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Review

An overview on limitations of TiO_2-based particles for photocatalytic degradation of organic pollutants and the corresponding countermeasures

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ABSTRACT

The pollutants classified as "persistent organic pollutants (POPs)", are being subject to high concern among the scientific community due to their persistence in the environment. TiO_2-based photocatalytic process has shown a great potential as a low-cost, environmentally friendly and sustainable treatment technology to remove POPs in sewage to overcome the shortcomings of the conventional technologies. However, this technology suffers from some main technical barriers that impede its commercialization, i.e., the inefficient exploitation of visible light, low adsorption capacity for hydrophobic contaminants, uniform distribution in aqueous suspension and post-recovery of the TiO_2 particles after water treatment. To improve the photocatalytic efficiency of TiO_2, many studies have been carried out with the aim of eliminating the limitations mentioned above. This review summarizes the recently developed countermeasures for improving the performance of TiO_2-based photocatalytic degradation of organic pollutants with respect to the visible-light photocatalytic activity, adsorption capacity, stability and separability. The performance of various TiO_2-based photocatalytic processes for POPs degradation and the underlying mechanisms were summarized and discussed. The future research needs for TiO_2-based technology are suggested accordingly. This review will significantly improve our understanding of the process of photocatalytic degradation of POPs by TiO_2-based particles and provide useful information to scientists and engineers who work in this field.

Contents

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1. Introduction

In recent times, the world faces enormous challenges ahead as drinkable water runs short due to natural disasters, population increase, and water pollution. In view to suppress the worsening of clean water shortage, the possible reuse of onsite rural wastewater or treated municipal wastewater from treatment plants for agricultural and industrial activities may be the best solution for the future of sustainable water management in water-deprived countries (Lapena et al., 1995; Bradley et al., 2002; Xu et al., 2012). Since these wastewaters constitute one of the largest possible water resources, their reuse is anticipated to offset more clean water resource.

Recycling wastewaters is usually associated with the presence of suspended solids, health-threat coliforms and the so-called persistent organic pollutants (POPs, e.g., pharmaceuticals, personal care products and endocrine disrupters) that are both tedious and expensive to treat (Viessman and Hammer, 1998; Miranda-Garcia et al., 2011; Zeng et al., 2013a,b). In particular, the POPs are frequently detected in treated sewage, surface and groundwater and even drinking water, and have been observed to be capable of long-range transport, bioaccumulate in human and animal tissue, biomagnify in food chains, and to have potential significant impacts on human health and the environment (Miranda-Garcia et al., 2011). Development of advanced water treatment technologies with low-cost and high efficiency to treat the POPs contaminated wastewater is desirable. Currently, available water treatment technologies such as adsorption or coagulation merely concentrate the pollutants present by transferring them to other phases, but they are not completely "eliminated" or "destroyed" (Padmanabhan et al., 2006). Other conventional water treatment methods such as sedimentation, filtration, chemical oxidation and biotechnology suffer from some disadvantages such as incomplete removal, high consumption of chemical reagent, high treatment cost, time-consuming and generation of toxic secondary pollutants (H.R. Dong et al., 2011; Oller et al., 2011; Zhou et al., 2014). Effective alternative water treatment technologies are therefore required to improve treated effluent quality.

Photodegradation process of POPs has attracted increasing attention during the past decades due to its effectiveness in rapidly degrading and mineralizing recalcitrant organic compounds (Legrini et al., 1993; Chong et al., 2010; Miranda-Garcia et al., 2011). Various photocatalysts including CdS, SnO_2, WO_3, SiO_2, ZnO, Nb_2O_3, Fe_2O_3 were being studied but the nano-TiO_2 photocatalyst is well-known among the metal oxides for its high efficiency, low cost, physical and chemical stability, widespread availability, and noncorrosive property (Carp et al., 2004; Herrmann et al., 2007). It can be used to degrade a variety of organic and inorganic pollutants. When nano-TiO_2 is irradiated with ultraviolet (UV) light, electrons are promoted from the valence band to the conduction band, resulting in the generation of energized "holes" in the former (Fujishima et al., 2000; Chong et al., 2010). Free electrons react with the oxygen to form superoxide radical anions ($O_2^{\bullet-}$), while energized holes react with water (H_2O) or hydroxyl ion (OH^-) to form hydroxyl radicals ($^{\bullet}OH$). To date, the main TiO_2 applications are focused on air purification (Ao and Lee, 2003; Zhao and Yang, 2003; Li et al., 2005a,b). Studies in wastewater treatment by TiO_2 are still mainly in the stage of laboratory experiments because of some technical barriers. Firstly, the widespread technological use of TiO_2 is to some extent constrained by its wide band gap (anatase, ~3.2 eV), which requires ultraviolet irradiation for photocatalytic activation, giving rise to a very low energy efficiency in utilizing solar light (Yin et al., 2003; Zaleska, 2008; Chong et al., 2010). Because UV light accounts for only a small fraction (5%) of the sun's energy compared to visible light (45%), the shift in the optical response of TiO_2 from the UV to the