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Photocatalytic TiO_2 films and membranes for the development of efficient wastewater treatment and reuse systems

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Abstract

In order to develop efficient photocatalytic TiO_2 films and membranes for application in water and wastewater treatment and reuse systems, there is a great need to tailor-design the structural properties of TiO_2 material and enhance its photocatalytic activity. Through a simple sol–gel route, employing self-assembled surfactant molecules as pore directing agents along with acetic acid-based sol–gel route, we have fabricated nanostructured crystalline TiO_2 thin films and TiO_2/Al_2O_3 composite membranes with simultaneous photocatalytic, disinfection, separation, and anti-biofouling properties. The highly porous TiO_2 material exhibited high specific surface area and porosity, narrow pore size distribution, homogeneity without cracks and pinholes, active anatase crystal phase, and small crystallite size. These TiO_2 materials were highly efficient in the decomposition of methylene blue dye and creatinine, destruction of biological toxins (microcystin-LR), and inactivation of pathogenic microorganisms (*Escherichia coli*). Moreover, the photocatalytic TiO_2 membranes exhibited not only high water permeability and sharp polyethylene glycol retention but also less adsorption fouling tendency. Here, we report results on the synthesis, characterization, and environmental application and implication of photocatalytic TiO_2 films and membranes.

Keywords: TiO_2; Photocatalysis; Membrane; Thin film; Advanced oxidation technologies; Sol–gel; Anti-biofouling; Biological toxins; Microbial inactivation; Water and wastewater treatment

1. Introduction

One of the main goals in the biological and physical research enterprise of the National Aeronautics and Space Administration includes improvement of the conditions of space habitation for extended on-orbit missions [1]. Providing enough safe drinking water has been a challenge in space exploration. Water transported or produced

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aboard the space shuttle can be adequate in short missions. However, in long-duration missions, there is a necessity to recycle water in order to assure conditions of self-sufficiency and sustainability. The inability of conventional treatment processes to decompose organic chemicals and inactivate pathogenic microorganisms in water resources has propelled the development of modern water treatment processes. Advanced oxidation technologies (AOTs) and membrane separation technologies (MSTs) have received great attention for environmental remediation. Along with the ability of MSTs to reject most contaminants in water, TiO_2/UV photocatalysis is among the most promising AOTs due to the effectiveness of TiO_2 to generate hydroxyl radicals along with its environmentally benign properties and relatively low cost [2,3]. In fact, TiO_2 photocatalysis has been found extremely effective for the complete mineralization of virtually all organic compounds and for the inactivation of pathogenic microorganisms present in contaminated water [4]. The destruction process of TiO_2 photocatalysis is also characterized by high reaction rates and short treatment times due to the reactivity and non-selectivity of hydroxyl radicals.

Titania is usually used in suspension for high catalytic activity. However, highly dispersed TiO_2 particles in suspension are difficult to remove after their application. Recently, many research studies have been carried out to immobilize TiO_2 catalyst onto various substrates as thin films and membranes despite their lower catalytic surface area than TiO_2 powder in suspension [5]. Moreover, if the TiO_2 material is immobilized onto porous support membranes, the photocatalytic membrane (i.e., MSTs–AOTs) reactors may gain tremendous popularity because of their multiple functions such as (i) decomposition of recalcitrant organic pollutants, (ii) destruction of biological toxins, (iii) inactivation and killing of pathogenic microorganisms, (iv) physical separation of contaminants and intermediate products, and (v) self-antibiofouling action.

Along with the crystallographic properties of TiO_2 such as crystalline phase and crystallite size, the structural properties of porous TiO_2 such as its surface area, porosity, film homogeneity, and pore size distribution are of importance for its photocatalytic properties. In the case of TiO_2 membranes, the structural properties can determine their permeability and selectivity at large extent. In order to develop highly efficient photocatalytic TiO_2 films and membranes, we have recently investigated a novel chemistry method employing surfactant molecules as a pore directing agent along with acetic acid-based sol–gel route [6,7]. Controlling materials at the nano-level makes it possible to develop new types of products with tailor-designed properties for environmental applications [8]. In this study, we have fabricated nanostructured TiO_2 films and membranes with enhanced photocatalytic activity to destroy organic pollutants in water such as methylene blue dye, creatinine, and a biological toxin (microcystin-LR MC-LR), as well as to inactivate pathogenic microorganisms such as *Escherichia coli* (*E. coli*). The TiO_2 membranes were further tested for their water permeability, organic retention, and anti-biofouling properties.

2. Materials and methods

2.1. Preparation of photocatalytic TiO_2 films and TiO_2/Al_2O_3 composite membranes

A suitable amount of surfactant (Tween 80, polyoxyethylenesorbitan monooleate) was homogeneously dissolved in isopropanol (iPrOH). Before adding alkoxide precursor, acetic acid was added into the solution for the esterification reaction with iPrOH to form water molecules. Then, titanium tetraisopropoxide (TTIP) was added and hydrolyzed. The molar ratio of the ingredients was optimized at Tween 80:iPrOH:acetic acid: TTIP = 1:45:6:1. The final sol was transparent and stable. A home-made dip-coating device was used to dip-coat borosilicate glass substrate in the sol at a withdrawal rate of 12.8 cm/min.