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Multivariate-parameter optimization of acid blue-7 wastewater treatment by Ti/TiO_2 photoelectrocatalysis via the Box–Behnken design

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Abstract

The aim of this study is to obtain optimal decolourization conditions for acid blue-7 (AB7) wastewater treatment by Ti/TiO_2 photoelectrocatalysis using response surface methodology (RSM). On the basis of a three-variable Box–Behnken design (BBD), RSM was used to determine the effect of pH values (range 3.2–6), light intensity (range 10–20×10^2 μW/cm^2) and bias potential (range 0.1–1.1 V) on the levels of response, i.e. decolourization efficiency. By applying the quadratic regression analysis, the equations describing the behaviors of the response as simultaneous functions of the selected independent variables were developed. Accordingly, the optimal conditions were determined as pH of 3.41, light intensity of 16.02×10^2 μW/cm^2 and bias potential of 0.68 V. Decolourization efficiency of 90.13%, obtained experimentally under such optimal conditions, agreed was highly with that of 90.44%, estimated by the equations.

Keywords: Acid blue-7; Box–Behnken design (BBD); Optimization; Response surface methodology (RSM); Ti/TiO_2 electrode

1. Introduction

During dye production and textile manufacturing processes, a large amount of wastewater containing dyestuffs with intensive color and toxicity can be produced and consequently introduced into aquatic systems. Because of the nature of synthetic dyes, conventional biological treatment methods appear ineffective for decoloring such wastewaters. Alternatively, dyes are usually removed by adsorption and/or coagulation in

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conventional industrial wastewater treatment. However, these methods merely transfer dyes from the liquid to the solid phase, causing secondary pollution and requiring further treatment [1–5].

The strong potential of advanced oxidation processes (AOPs) for dye wastewater treatment is universally recognized. Many oxidation processes such as TiO_2/UV, H_2O_2/UV, photo-Fenton ozone (O_3, O_3/UV, O_3/H_2O_2), etc., are currently employed by many investigators [6–9]. Among these, an attractive process popularized in the past few years for degrading organic pollutants is the photoelectrocatalytic (PEC) process. The method consists of applying a biasing potential into the photocatalytic process. In this system, a biasing potential is applied across a photoanode on which the catalyst is supported. This configuration allows for a more effective separation of photogenerated charge carriers (e^- and h^+ generated on the electrode surface due irradiation of UV light lower than 380 nm) thereby increasing the lifeime of these electron-hole pairs [10–12]. Many studies have reported that the photo-anodes were prepared by coating TiO_2 on a conducting material. But the weakness of such photoanode is the poor mass transition of electron mass transfer between TiO_2 films and supporting carriers. Recently, our research group successfully prepared an Ti/TiO_2 photoelectrode by anodising a TiO_2 film on titanium (Ti) for PEC degradation of fulvic acid [13]. This electrode had a large surface area and its microporous surface structure achieved an excellent adsorption of pollutants. Some investigators have also studied the influencing parameters on PEC oxidation including pH, bias potential and electrolyte, etc. [14,15].

In assessing the effect of parameters on treatment results, response surface methodology (RSM) is a well known efficient experimentation technique and has been applied in a wide range of fields such as drug and food industry, chemical and biological processes etc., for the purpose of either producing high quality products or operating the process in a more economical manner and ensuring the process in a more stable and reliable way [16,17]. RSM is a multivariate technique that mathematically fits the experimental domain studied in the theoretical design through a response function [18]. The two most common designs commonly used in RSM are the central composite design (CCD) and the Box–Behnken design (BBD). BBD is considered as an efficient option in RSM and an ideal alternative to CCD [19].

RSM has been assisted by the developments in the field of computer software, such as SAS, Minitab, and Design-Expert etc. Generally, the RSM usually contains five steps [20]: (1) defining the independent input variables and desired responses with the design constrains while adopting experimental design, (2) performing the regression analysis with the quadratic model of response surface, (3) calculating the statistical analysis of variance (ANOVA) for the independent input variables and to find which parameter significantly affects the desired response, (4) obtaining the optimal influencing parameters with the design constrains, (5) conducting a confirmation experiment to verify the optimal parameters.

A literature survey has shown that RSM has been successfully applied to different oxidation processes to optimize the experimental design. Its application includes TiO_2-coated/UV oxidation [21,22], TiO_2 slurry/UV oxidation [23,24], O_3 oxidation [25] and electrochemical oxidation [26]. However, the application in Ti/TiO_2 photoelectrocatalysis for acid blue-7 (AB7) decolourization is not yet reported.

Therefore, the aim of this work is to optimize the influencing factors on photoelectrocatalytic oxidation for AB7 decolouring. A laboratory scale photoelectrocatalytic reactor was employed for an artificial AB7 wastewater treatment. A BBD was selected to study simultaneously the effects of three influencing variables (pH, light intensity and bias potential) on the response