

Research on Photochemical Catalytic Sewage Degradation Property Based on Photovoltaic Technology

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In this paper, the photochemical catalytic wastewater degradation property based on photovoltaic technology is studied. The spectral segmentation and utilization technology is taken as the bond to achieve the effective combination of photocatalytic oxidation technology and photovoltaic power generation technology to achieve the goal of sewage purification using solar energy. The photocatalytic and electrical performance of different simulated pollutants, such as methylene blue and p-chlorophenol at different initial concentrations are investigated through the established SOLWAT system. The results show that: with the SOLWAT system, the catalytic degradation rate of the simulated pollutant machine dye methylene blue exceeds 99% and the degradation rate of p-chlorophenol exceeds 90%; and the total organic carbon content of simulated wastewater is reduced by more than 80%, which proves the SOLWAT system can completely mineralize the simulated pollutants into CO₂ and H₂O; the degradation of colorless simulated pollutants does not affect the electrical performance of the system; the degradation of colored pollutants will increase the output power of the system.

1. Introduction

At present, the control of water pollution in China faces many bottlenecks, which is significantly correlated with the rough economic development model (Doll and Frimmel, 2005; Molinari et al., 2002; Tian et al., 2012). Organic polluted wastewater is not only very harmful, but the damage lasts for a long time. Also, the treatment of wastewater is very complicated and difficult. Traditionally, advanced oxidation treatment, general oxidation, activated carbon adsorption and chlorine oxidation sterilization have been used in the treatment (Fourcade et al., 2012; Wang et al., 2013; Chun et al., 2013). Due to the complexity of high-concentration organic wastewater, which contains various pollutants, such as heterocyclic compounds, fused ring compounds and chlorinated aliphatic compound, it is difficult to achieve immediate treatment effect by using conventional treatment processes only. In addition, such wastewater is characterized by difficult to achieve product degradation, complex composition, toxicity and deep colority (Li et al., 2018; Hiskia et al., 2006; Matos et al., 2001). Based on this, in order to effectively solve the problem of organic wastewater and reduce the environmental impact of such wastewater, it is imperative to actively develop more efficient treatment technologies.

The photochemical catalytic oxidation technology is to excite the electron transition in the semiconductor when the ultraviolet light is irradiated on the surface of semiconductor materials, such as TiO₂, ZnO, WO₃, SnO₂, etc., thereby forming photogenerated electrons, electron-hole pairs and a hydroxyl radical•OH with strong oxidizing property to achieve the oxidation treatment of pollutants (Ranjit et al., 1999; Hop et al., 2002; Zhao et al., 2005). In the photochemical catalytic degradation reaction, the catalyst nano-TiO₂ can decompose and destroy various organic substances with its super-oxidative ability and finally mineralize these substances into CO₂ and H₂O, thus achieving the goal of removing pollutants. Up to now, the photochemical catalyst TiO₂ can achieve the effective disinfection, decoloration, deodorization and degradation of the main organic pollutants in water, including dyes, pesticides, surfactants and VOC. It is of great significance for environmental protection, maintaining ecological balance and the sustainable development of economy to use solar energy, a renewable energy source, for photochemical catalytic treatment of wastewater, which is what scholars have been working on for a long time (Mahmoodi et al., 2007; Huang et al., 2008; Wang et al., 2014).

This paper takes the mixed water treatment system as the research object. This system integrates the photovoltaic-photochemical catalysis, which can realize the organic combination of photochemical catalysis and photovoltaic function and fully exert the synergy between the two, thus opening up new channels and laying a foundation for the catalytic wastewater treatment through the industrialization of solar energy.

2. Experimental Principle

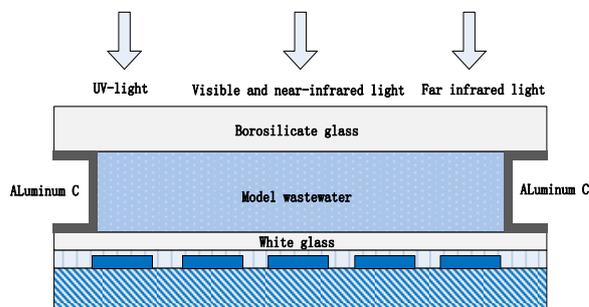


Figure 1: The structure diagram of SOLWAT system

As shown in Fig. 1, the solar panel formed by the rectangular flow channel, which is surrounded by C-type aluminum and is located on the solar panel. In this experiment, this part is used as a photochemical catalytic reaction vessel; the borosilicate glass is used as a cover plate above the flow channel, whose thickness is about 4 mm. The transmittance to the 200 to 400 nm of the ultraviolet wave can reach about 83%. In the wavelength range of single crystal silicon solar cell spectrum, the spectral transmittance can reach 90%.

