutants through electrooxidation and electrocoagulation (EC). The key process in electrolysis is the interchange of atoms and ions by the removal or addition of electrons from an external circuit. Electrocoagulation occurs during electrolysis. The anode is involved in rapid adsorption of soluble organic compounds and trapping of colloidal particles that can be easily separated from an aqueous medium by H_2 flotation. Mollah et al. [6] reported that a gelatinous suspension was produced in an aqueous medium because of oxidation, which can remove pollutants from wastewater by either complexation or electrostatic attraction, followed by coagulation. This process has an advantage in that it can even remove very small colloidal particles because the applied electric field sets them in rapid motion and thereby facilitates their coagulation. Also, electrooxidation occurs during electrolysis because of the oxidative action of hydroxyl and hypochlorite ions. Hydroxyl ions can successfully remove toxic organic chemicals in wastewater because the hydroxyl radical is more powerful as compared to conventional oxidants such as chlorine, chlorine dioxide, and potassium permanganate [7]. The oxidation efficiency of hydroxyl ions depends on their interaction with the materials present in a water stream. In a solution, NaCl supplies a sufficient number of chloride ions (Cl^-) that generate chlorine at the anode and immediately react with water to form hypochlorite (HOCl), which then reacts with ammonia during electrolysis to produce N_2 gas. Chen [8] reported that NaCl could significantly reduce the adverse effect of other anions such as HCO_3^- and SO_4^{2-} in addition to providing chloride ions in the electrolytic media. Further, the electrolysis efficiency depends on several factors such as electric current density, pH, ionic concentration, and electrode material, especially the anode material [9,10]. The anode material plays an important role in deciding the operating cost and the removal efficiency. Kim et al. [11] reported that a titanium anode coated with IrO_2 successfully oxidized organic pollutants in aqueous media. An IrO_2 coating imparts dimensional stability to a Ti anode and makes it corrosion-resistant; for example, a lifetime of more than 10,000 h has been demonstrated under severe operating conditions [12]. Mussy et al. [13] reported that a IrO_2-coated Ti anode exhibits long-term catalytic stability during electrolysis.

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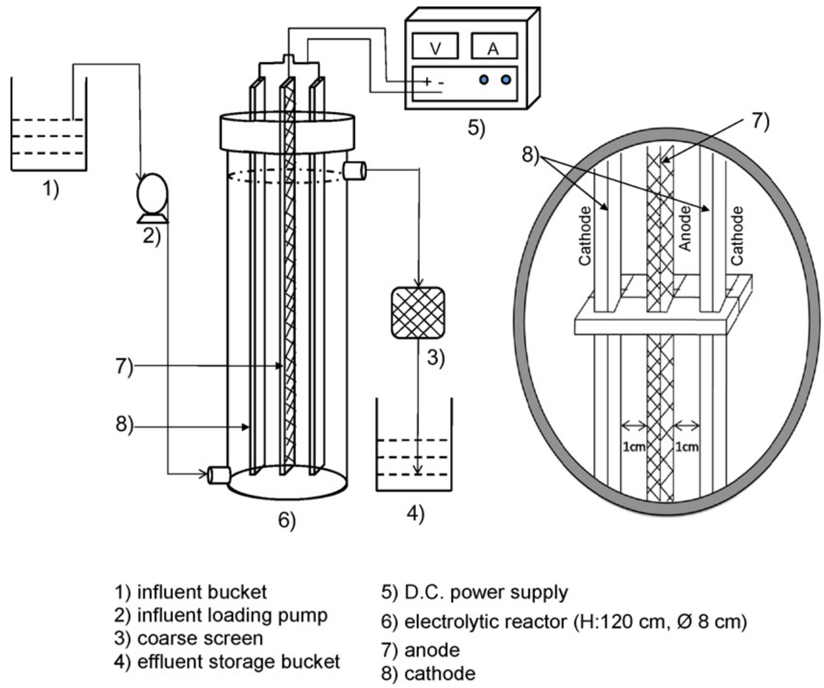

Fig. 1. Schematic of the electrolytic process.

