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A solar-driven CPC photoreactor for decomposition of emerging contaminants in wastewater: Modeling and optimization

Leila Ghalamchi [a], Mohammad Hossein Rasoulifard [a], Zohreh Mohammadi [a], Mir Saeed Seyed Dorraji [a], Negar Sehati [b], Mohammad Reza Eskandarian [a, c]

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Abstract

In the present work, a new component parabolic collector (CPC) was introduced as a solar photocatalytic reactor and applied in pilot-scale for degradation of Phenazopyridine (PhP) via a Solar/H_2O_2/$S_2O_8^{2-}$/TiO_2 process. The TiO_2 nanoparticles were immobilized on the outer surface of CPC receivers' tubes by physicochemical processes. Field emission scanning electron microscopy (FESEM) was demonstrated a favorable attachment of nanoparticles on the glass tubes. Low Ti leaching during repeated experiments was approved by inductively coupled plasma (ICP) analysis. The final degrading by-products of PhP were identified and analyzed by gas chromatography-mass spectroscopy (GC-MS) analysis. Moreover, the impact of the effective parameters on the degradation of PhP during dual oxidation process in a solar-driven photocatalytic reactor such as flow rate, oxidant, PhP concentration, and pH was investigated and simulated with Artificial Neural Network (ANN) analysis and optimized with Genetic Algorithm (GA) and Ant Colony Algorithm (ACA). Consequently, the toxicity of effluent was tested with plants in optimal conditions when the oxidation step proceeded. This report summarized the current status of solar photocatalysis favorable photocatalytic activity under solar light irradiation

enhanced with CPC photoreactor which was successfully prepared. Guided by studies to explore the determination of optimal conditions for disinfection of real municipal wastewater, the biological treatment was investigated. In addition, the antibacterial assessment was considered to determine the presence of bacteria after solar disinfection.

Introduction

Generally, component parabolic collectors so-called CPCs are such interesting mediocrity between concentrators and one-sun systems. Solar photoreactors were utilized originally for photochemical applications as the format of line-focus parabolic-trough concentrators (Bigoni et al., 2014, Ndounla and Pulgarin, 2015, Spasiano et al., 2015). It is worth noting that the most recited superiority of CPCs is the possibility of using solar UV radiation coming from both direct and diffuse UV light, simplicity of construction and operation, ameliorating mass transfer by turbulent flow regime, and high reduction of vaporization of volatile pollutants. For solar photochemical applications, compound parabolic concentrators (CPCs) are being considered a good choice (Bigoni et al., 2014, Bilal et al., 2018, Carbajo et al., 2021, Maniakova et al., 2020, Meriño-Mantilla et al., 2019, Tanveer and Guyer, 2013). Among Advanced Oxidation Processes (AOPs), photocatalysis has shown a great potential such as being low-cost, environmentally friendly for treating polluted water with organic toxic compounds and pathogen microorganisms (Barzegar et al., 2021, Klauson et al., 2019, Miralles-Cuevas et al., 2014, Mohapatra and Ghosh, 2021, Rodríguez et al., 2021). In general, processes based on the interaction of light and semiconductors are known as heterogeneous photocatalysis. Among various strategies, TiO_2-based materials have been the most promising candidates for photocatalytic decontamination due to their strong oxidation capability, non-toxicity, high stability, and low price, thereby often being used in solar energy applications, environmental protection, and other fields (Bahadur and Bhargava, 2019, Cao et al., 2017, Khataee and Kasiri, 2010, Saien et al., 2011). Usually immobilizing a catalyst over support allows one to elude separation and recovery steps, in contrast with a suspended catalyst (Sheidaei and Behnajady, 2015). According to the existing literature, a dual oxidant ($H_2O_2/S_2O_8^{2-}$) is considered a significant and environmentally friendly oxidant. In the $H_2O_2/S_2O_8^{2-}$ system, generation and combination of sulfate radical ($SO_4^{-\bullet}$, E_0 ($SO4^-$)= 2.60 V) and hydroxyl radical ($HO^\bullet$, E_0 ($HO^\bullet$)= 2.70 V) can show a better platform for the oxidation performance than each oxidant separately (Hadjltaief et al., 2016, Wang et al., 2016). There are a few studies on the reaction mechanism of the $H_2O_2/S_2O_8^{2-}$ system.