In order to simulate that the suspension state of TiO₂ particles in the system, the stirring is required to be added to the vessel to avoid particle deposition. In terms of driving equipment, the system considers that the DC voltage can work normally at 3-12V. The indenter is 6m and the maximum flow rate per minute can reach 2.8L, ensuring that the simulated wastewater in the reactor is in a normal circulation state.

The system organically combines photochemical catalytic oxidation technology and photovoltaic power generation technology, and fully exerts the role of solar energy combined with the principle of spectral segmentation and utilization principle. A green environmental protection system is established, namely the SOLWAT System (Solar water purification and renewable electricity generation system).

After the sunlight is irradiated on the surface of the system, I will directly reach the surface of the battery through the near-infrared light on the flow channel and the cover glass; the simulated wastewater in the system can circulating and flowing under the action of photovoltaic power generation; the photochemical catalyst in the flow channel absorbs the ultraviolet light in the spectrum to further degrade the simulated wastewater; it does not have function in the photovoltaic power generation and photochemical catalysis. The simulated wastewater is taken away in the form of heat and the battery assembly thus maintains the low temperature working condition, which is conducive to improving the power generation efficiency of the battery. This will maximize the role of the solar system and ensure that the system can truly play its role, namely purifying wastewater.

3. Experimental Methods

3.1 Experimental Materials

3.1.1 Catalyst

In this experiment, titanium dioxide is used as a photochemical catalyst and TiO₂ nanoparticles are used as a catalyst. It is a 21 nm particle produced by Degussa AGTego by gas phase method and the specific surface area is 50m²/g.

3.1.2 Simulated pollutants

There are two main types: one is the organic dye methylene blue; the other is the colorless organic p-chlorophenol.

Tab. 1 Basic information of simulated pollutants

Sample	Abbr	Formula	G mol	Colour	λ_{\max}	CAS	Company
MB	MB	$C_{16}H_{18}ClN_3S$	320	Blue	665	61-73-4	Aladdin
4-CP	4-CP	C_6H_5ClO	129	Colourless	225	106-48-9	TCI

3.2 Experimental Scheme

The reactor mainly contains the following media: the first is air; the second is methylene blue simulated wastewater; the third is deionized water; the fourth is p-chlorophenol simulated wastewater; the system performance and the correlation between these two types of stimulated wastewater at the initial concentration of 20, 10 and 5 mg/L are analyzed. There are two blank control groups in the experiment: one is blank P25; the other is deionized water. The photochemical catalysis and electrical performance are compared and analyzed.

4. Experimental Results and Discussion

4.1 Photochemical Catalytic Performance of the System

Before starting the experiment, accurately weigh the simulated pollutants (fixed amount) and put them into the water (8L) for agitation. The initial concentration needs to be controlled and then relevant simulation is performed. Fig. 2 is the curve of pollution concentration degradation.

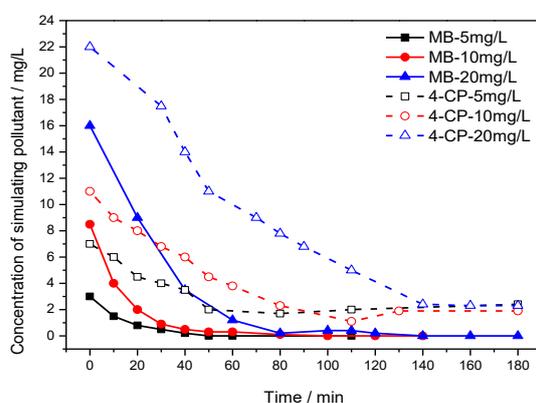


Figure 2: Simulated pollutants degradation curve with different initial concentration for MB and 4-CP

