Chemical Engineering Journal 317 (2017) 586–612

Contents lists available at ScienceDirect

Chemical Engineering Journal

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

Review

An application of ultrasound technology in synthesis of titania-based photocatalyst for degrading pollutant

Chee Yang Teh [a], Ta Yeong Wu [a,*], Joon Ching Juan [b]

[a] Chemical Engineering Discipline, School of Engineering, Monash University, Jalan Lagoon Selatan, 47500 Bandar Sunway, Selangor Darul Ehsan, Malaysia
[b] Nanotechnology & Catalysis Research Centre (NANOCAT), University of Malaya, 50603 Kuala Lumpur, Malaysia

HIGHLIGHTS

- Ultrasound was used as a mean to synthesize titania-based photocatalyst.
- Principal of ultrasound and its uniqueness in materials synthesis were highlighted.
- Operating conditions affected sonochemical synthesis of photocatalyst.
- Ultrasound synthesized titania-based photocatalysts were able to degrade pollutants.
- Advantages, challenges and perspectives using ultrasound in synthesis were examined.

ARTICLE INFO

Article history:
Received 7 January 2016
Received in revised form 28 December 2016
Accepted 1 January 2017
Available online 4 January 2017

Keywords:
Advanced oxidation process
Photocatalysis
Sonochemical
Titanium dioxide
Ultrasonication
Wastewater treatment

ABSTRACT

Since the development of heterogeneous photocatalysis in 1970s, titania-based photocatalyst has been one of the most actively studied materials for wastewater remediation applications. Its attractiveness lies not only on its interesting photocatalytic activities, but also its chemical stability, low cost, biocompatibility and non-toxic nature. With myriad of studies on the preparation of titania-based photocatalysts in the past years, growing interest on the principles of green chemistry and sustainable has stimulated the exploration of new methods for clean and efficient synthesis. Currently, the use of ultrasound as an efficient and innocuous mean for material synthesis has been subjected to intense research. The unusual phenomena of acoustic cavitation caused by ultrasonic waves have opened up a new world of possibilities for producing highly-efficient photocatalysts with novel structures. This critical review is intended to discuss the recent advancements, challenges and future prospects on the use of ultrasound in the development and modification of titania-based photocatalyst targeting on pollutant degradation purposes.

Contents

* Corresponding author.
E-mail addresses: wu.ta.yeong@monash.edu, tayeong@hotmail.com (T.Y. Wu).

http://dx.doi.org/10.1016/j.cej.2017.01.001
1385-8947/

1. Introduction

The late 20th and early 21th centuries have seen an unprecedented and remarkable growth in industries around the world. Technological change in industries has driven the enormous increase in the production of goods and services, in order to sustain the ever-increasing world population and the vast improvements in the standard of living. However, promising development in industrialization often accompanied by an increase in quantity and complexity of wastes. With inadequate environmental management in most developing countries, the produced toxic wastes are often relentlessly released into the air, water and soil, giving rise to serious impact on both the environment and human health. This problem becomes more acute as technological progress in different fields have led to the presence of new compounds in effluent streams of processing plants which are not readily degraded by the conventional effluent treatment methods [1]. Of late, it has been shown that nanotechnology exhibits remarkable features for advanced, robust, and multifunctional treatment processes that can enhance pollution monitoring and treatment efficiency. According to Ibrahim et al. [2], nanotechnology has the potential to improve the environmental remediation system by preventing the formation of secondary by-products, decomposing some of toxic pollutants by zero waste operations, and prohibiting contamination by converting the pollutants from labile to non-labile phases. For examples, nanomaterials are widely explored as highly efficient adsorbents [3], photocatalyst [4] and disinfectant [5] for treating water and wastewater. Nanomaterial is arguably the most promising candidate for the development of next generation water and wastewater technology [6].

