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Continuous treatment of biologically treated textile effluent using a multi-cell electrochemical reactor

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HIGHLIGHTS

- The biologically treated textile effluent was treated using a multi-cell reactor.
- The reactor was highly effective in COD and color removal.
- The reactor consumed low energy and required short retention time.
- The dissolution of PbO_2 anode was not significant.

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ABSTRACT

The refractory components of textile wastewater usually cannot be effectively removed using biological methods. In this paper, the electrochemical treatment of biologically treated textile effluent was investigated using a continuous multi-cell reactor. The operational variable effects were firstly examined using the wastewater which was obtained by diluting the raw textile wastewater to a chemical oxygen demand (COD) level close to the biologically treated effluent. The proper current density and retention time were found to be about 12 mA cm^{-2} and 30 min, respectively. The biologically treated effluent was then treated under the proper conditions above. The reactor performed quite well. The COD of the wastewater could be reduced from 238–249 mg L^{-1} to 43–54 mg L^{-1}; the effluent pH ranged from 6.37 to 6.48; the color of the wastewater turned from brown to transparent; the current efficiency and energy consumption were 42.5–43.6% and 16.2–16.6 kWh m^{-3}, respectively. In addition, it was demonstrated that the electrode dissolution was not significant. The effluent Pb content was below the permissible value of the discharge standard of China, 0.1 mg L^{-1}. The experimental results clearly indicate that the multi-cell electrochemical reactor is a good alternative for the treatment of biologically treated effluent.

1. Introduction

Nowadays, the contamination of water body by different pollutants is one of the most difficult societal challenges [1]. Textile industries are important sources of pollution. They release massive quantities of wastewater annually containing different kinds of pollutants such as dyestuffs, dissolved inorganic salts, dispersing agents and surfactants [2,3]. Once released untreated, these compounds may remain in the waterbody for long periods, and pose great threats to the environment and human health.

Various conventional technologies are applied to treat textile wastewater, including physicochemical methods, advanced oxidation processes (AOPs) and biological methods. Physicochemical methods such as chemical coagulation/flocculation are easy in application, but they are inefficient in the color removal and may generate a considerable amount of sludge [4]. AOPs such as ozonation, Fenton oxidation and photocatalytic oxidation provide fast decolorization and COD removal, but they are expensive and have operational problems [5–8]. Biological methods are by far the most widely used methods due to their economical feasibility [9,10]. However, they have limitations in degrading the toxic and refractory pollutants [11]. Therefore, more efficient techniques are imperative.

In recent years, electrochemical oxidation has received increasing attention due to its high efficiency in mineralizing refractory pollutants. This technique has been applied to degrade phenol [12–15], ibuprofen [16], synthetic dyes [17,18], as well as to treat industrial wastewater [19,20], domestic wastewater [21] and landfill leachate [22]. Some other researchers also investigated

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the continuous electrochemical treatment of paint and citric acid wastewater [23,24]. In the electrolysis process, pollutants can be removed directly [25] at the electrode surface, or indirectly [26] via the electro-generated hydroxyl radicals which are the second strongest oxidants known after fluorine. This technique has also been applied to treat textile wastewater [27–30]. Sakalis et al. [31] investigated the electrochemical treatment of textile wastewater using a continuous reactor with parallel plate electrodes, and achieved a decolorization efficiency of over 90%. Körbahti and Tanyolac [32] studied the electrochemical treatment of textile wastewater using a continuous tubular reactor, and also obtained high pollutants removal efficiency. However, textile wastewater is usually characterized by high organic load, and therefore electrochemical treatment of the raw wastewater is costly. Biological processes are economical but cannot degrade the refractory pollutants effectively. A good solution to these problems is to combine the biological processes with the electrochemical oxidation. The former is used to remove most part of pollutants, while the latter is used to remove the residual refractory ones to make the effluent comply with the discharge limits [33]. However, due to the complex wastewater composition, the conventional single-cell electrochemical reactor with parallel plate electrode usually requires long reaction time and high energy consumption. For example, to reduce COD of the biologically treated textile effluent from 532–685 to 99–376 mg L^{-1}, the time required and the energy consumed were 8–12 h and about 199 kWh m^{-3}, respectively [34,35]. In addition, batch treatments were conducted in these works, whereas very few efforts were paid to the continuous ones.

