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Experimental study of a solar-driven photo-electrochemical hybrid system for the decolorization of Acid Red 26

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A B S T R A C T

This study presents a new solar-driven hybrid system that integrated a photo-electrochemical reactor with a photovoltaics (PV) panel for azo dyes' decolorization and electricity generation. Full spectrum of sunlight is utilized to optimize the color removal of Acid Red 26 (AR26) in this hybrid system. Persulfate (PS, $S_2O_4^{2-}$) was selected as the photochemical oxidant and Ti/IrO_2-Ta_2O_5 electrode was used as the anode. Experiments were made to evaluate the efficiency of decolorization and the performance of PV panels in different reaction conditions outdoors. The results showed that the synergistic effect of two processes was observed for the AR26 decolorization. Comparing with the solar/persulfate process or the electrochemical process alone, the complete color removal time by the hybrid system decreased up to 50% and 44.4% respectively. In this system, the water layer in the flow channel cooled PV panels by absorbing the far infrared spectrum of sunlight, and the increased temperature of wastewater from 7 °C to 16 °C enhanced the decolorization efficiency of AR26. Moreover, the generated electricity by PV panels could satisfy the energy demand of electrochemical oxidation.

1. Introduction

Recently, the purification of wastewater from the textile industry has attracted worldwide attention. Azo dyes make up a large percent of dyes generated today that are widely utilized in various industries, however, a large amount of them are released to the textile effluents during the dyeing process [1].The toxic aromatic dyes are the main pollutants in the colored wastewater, posing considerable threats to the environment [2]. Since azo dyes are designed to be resistant to detergent, weather, biodegradation and photolysis, it is difficult to remove them by traditional wastewater treatment processes [3,4]. Meanwhile, the water purification technologies are associated with high consumption of energy, thus the methods for dealing with this type of dyes efficiently and environmentally have been increasingly studied [5].

As a clean alternative energy resource, solar energy contributes an important role in energy generation, and great efforts have been devoted to solar energy conversion for water purification due to its wide spectrum. There are many hybrid systems, including integrated photovoltaics (PV) with various water treatments, to achieve the solar energy conversion for wastewater purification [6,7]. Vivar et al. built a hybrid device that combined photocatalysis reactor with photovoltaic cells into a single unit to achieve both water purification and electricity generation, which realized full use of the solar spectrum and lowered the temperature of solar cells [8–11]. Based on this system, Zhu et al. utilized the generated electricity for driving UV-LED to enhance the degradation of the dyes. Though it enhanced the decolorization efficiency, the photoelectric conversion efficiency of UV-LED is low and UV-LED is less cost-effective for the wastewater treatment [12]. In addition, the electricity generated by above photocatalysis systems was rather low because of the optical scattering of suspended TiO_2 in the liquid. And the separation of small photocatalyst particles requires more complicate technology.

Another type of water purification system integrated the solar photochemical reactor with PV panels was constructed by Cui et al. [13]. In this system, UV bands of the solar spectrum was utilized as light source to active potassium persulfate ($K_2S_2O_8$) into strong sulfate radicals, which can react with large scale of organic and inorganic

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Nomenclature

PV	photovoltaics
PS	persulfate
EC	a water purification process by electrochemistry
S/PS	a solar water purification process by persulfate
EC/PS	a water purification process by electrochemistry and persulfate
S/EC/PS	a solar water purification process by electrochemistry and persulfate
AR26	Acid Red 26
UV	ultra violet
UV-LED	ultraviolet-lighting emitting diode
DAS	dimensionally stable anodes
I_{sc}	short-circuit current, A
P_{max}	the maximum output power, W
V_{oc}	open-circuit voltage, V
FF	fill factor
I_{sc} (@1sun)	the normalized short circuit current, A
P_{max} (@1sun)	the normalized maximum output power, W
GC–MS	gas chromatography-mass spectrometry
TOC	total organic carbon, mg/L
LSV	linear sweep voltammetry
CV	cyclic voltammetry
M	anode

contaminants. The homogeneous solar photochemical reaction significantly promoted the output power of PV panels, but the initial concentration of dyes is too low for a system to be developed at commercial level, and in comparison to the dye concentration, the amount of persulfate is high. In addition, the timely contaminant removal need to be optimized.

