Bioresource Technology 137 (2013) 57–62

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Improvement in settleability and dewaterability of waste activated sludge by solar photocatalytic treatment in Ag/TiO_2-coated glass tubular reactor

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HIGHLIGHTS

- Photocatalysis as a new way could enhance sludge dewaterability and settleability.
- Ag/TiO_2 photocatalysis significantly improved sludge dewaterability/settleability.
- Synthesized Ag/TiO_2 had much higher photocatalytic activity than TiO_2 under sunlight.
- Ag/TiO_2 photocatalysis degraded sludge in a stepwise and mild manner.

ARTICLE INFO

Article history:
Received 8 January 2013
Received in revised form 8 March 2013
Accepted 9 March 2013
Available online 18 March 2013

Keywords:
Ag/TiO_2
Solar photocatalysis
Waste activated sludge
Dewaterability
Settleability

ABSTRACT

In this study, photocatalysis was used to improve the dewaterability and settleability of waste activated sludge (WAS) by a solar photocatalytic reactor with transparent Ag/TiO_2 film as photocatalyst. Specific resistance of filtration (SRF) and sludge volume index (SVI) were used to evaluate WAS dewaterability and settleability, respectively, and the mechanism of photocatalysis was interpreted from the changes of pellets, loosely/tightly bound extracellular polymeric substances (LB-EPS/TB-EPS), proteins (PN) and polysaccharides (PS) in WAS. Results showed that the SRF and SVI values decreased by 86.0% and 80.0%, respectively after photocatalysis treatment for 18 h. The changes of LB-EPS/TB-EPS and morphology of WAS indicated that WAS was degraded in a stepwise and mild manner, in which the sludge pellets were possibly converted into TB-EPS and then LB-EPS. Simultaneously, LB-EPS were degraded into carbon dioxide and water by Ag/TiO_2 photocatalysis.

1. Introduction

Large quantities of wastewater is treated successfully by activated sludge technology. Meanwhile, a lot of waste activated sludge (WAS) is produced in this process. Reducing the volume and water content of the WAS is still a major concern (Yuan et al., 2011). The commonly used chemical treatment methods hardly decrease water content below 80%, and the volume of dewatered sludge obviously increases with the addition of inorganic conditioners (Chen et al., 2001). In order to dispose WAS economically and efficiently, dewatering and settling processes are essential to reduce the sludge volume, which is still a bottleneck for sludge treatment (Guan et al., 2012).

The dewatering and settling characteristics of WAS are different based on wastewater sources and treatment processes. Furthermore, detailed factors that influence sludge dewaterability and settleability are not yet well understood (Yu et al., 2008a,b). Extracellular polymeric substances (EPS) concentration of WAS, proteins and polysaccharides content of EPS are reported to play a predominant role in sludge dewaterability and settleability (Chen et al., 2001; Li and Yang, 2007). Moreover, the layered theory of EPS is proposed to explicate the mechanisms of EPS impact on WAS dewaterability and settleability. EPS can be divided into loosely bound extracellular polymeric substances (LB-EPS), tightly bound EPS (TB-EPS) and pellet (Li and Yang, 2007; Yu et al., 2008a,b).

Based on the theory above, many kinds of methods have been developed to improve the sludge dewaterability and settleability, including acid or alkaline treatment (Devlin et al., 2011; Thapa et al., 2009), metal ions (Fe^{3+}, Ca^{2+}) addition (Liu and Horn, 2012), electro-chemical treatment (Yuan et al., 2010), thermal treatment (More et al., 2012), sonication (Feng et al., 2009; Saha et al., 2011), microwave (Tang et al., 2010), explosive explosion shockwave (Chen and Yang, 2012), pressurised electro-osmotic (Citeau et al., 2012) and biological treatment (More et al. 2010).

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0960-8524/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biortech.2013.03.071

Although these technologies exhibit some enhancement effect on sludge dewaterability and settleability, some problems limit their application. On the other hand, photocatalytic technology may be proposed to improve sludge dewaterability and settleability by degrading EPS in WAS. Moreover, it is eco-friendly compared to acid or alkaline treatment, metal ions addition and electro-chemical treatment, and low-energy consumption compared to thermal treatment, sonication, microwave, explosive explosion shockwave, and pressurised electro-osmotic treatment. It is also a low-cost method compared to other treatment methods because it uses sunlight.

TiO_2 photocatalytic technology, an advanced oxidation process (AOP) utilizing free radicals as a primary oxidant, has been successfully applied in wastewater treatment (Gaya and Abdullah, 2008). Many organics can be degraded due to its non-selective oxidation capability. It is supposed that the pore water and interstitial water in WAS could be released with the degradation of WAS. In addition, the odour, turbidity and organics content in WAS can be decreased during the process. Two kinds of photoctalytic reactors (suspended-type and supported-type) can be used in the treatment of WAS. Although having higher photocatalytic activity, the suspended-type TiO_2 photocatalysis has higher cost of post-treatment (Mozia, 2010). Due to lower interaction efficiency with contaminants and higher recombination rate of the electron/hole, the supported-type TiO_2 photocatalysis has lower photocatalytic activity (van Grieken et al., 2009). Therefore, it is promising to synthesize some novel and effective immobilized photocatalysts. Ag exhibits an efficient plasmon resonance effect under sunlight and plays an important role of electron–hole separation produced by TiO_2 (Ma et al., 2012). Thus, several modified TiO_2 photocatalysts with Ag-doped have been developed (Ji et al., 2011). However, the effect of photocatalysis on WAS dewaterability and settleability has not been reported up to now.

