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Integrated electrochemically enhanced adsorption with electrochemical regeneration for removal of acid orange 7 using activated carbon fibers

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Abstract

The main objective of this study is to explore the feasibility of the combination of enhanced adsorption for acid orange 7 (AO7) in solution and regeneration of activated carbon fibers (ACFs) by electrochemical method. Electrochemical polarization can cause an increase of the adsorption rate and capacity for AO7 on the ACFs. The adsorption rate and capacity at the polarization of 600 mV increase by 120% and 115%, respectively. In all these cases the adsorption isotherms are in good agreement with Langmuir isotherm model. The effective electrochemical regeneration of ACFs saturated with AO7 is realizable. The regeneration efficiency of over 90% is achievable at −5 V, and the regeneration potential higher than −5 V is not advantageous to the readsorption of AO7. The results of the integrative electrosorption/regeneration cycle experiment show that the regeneration efficiency still maintains over 70% after 10 cycles. The integrative electrosorption/regeneration cycle process can reduce the regeneration procedure, and also decrease the adsorption costs. These indicate that the integrative electrosorption/regeneration cycle process is technically feasible and promising for the treatment of industrial effluents and the purification of supplying water.

Keywords: Electrosorption; Acid orange 7; Activated carbon fibers; Electrochemical regeneration

1. Introduction

The adsorption of activated carbon is considered to be one of the most effective methods of advanced waste treatment [1]. However, it is expensive for large-scale application [2]. The major factors influencing the costs of an adsorption process include adsorption rate and capacity as well as regeneration efficiency and costs [3–5]. Therefore, improving adsorption rate and capacity, enhancing regeneration efficiency and reducing regeneration costs are the effective ways to reduce the adsorption operating costs, which are the focus in the research area for the adsorption of activated carbon.

An attractive method enhancing adsorption rate and capacity is the electrochemical polarization employing high area porous adsorbent materials with a high conductivity [6–10], which can be used in situ. In the earlier studies of electrochemically enhanced adsorption, the results obtained by the researchers have shown good removal efficiency of metal ions by porous materials, and the industrial products have been developed. Electrochemical polarization has been also successfully used to increase the adsorption of some substituted and non-substituted phenols and chlorinated organic compounds [3,4]. The adsorption process using activated carbon as adsorbents is one of the efficient methods to remove dyes from the effluent [11]. However, electrochemically enhanced adsorption for dyes has not been found in the literatures.

Activated carbon is prone to be exhausted by organic pollutants. Sometimes the activated carbon saturated with pollutants is disposed of by the landfill and incineration, which would not only cause the waste of carbon resource and introduce the secondary pollutants into the environment but also increase the costs of adsorption operating processes. Therefore, researchers are exploring the effective regeneration approaches for the activated carbon exhausted with pollutants. The most widely used process for the industry is the thermal regeneration [12]. However, it is a process with the high energy consumption and the high costs. Moreover, the thermal regeneration results in material losses of 5–10%. Electrochemical regeneration is considered as one of the most effective and promising regeneration methods [13], which are being widely studied [14]. Electrochemical regeneration

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refers to the regeneration of an exhausted adsorbent in proper electrolyte solution by a given potential or current [12,14–17]. The electrochemical regeneration mechanism involve electrodesorption and/or destruction of the adsorbed organic pollutants to restore the adsorption capacity. García-Otón et al. [17] concluded that the electrochemical method is more effective for regeneration of activated carbon compared with conventional thermal regeneration as it hardly modify the porous structure of the material.

Therefore, electrochemical technology can increase the adsorption capacity of activated carbon on one hand and also regenerate the activated carbon exhausted in situ on the other hand. However, to the best of our knowledge, no report has been found with respect to the combination between electrochemically enhanced adsorption and regeneration for activated carbon saturated. Activated carbon fibers (ACFs) is a new type of high efficiency adsorbent. It has bigger specific surface area, faster adsorption velocity and larger adsorption capacity than activated carbon. The contact potential difference of the ACFs electrode is smaller than that of the activated carbon electrode. And the ACFs are not prone to cause the local groove. Therefore, the ACFs were used in this study. The objectives of this study are to use electrochemical polarization to enhance adsorption rate and capacity of acid orange 7 (AO7) selected as target, and to explore the application possibility of the combination between electrochemically enhanced adsorption and electrochemical regeneration of ACFs. AO7 was selected due to that azo dyes are among the largest group of colorants used in a variety of industries ranging from textile to paper [18] and stable with respect to biochemical oxidation.