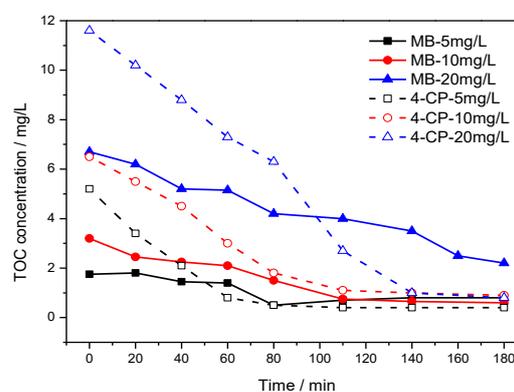


Figure 3: The mineralization rate curve of simulated pollutants (MB and 4-CP)

It is found through the observation that the concentration of sample simulated pollutants is lower than the configured concentration when the time is 0 min, which is related to the absorption of simulated pollutants by photochemical catalysts; in addition, all simulated pollutants (with different initial concentration) have achieved a relatively complete catalytic degradation reaction after the experiment, in which the degradation rate of methylene blue is higher, up to 99% and the degradation rate of p-chlorophenol can also reach more than 90%.

4.2 Study on the Mineralization Rate of Simulated Pollutants

Total organic carbon, or TOC is used to indicate the total carbon content of suspended and dissolved organic matters. This indicator can be used to indicate the degree of organic pollution in water.

In can be seen from the analysis in Fi.3 that the mineralization rate of the two simulated pollutants is more than 80%. In terms of mineralization rate, the efficiency of p-chlorophenol is the highest, up to more than 90%. It can be seen from the TOC results of the methylene blue sample that the there is a small amount of organic carbon in the sample solution with an initial concentration of 5 mg/L after three hours of outdoor experiment, but a relatively smooth mineralization curve is formed. It is analyzed that this is related to insufficient light at the end of the experiment, which reduces the mineralization rate of the simulated pollutants. During this period, there are still products in the form of organic carbon and the organic carbon in the solution that has not been completely mineralized; also, due to the small amount of organic carbon in the solution, the organic matter will influence the test results to some extent. In addition, through the analysis of the experimental results of 20 and 10 mg/L initial concentration, it can be concluded that there is still large amount of organic

carbon in the solution and there is an obvious degradation trend, which indicates that although the experiment is over, there is still mineralization phenomenon. Restricted by external conditions, the system still cannot absorb enough sunlight in the outdoor experiment, so this experiment lasts only for four hours.

The TOC of p-chlorophenol sample is detected, the three different initial concentrations shown in the Figure can achieve the complete mineralization of p-chlorophenol. The mineralization curve has gradually flattened out at the end of the experiment.

4.3 Study on the Electrical Performance of the System

The I-V tester is used to detect the maximum output power of the system mainly through the built-in inner container. This capacitor acts like a variable load in the detector. When the impedance is initially charged, it corresponds to the short-circuit state. At this time, the data of the output short-circuit current is recorded. After the capacitor is charged, the charging circuit of the impedance is disconnected and the open circuit voltage data is recorded. In the charging process of the capacitor, that is, using the solar panel to test the I-V, the impedance of the capacitor is changed, from the original zero to infinity. Similarly, the load of photovoltaic cells also change accordingly. In the experiment, the detection time of each detection point is 10s. At this time, the change of solar radiancy can be neglected and the standardized processing can be performed on the output power combined with the solar irradiance value, which lays a foundation for the subsequent comparative studies.

4.3.1 Standardized processing of the maximum output power based on each initial concentration condition

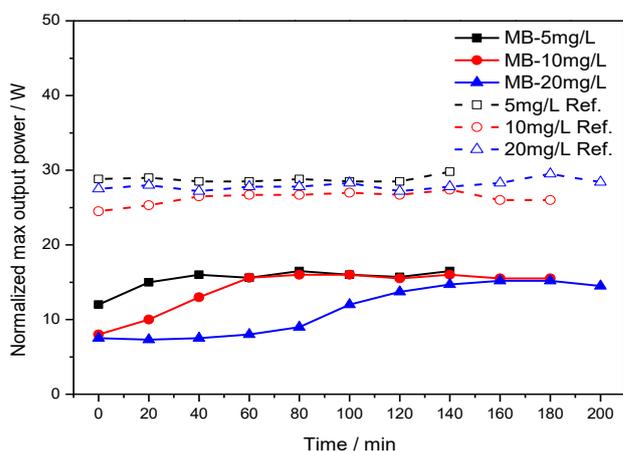


Figure 4: The normalized max output power of system with different initial concentration for MB