In recent times, electrolysis has been effectively applied to treat various types of wastewater such as poultry wastewater [14], cattle slaughterhouse wastewater [15], poultry slaughterhouse wastewater [16], tannery wastewater [17], textile wastewater [18], laundry wastewater [19], and restaurant wastewater [20]. However, most of these researches have focused on organic matter removal from wastewater using aluminum or iron as the anode. The combined removal of nitrogen (N), organic matter, phosphorus (P), and color from high-strength animal wastewater such as swine wastewater has rarely been conducted. Thus, the ideal operational parameters required for achieving enhanced pollutant removal from animal wastewater, such as optimal NaCl concentration and electric voltage or current density, have not been established yet.

Therefore, in this study, we designed an up-flow electrolytic reactor with an IrO_2-coated Ti anode and examined the effects of electric voltage and NaCl concentration on the performance of the electrolytic process in the treatment of swine wastewater.

2. Materials and methods

2.1. System configuration and process operation

The electrolytic reactor was made of Plexiglas; it had eight spigots that were separated from each other by a distance of 15 cm in order to maintain the reaction volume and facilitate effluent decanting. The height, diameter, and working volume of the reactor were 120 cm, 8 cm, and 6.0 L, respectively. One Ti plate (thickness: 1 mm) and two stainless steel plates (thickness: 1.2 mm) were used as the anode and the cathodes, respectively. The anode was coated with IrO_2 to make it dimensionally stable. Two cathodes were arranged parallel to each other on either side of the anode plate by means of an acrylic band; they were positioned at a distance of 1.0 cm from each other in order to obtain an efficient electric field. The electrolytic reaction is normally inversely proportional to the distance between the electrodes. However, a very small separation between the electrodes can result in the coagulation of solids and the adsorption of colloidal materials on the electrodes, thereby interfering with the water flow in the electrolytic reactor. In contrast, a very large separation between the electrodes will definitely inhibit the electrolytic reaction. Therefore, it is important to maintain an appropriate distance between the electrodes for effective electrolysis. In several researches [6,10,11,16–22], the gap between the electrodes was maintained at approximately 10 mm or in the range of 5–15 mm. In this study as well, the distance between the electrodes was fixed as 10 mm. The anode surface area appropriate for installing the anode along with two cathodes in the designed electrolytic reactor, as shown in Fig. 1, was 480 cm^2 (80 cm^2/L, 120 cm × 4 cm). The apex of the reactor was sealed along with the electrodes by means of acrylic and silicone gel. The electrodes were connected to a digital DC power supply (DC 12 V 30 A, Model: WER 312) that regulated the electricity. Influent wastewater was loaded into the reactor through the lowermost spigot by using a pump, and the effluent decanted from the reactor was stored in a bucket after passing it through a filter. The filter was made of Plexiglas (10 cm × 10 cm × 15 cm), and textile fabrics (3 cm × 4 cm) were packed into the filter system. A schematic diagram of the electrolytic process is shown in Fig. 1. The electrolysis process was operated in a continuous up-flow mode and the hydraulic retention time (HRT) was 6 h. In a preliminary batch test, which was conducted at conditions of high voltage (7 V) and high NaCl levels (0.2%), the amount of N removal began to dramatically decrease after 5 h; the color removal at 5 and 6 h was approximately 70% and 90%, respectively, indicating that 6 h might be required for obtaining a high N and color removal. Therefore, 6 h was considered as HRT and the changes in the performance of the electrolytic process at various NaCl and voltage levels were studied to ultimately determine the optimal NaCl and voltage levels required to achieve a high removal of pollutants.

2.2. Experimental design

Two different experiments were conducted to study the effects of electric voltage and NaCl concentration on electrolysis. In order to determine the optimal NaCl and electric voltage levels for the designed electrolytic reactor, the electrolysis was studied by gradually reducing the NaCl and voltage level. First, in

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