2. Experimental

2.1. Materials and instrumentation

AO7 (98% pure) was obtained from Jierda Dye Chemicals, Jinzhou, Hebei, China. The ACFs made from polyacrylonitrile resin was purchased from Anshan Activated Carbon Fiber Company, China. The ACFs was treated by NaOH and HCl, which was described in previous work [4]. All the experiments were performed in conventional three-dimensional electrodes system setup, which was shown in Fig. 1, described in another paper [3].

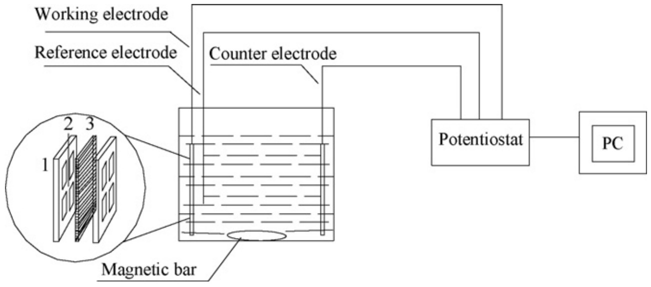

Fig. 1. Schematic of the setup for the adsorption/electrosorption experiments. The expanded schematic of the working electrode is shown in the circle: (1) Plexiglas with four holes, (2) platinum wire and (3) ACFs.

2.2. Procedure for adsorption experiments and mathematical analysis

The adsorption/electrosorption kinetics experiments were carried out in 100 mL of AO7 solution with the fixed ACFs (30.0 ± 0.5 mg). 0.5 mL sample was withdrawn at predetermined time intervals, diluted to 10 mL, and absorbances were measured by UV–vis spectrophotometer (Jasco V-550, Japan) at 485 nm. The adsorption rate constants were determined from the Lagergren Eq. (1) [19]:

$$\log(q_{\mathrm{e}} - q) = \log q_{\mathrm{e}} - \frac{k_{\mathrm{ads}} t}{2.303} \tag{1}$$

where k_{ads} (min^{-1}) was the adsorption rate constant, q_{e} and q were the adsorption amounts (mmol g^{-1}) at equilibrium and time t (min), respectively.

After the investigation of kinetics, isotherm experiments at different bias potentials were also performed with fixed amount of ACFs (30.0 ± 0.5 mg) at 298 K for 22 h when the adsorption reached the equilibrium. The isotherms were fitted by two classical empirical models of Langmuir and Freundlich described in pervious work [4]. The normalized percent deviation was determined according to the following equation:

$$D\% = \left(\frac{100}{N}\right) \sum \left[\frac{q_{\mathrm{e,exp}} - q_{\mathrm{e,pred}}}{q_{\mathrm{e,exp}}}\right] \tag{2}$$

where N is the number of data points, $q_{\mathrm{e,exp}}$ and $q_{\mathrm{e,pred}}$ are experimental and predicted q_{e} values, respectively.

2.3. Electrochemical regeneration

Before electrochemical regeneration, the ACFs (30.0 ± 0.5 mg) were saturated at polarized potential of 600 mV in 1 mmol L^{-1} AO7 solution, and then were washed by little deionized water. The electrochemical regeneration was performed with 80 mL 2% NaCl solution in the reactor used in the electrosorption experiment. The regeneration potentials were controlled under the magnetic stirring in the range of −10 to 10 V for 2 h by constant-voltage power. The AO7 concentration of the regeneration solution was measured by UV–vis spectrophotometer, and the COD was also investigated by the standard dichromate method. When the electrochemical regeneration ended, the ACFs were washed by deionized water, and dried at 105 °C for 24 h. The ACFs after regenerating was used to adsorb AO7 at the polarized potential of 600 mV, and regenerated again and again under the same conditions. The regeneration process is evaluated using the percent of regeneration efficiency (RE):

$$\mathrm{RE}\,(\%) = \frac{q_{\mathrm{r}}}{q_{\mathrm{e1}}} \times 100 \tag{3}$$

where q_{r} and q_{e1} are the adsorptive capacity of regenerated and fresh ACFs at the potential of 600 mV, respectively. The surface chemical properties of ACFs after regeneration were examined by Boehm titration [20].