The objective of this research is to synthesize a novel Ag/TiO_2 immobilized as photocatalyst which can be used under sunlight irradiation to improve WAS dewaterability and settleability. The changes of LB-EPS, TB-EPS, proteins (PN) and polysaccharides (PS) in WAS have been investigated during the photocatalytic process in addition to their effects on specific resistance of filtration (SRF) and sludge volume index (SVI) values. In addition, the variation of morphology was compared between the WAS samples before and after photocatalysis by scanning Electron Microscopy (SEM). The related mechanisms, especially the role of EPS in WAS dewaterability and settleability are also discussed.

2. Methods

2.1. WAS and catalyst

The WAS was collected from a domestic wastewater treatment plant in Shimodate, Ibaraki, Japan. The sludge sample was immediately transferred to the lab and stored in a plastic container at 4° for use. The initial characteristics of WAS were as follows (g/l except pH): pH 6.7, total solid (TS) 4.0, volatile suspended solid (VSS) 3.6, total and soluble chemical oxygen demand (TCOD and SCOD) 8.7 and 0.31, respectively. Catalysts used in this study were slurry of P-25 TiO_2 (Degussa AG, Germany) and Ag/TiO_2 coated on the inner wall of glass-tube, respectively. The catalyst of Ag/TiO_2 was synthesized using a modified impregnation–precipitation–photoreduction method (Ma et al., 2012). Briefly, the TiO_2-film coated glass tubes were impregnated by immersing into $AgNO_3$ (WAKO, Japan) solution (0.5 mol/l) for 20 min with UV light irradiation; then the glass tubes were calcined (300 °C, 1 h) in a vacuum oven (Hasuc, Shanghai, China); and finally, cooled to room temperature under UV-light. The phase composition and the degree of crystallinity in TiO_2 and Ag/TiO_2 were determined by X-ray diffraction (XRD). The XRD patterns of the as-prepared samples (2θ ranges from 10° to 90°) were recorded at room temperature with scanning speed of 10° min^{-1} using Cu Kα radiation (λ = 0.154 Å) from a 40 kV X-ray source (Bruker D8 Advance).

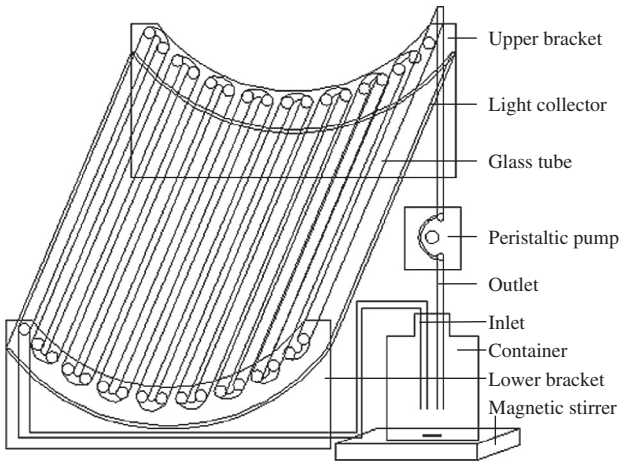

Fig. 1. Schematic of Ag/TiO_2-coated glass tubular photocatalytic reactor.

2.2. Experimental set-up

All the experiments were carried out in a solar photocatalytic reactor with support catalyst (shown in Fig. 1), which contained 10 glass tubes (18 cm in length, 1 cm in diameter) with TiO_2 or Ag/TiO_2 film coated on inside wall. The working volume of the reactor was 700 ml, and the WAS flowed in the reactor at 100 ml/min by a peristaltic pump (Cole-Parmer 6-600RPM, Chicago). In this study, sunlight was used as light source, and the mean UV-light intensity (290–390 nm) in sunlight was recorded from 9:00 to 15:00 [shown in Fig. 2(a)]. The control experiments were conducted by using the same reactor under the same light conditions but without catalyst on the inner wall of the glass tubes.

2.3. Experimental procedure

The WAS was treated in the solar photocatalytic reactor for 48 h (6 h photocatalysis for one day under the sunlight, then the reactor was covered with a black cloth avoiding sunshine) during September 2012. Sampling was done right after photocatalysis every day for subsequent analysis. Specific resistance of filtration (SRF) and sludge volume index (SVI) were checked to assess the dewaterability and settleability of the WAS before and after photocatalysis. LB-EPS, TB-EPS, PN and PS concentrations of the sludge samples were also measured to disclose the mechanisms related with the changes of sludge dewaterability and settleability.

2.4. EPS extraction

LB-EPS and TB-EPS were extracted from WAS by a modified heat extraction method (Li and Yang, 2007). The WAS was first centrifuged (MX-301, TMY) at 4000*g* for 5 min in a 15-ml centrifuge tube to dewater, then the sludge sediment in the centrifuge tube was re-suspended with NaCl solution (0.05%, 70 °C) to the original volume. Without any delay, the sludge suspension was sheared by a vortex mixer (VORTEX-GENIE G-560, scientific industries, INC.) for 2 min, followed by centrifugation at 4000*g* for 10 min. The organic matter in the supernatant was the LB-EPS of WAS. For the TB-EPS, the WAS was firstly centrifuged at 4000*g* for 5 min in a 15-ml centrifuge tube, then the liquid phase was discarded and the solid phase