As shown in Fig. 4, the standardized processing of the maximum output power mainly stimulates the use of pollutant methylene blue and p-chlorophenol under outdoor conditions. Through the analysis of the Figure, it can be seen that after simulating the degradation of these two pollutants until colorless, the standardization of the maximum output power appears around 16W and a micro pump rated at 6W is used in the system. It is generally believed that there is a linear relationship between the system output power and the solar irradiance. Therefore, the solar irradiance of 375 W/m² or above can be obtained by calculation, which can meet the needs of system operation. However, when the system initially degrades the colored dye, it will absorb larger spectrum, so the output power is at the initial stage is minimal.

In combination with the MB experiment, the initial concentration is 10 mg/L and the standardization of the maximum output power is only 7.8 W. It can be seen from the calculation that the system rotation can be satisfied only when the minimum radiance reaches 770 W/m² or above. Assuming that the irradiance fails to meet the demand, it can exert the unique energy storage function of the accumulator. The subsequent surplus power generation can be stored to solve the problem of insufficient power generation, so that the system can meet the usage requirements of various weather conditions.

The maximum output power is calculated based on formula (1). The main influencing factors include: the first is the fill factor; the second is VOC, the third is the short-circuit current, which is represented by FF, VOC, and ISC impact.

$$P_{mp} = V_{mp} \times I_{mp} = V_{OC} \times I_{SC} \times FF \quad (1)$$

After reducing the operating temperature of the system, the V_{oc} and FF are slightly increased, but the most important influencing factor is I_{sc} .

4.3.2 Simulating the standardized maximum output power for each pollutant condition.

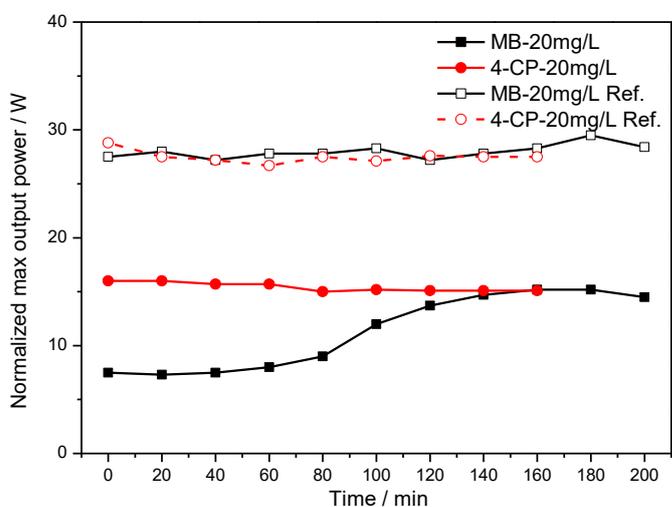


Figure 5: The normalized max output power of system with different pollutants

As shown in Fig. 5, the standardized maximum output power of the reference system and the SOLWAL system is analyzed at an initial concentration of 20 mg/L. The output power of the system is not affected by colorless pollutant p-chlorophenol and there is almost no change in the system in the initial stage of the degradation of methylene blue. The output power is stable at around 15 W over time, which fully simulates that the degradation of colorless pollutants is not affected by the electrical performance of the system; for the degradation of colored pollutants, the output power of the system is higher. In addition, the degradation path is different, so there are certain differences in the way of enhancing the output power.

5. Conclusion

- (1) With the SOLWAT system, the catalytic degradation rate of the simulated pollutant machine dye methylene blue exceeds 99% and the degradation rate of p-chlorophenol exceeds 90%.
- (2) The results show that the total organic carbon content of the simulated wastewater is reduced by more than 80%, which proves that the SOLWAT system is not a simple destruction of functional groups of the simulant, but the simulant is completely mineralized to CO_2 and H_2O .
- (3) The degradation of colorless simulated pollutants exerts no effect on the electrical performance of the system; the degradation of colored pollutants will increase the output power of the system and the degradation path will also affect the way of enhancing the output power.

Acknowledgments

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