$$S_2O_8^{2-} \rightarrow 2SO_4^{\bullet-}$$
$$SO_4^{\bullet-} + H_2O \rightarrow H^+ + SO_4^{2-} + {}^\bullet OH HO^\bullet + H_2O_2 \rightarrow H_2O + HO_2^\bullet$$
$$HO_2^\bullet + S_2O_8^{2-} \rightarrow O_2 + HSO_4^- + SO_4^{\bullet-} HO_2^\bullet + H_2O_2 \rightarrow O_2 + H_2O + HO^\bullet$$

In 2016 Wang et al. showed that the combination of $Na_2S_2O_8$ and H_2O_2 has a significant synergistic effect on the removal of NO (Wang et al., 2016). Li et al. reported for the first time that the presence of hydrogen peroxide (H_2O_2) can induce visible-light activity of bared TiO_2 particles (Li et al., 2001, Nasir et al., 2020, Wu et al., 2016). The addition of H_2O_2 to the TiO_2 noticeably

enhanced the photocatalytic activity under visible light irradiation. Phenazopyridine (PhP), is a commonly used anti-inflammatory pharmaceutical in urinary tract treatment and other medical prescriptions. Its structure and characteristics are given in Table S1. Herein it was selected as the organic and synthetic contaminant, due to the presence of the azo group which made it a resistant compound to biodegradation (Durán et al., 2008, Malato et al., 1997). So, it could be used as an appropriate model for future secure degradation of emerging water pollutants (Durán et al., 2008, Eskandarian et al., 2019, Mahdizadeh et al., 2014). There has been some work on the comparison of the performance of different solar photocatalytic reactors for the degradation of pollutants (Alalm et al., 2015, Manjón et al., 2008, Vilar et al., 2011).

In the present work, a novel solar and pilot-scale CPC photoreactor was fabricated successfully. The efficiency of simultaneous utilization of $S_2O_8^{2-}/H_2O_2$ oxidants together with immobilized TiO_2 on the outer surface of CPC photoreactor was investigated for the first time in the presence of solar light for decontamination of organic compounds. Target pollutant degradation, mineralization, and acute toxicity were the selected parameters to study the feasibility of the process. The effect of the $S_2O_8^{2-}$ and H_2O_2 concentration, pH variation, flow rate, and reaction time was evaluated in the present study, as well. ANN method was established to achieve a logical-mathematical model. Eventually, to assess the practical applicability of the as-made treated CPC, real municipal wastewater was applied under optimal conditions for degradation of the remaining organic materials after the primary biological treatment process and disinfection.

Section snippets

Materials

Phenazopyridine (PhP) with a purity of 99% was purchased from Dana pharmaceutical company® (Tehran, Iran) and used without further purification. The as used photocatalyst was TiO_2 P25 (Degussa-Evonik) with the crystallites mean size of 21 nm (Merck®). Potassium persulfate salt ($K_2S_2O_8$) (99.0%) was purchased from Sigma-Aldrich Co. Ltd.® Hydrogen peroxide H_2O_2 (30%), sodium hydroxide (NaOH) (99.0% purity), sulfuric acid (H_2SO_4) (98.0% purity) were also purchased from Merck Co.® Double-distilled...

Characterization of immobilized TiO_2 nanoparticles

The superficial and cross-section morphologies of uncovered and TiO_2-coated glass tubes were determined by FESEM analysis (Fig. 2a). As shown in Fig. 2a, there are the highly rough, coarse, and valley on the uncovered glass surface. Fig. 2b-d illustrate the morphology of the immobilized TiO_2 on the outer surface of the glass tube. According to the FESEM images, TiO_2 thin film is

formed in the high porosity network of the glass tube with an approximately particle size of 78 nm. The nanoparticles ...

Conclusion

This work provided new insights for photocatalysis fate of PhP and disinfection of wastewater by Solar/H_2O_2/$S_2O_8^{2-}$/TiO_2 process in CPC photoreactor. The result showed the significant degradation efficiency by solar photocatalysis of TiO_2 thin film process in pilot plant scale. The improvement was assigned to further reaction by adding oxidants. The main treasure includes:

- A highly effective Solar CPC was designed and applied for wastewater treatment and disinfection....
- To the more promising...

...

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article....

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