In our previous work [36], we developed a continuous multi-cell reactor for wastewater treatment, and found that this reactor performed much better in degrading phenol than the conventional ones. In this work, the continuous multi-cell reactor was used to treat the biologically treated textile effluent. The objectives of this study are to examine the effects of operational variables on the electrolysis process, and to evaluate the performance of the reactor in treating the biologically treated effluent.

2. Experimental

2.1. Wastewater source

Considering the large wastewater volume required in the continuous treatment tests, two dilutions of a raw textile wastewater, Dilution 1 and Dilution 2, were used to examine the operational variable effects and to determine the proper operational conditions first. Dilutions 1 and 2 were prepared by diluting the raw textile wastewater in tap water to 15% and 10%, respectively. A biologically treated textile effluent was then used to evaluate the performance of the multi-cell reactor under the proper conditions. Both the raw wastewater and the biologically treated effluent were collected from a local dying factory (Chongxian dyeing, Hangzhou, China). The raw wastewater was treated by activated sludge process after primary sedimentation in this factory, and no other physicochemical methods were used. The biologically treated effluent was collected at the outlet of the secondary sedimentation tank. The physicochemical characteristics of the raw wastewater, the diluted wastewater and the biologically treated effluent are listed in Table 1.

2.2. Electrolysis

Electrolysis was carried out in a continuous multi-cell reactor. The reactor has a working volume of about 8.4 L, consists of 10 polyvinyl chloride cells with dimension of 300 mm × 250 mm × 35 mm. Each cell has either an upper or lower outlet. Ti/PbO_2 mesh with dimension of 165 mm × 165 mm × 5 mm worked as the anode, and stainless steel plate with the same area worked as the cathode. The reactor scheme and other details can be found in our previous work [36]. Treatment of the diluted effluents were conducted under an operation time of 200 h which was divided into 5 runs with varied current density (j), hydraulic retention time (HRT) and influent COD. Treatment of the biologically treated effluent was conducted for 10 h under the proper conditions determined in the treatment of the diluted effluents. Before the electrolysis started, the reactor was filled with wastewater, and hence samples withdrawn at the outlet of the reactor showed a transient period. During the electrolysis process, wastewater was continuously fed into the reactor through a peristaltic pump (Lange Co., Baoding, China). A digital DC power supply (Atten Electronics Co., Shenzhen, China) was used, and the constant current was maintained at a desired value with only minor adjustments of the applied voltage. Sample was collected once an hour.

2.3. Analysis

The effluent COD was measured using a spectrophotometer (DR/2500 HACH co., USA) according to the standard methods [37]. The absorption spectrum was measured using a UV–vis spectrophotometer (TU-1800PC Persee Instruments Co., Beijing, China), with the absorbance being measured from 200 to 800 nm. The pH value was measured using a Mettler Toledo SG2 pH meter. The Pb content was analyzed by Atomic Absorption Spectrophotometry (AAS), using a Shimadzu spectrophotometer, model AA-6300C.

The properties of the PbO_2 anode before and after treatment of the diluted wastewater were investigated by cyclic voltammetry (CV) using an electrochemical workstation (CHI660D Chenhua Instrument Co., Shanghai, China) and a three-electrode cell. The Ti/PbO_2 mesh, which was cut from the anode, served as the working electrode, whereas an Ag/AgCl electrode (3 M KCl, 0.205 V vs standard hydrogen electrode, SHE) and a Pt electrode were used as the reference electrode and the auxiliary electrode, respectively. CV scanning was conducted between 0 and 2.5 V (vs. open circuit potential) at a scan rate of 1 mV s^{-1}. Dilution 1 and 1 mol L^{-1} Na_2SO_4 solution were used as the electrolyte separately. All measurements were conducted at room temperature (25 ± 2 °C).

Table 1
Physicochemical characteristics of the raw effluent, two dilutions of the raw wastewater and the biologically treated effluent.

Parameter	Raw wastewater	Dilution 1	Dilution 2	Biologically treated effluent
pH	7.32–7.94	7.08–7.62	7.01–7.42	7.28–7.39
Conductivity (ms cm^{-1})	6.03–6.33	1.60–1.78	1.41–1.53	7.10–7.34
Chloride (mg L^{-1})	715–727	72–84	64–74	777–857
COD (mg L^{-1})	1658–1692	232–262	137–159	238–249
Pb content (mg L^{-1})	–[a]	–	–	–

[a] Below the detection limit.