Currently, increasing social and political concerns on the environment have led to extensive research on advanced oxidation processes (AOPs) as a better alternative in the field of water and wastewater treatment. AOPs are especially important to degrade soluble organic contaminants from the waters and soils at ambient condition [7]. Among the AOPs, enormous effort has been devoted to the studies on titania-based photocatalysis. This technique utilizes TiO_2 semiconductor for the in situ generation of reactive species such as hydroxyl radicals (•OH) and superoxide anion ($O_2^{\bullet-}$) upon absorption of radiation when it is in contact with water and oxygen [8]. These reactive species will non-selectively degrade recalcitrant, toxic and non-biodegradable compounds to various by-products and eventually to harmless carbon dioxide and water [9,10]. For more efficient treatment of wastewater using AOP, two or more AOPs, namely hybrid advanced oxidation processes (HAOPs) have recently attracted the significant attention of researchers. Until now, the mechanistic synergy underlying HAOPs has mostly remained unexplored [11]. However, the latest investigations found that HAOPs degraded recalcitrant pollutants such as Acid Red B [12]. It is expected that certain physicochemical pretreatment process such as coagulation-flocculation could integrate with HAOPs to enhance the efficiency of wastewater treatment [13]. In addition, Chakma and Moholkar [14] found that an addition of salt to the reaction mixture during HAOPs (sonophotolyis) treatment caused effective partitioning of the pollutant molecules in the interfacial region of the transient cavitation bubble, leading to further improvement in degradation and mineralization of pollutants. According to Chakma and Moholkar [15], the nature of synergy in an HAOPs was independent of the chemical nature of pollutant, namely similar type of synergy was observed for either Acid Red B or Bisphenol-A.

As novel photocatalytic materials with activities surpassing titania-based photocatalysts are being extensively sought-after, alternatives which have the advantage in terms of versatility, economical, stability, abundance and non-toxic nature possessed by TiO_2 are rare. Hence, developing and improving TiO_2 using various approach seemed to be the most viable and practical way to obtain photocatalysts suitable for real-life applications [16]. Generally, TiO_2 applications are divided into "energy" and "environmental" categories, many of which depend not only on the properties of TiO_2 materials itself, but also its interaction with the environment [17]. Continuous progress on TiO_2 material research has resulted in a rich database on its synthesis, properties, modification and applications. A variety of methods to synthesize titania-based photocatalyst such as sol-gel, micelle and inverse micelle methods, direct oxidation, precipitation, thermal methods (ethanol thermal, hydrothermal, solvothermal), chemical solvent and chemical vapor deposition, physical vapor deposition, electrodeposition and microwave method have been reported [17,18]. Selecting the appropriate synthetic route is of utmost importance as it ultimately determines the physical properties and application of the produced materials. In fact, this has been the main motivation for scientists and engineers to develop new versatile and generalized synthetic methods which are readily adaptable for the preparation of different nanostructured materials [19]. Recently, there has been an upsurge of interest in the use of ultrasound as an efficient and innocuous tool for synthesis of materials with novel properties. High intensity ultrasound has found many important applications in organic synthesis, materials and organometallic chemistry and industrial manufacturing processes [20].

In this review, the development and modifications of titania-based photocatalysts using ultrasound synthetic methods based on sonochemistry and its attractive use in pollutant degradation were discussed. An overview was given to shed some light on the nature and origin of ultrasound and its unique underlying phenomena for materials synthesis. Next, a critical review on the recent advancement of titania-based photocatalyst synthesized via ultrasound method was provided, focusing on its potential use in degradation of pollutant. Important synthesis parameters were further highlighted in this work. Finally, the advantages, challenges and future perspectives on the use of ultrasound in synthesis were examined in the final part of the review.

2. Basic principles of sonochemistry

Sonochemistry is a field of research dealing with the effects and application of ultrasonic waves [21]. Ultrasound is a longitudinal wave with a frequency above 20 kHz (20,000 cycles/s), greater than the upper limit of human hearing. When ultrasound wave is introduced into liquid, positive and negative pressure are exerted onto the liquid by alternating compression and expansion cycles of acoustic wave, respectively [22,23]. Cavitation bubbles (i.e., voids or cavity) will form from pre-existing impurities and oscillate with the applied sound field. These bubbles accumulate ultrasonic