Hence, we prospered a more comprehensive solar-driven process by coupling photochemistry and electrochemistry simultaneously to enhance the decolorization of dyes. Electrochemical oxidation has great advantages on the wastewater treatment, such as safety, high energy efficiency, environmental-friendly and feasibility for most organics [14,15]. Besides, industry effluents usually contain some kind of salts, thus the addition of electrolyte will not bring in new ions. In electrochemical experiment, the choice of electrodes heavily influences the oxidation process of organics and the experimental cost [16,17]. Among the electrodes, dimensionally stable anodes (DSA) are more suitable to industrialize, because they have excellent chemical stability, long life time, low cost and some of them can achieve high mechanical resistance in extremely acid aqueous solution [18,19].

The integration of the two processes provides an improved utilization for chemical agents and solar energy. SO_4^{2-} would be generated during the sloar/persulfate process, both $S_2O_8^{2-}$ and SO_4^{2-} can act as a role of electrolyte in electrochemical process. Meanwhile, the generated electricity by PV panels can be used as energy source of electrochemical oxidation. Furthermore, the wastewater temperature would increase by absorbing far infrared bands of solar spectrum. It is confirmed that the increased temperature can improve reaction rate in both photochemical and electrochemical processes within a certain range of temperature [13,20,21]. Thus, the combination of two processes is required for the further use of the solar spectrum and the chemical oxidant.

The main purpose of this study is to construct a new hybrid system integrating the photo-electrochemical reactor with photovoltaics. As far as we know, there has been none hybrid system like that modality. The system optimized the use of full solar spectrum (Fig. 1): UV bands activated persulfate in the flow channel, visible and near infrared spectrums were converted to electricity by PV panels as energy source of the system, far infrared spectrum was used for thermal reactions. The Acid Red 26 (AR26), a type of azo dyes with an absorption peak at 505 nm, was chosen as the model azo dye pollutant. Ti/IrO_2-Ta_2O_5 electrode and Ti sheet were selected as electrochemical electrodes. The whole experiment was carried out outdoors to investigate the decolorization of AR26 and PV performance in Tianjin, China.

2. Materials and methods

2.1. Chemicals

Chemicals including sodium chloride (NaCl), sodium sulfate (Na_2SO_4), sodium persulfate ($Na_2S_2O_4$) and hydrochloric acid (HCl) with analytical grade were supplied by Yuanli Company. AR26 ($C_{18}H_{14}N_2Na_2O_7S_2$) with reagent purity grade was purchased from Tokyo chemical industry Co., Ltd.

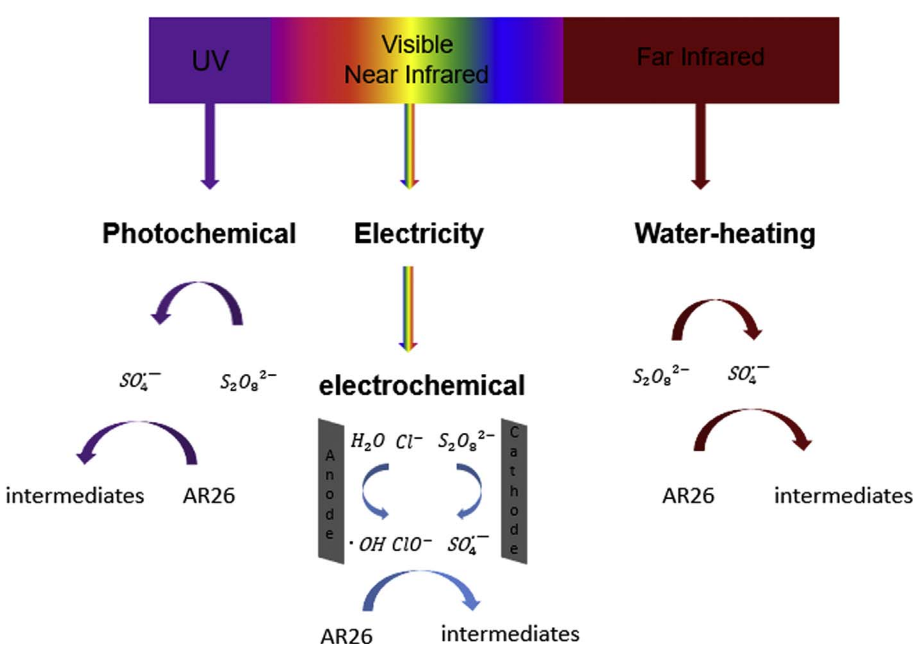

Fig. 1. Usage of full solar spectrum for the decolorization of AR26.