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Effects of bromide on inactivation efficacy and disinfection byproduct formation in photocatalytic inactivation

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ABSTRACT

The high effectiveness of TiO_2-UVA system in bacterial disinfection has gained attention to use this technology in water treatment on different source waters, including desalinated sea water and grey water. However, source waters containing a significant level of bromide could have different chemical pathways during TiO_2-UVA disinfection process because reactive bromine species could be formed. To illustrate the water safety from the Br-TiO_2-UVA system, this study investigated bacterial inactivation efficiency and disinfection byproduct (DBP) formation under different pH, TiO_2 dosages and bromide concentrations in a laboratory setting. At a high bromide concentration (65 mg/L, equivalent to the concentration of natural sea water), the bacterial inactivation rate increased 2 times at pH 5 and more than 5 times at pH 8. However, a significant increase of brominated DBPs, which were considered more carcinogenic and toxic than chlorinated DBPs, was observed. The bacterial inactivation pattern was shifted from the "shoulder-log" to the "log-tail" under different bromide concentrations, suggesting the existence of bromide altered the bacterial inactivation mechanisms. We also observed that the inactivation kinetics of Br-TiO_2-UVA system was greatly influenced by water pH. Our laboratory experiments demonstrated that bromide could improve the performance of photocatalytic inactivation, but it also could reduce the water safety by generating a higher level of brominated-DBPs in treated water. Water engineers should pay attention to the brominated DBP formation when applying TiO_2-UVA photocatalysis on source waters with a significant level of bromide.

1. Introduction

The need of clean drinking water is increasing in the 21st century. There are 1.2 billion people lack access to safe and clean drinking water and 2.6 billion have drinking water with little or no sanitation [1]. Thousands of children are died annually from diseases transmitted through unsafe water or human excreta [1,2]. Therefore improving the technology for drinking water sanitation is one of the least expensive and most effective means to improve public health and save lives [2]. On the other hands, though disinfection process can inactivate pathogenic microbes in the water, various disinfection byproducts (DBP) are usually produced in the processes. Different bacterial cellular components, such as nucleic acid, amino acid and extracellular polymeric substances, are proved to be DBP precursors [3–6]. These DBPs are toxic and carcinogenic which increase the risk of health in drinking water [7–9]. In order to balance the risk of pathogen bacterial and DBPs, achieving high disinfection efficiency with low DBPs formation become a major target in the improvement of water disinfection technology.

Photocatalytic inactivation has been extensively studied for water disinfection. Photocatalytic inactivation not only effectively inactivates different microorganisms [10–12], but also produces less DBPs when compared with chlorination [13]. Therefore, it is believed to be a good alternative disinfection process. Recently, there are studies showing that presence of bromide in the water can effectively enhance the disinfection efficiency of photocatalytic inactivation, due to the formation of the powerful reactive bromine species [14]. On the other hands, bromide is an inorganic DBP precursor and its existence in water usually increases the quantity of DBP formation in disinfection process.

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In the study of DBP formation of chlorination, a higher DBP formation is usually observed in the presence of bromide due to the higher reactivity of HOBr and OBr^- [15]. Moreover, the presence of bromide increase the formation of brominated DBP (Br-DBP) [15,16], which are more toxic and carcinogenic in nature compared to traditional carboneous-DBP (C-DBP) [15,17]. Bromide is commonly present in many aqueous systems, in the range from several mg/L in surface water [18–21] to over 60 mg/L in sea water [15]. Formation of DBP from disinfection of desalinated water also received increasing concern. As the concentrations of bromide and iodide in desalinated water are high, the formation of more toxic Br-DBP and I-DBP poses a risk on environment and human health [22]. Thus, understanding the effects of bromide on the inactivation efficiency and DBP formation of photocatalytic inactivation is important for evaluating the performance and safety of photocatalytic disinfection for seawater or wastewater with high bromide concentration.

However, there is no study to investigate the effect of bromide on the inactivation efficiency and the formation of DBPs of photocatalytic inactivation simultaneously. This study aims to investigage the balance of the bacterial inactivation efficiency and DBP formation of Br-TiO_2-UVA photocatalytic inactivation. The bacterial inactivation efficiency, as well as the DBP formation of TiO_2-UVA system under different pH, TiO_2 dosage and bromide concentration, were investigated.

2. Materials and methods

2.1. Bacterial inactivation

Escherichia coli K12 (ATCC, USA) were cultured in nutrient broth (BioLife, Italy) at 37 °C in incubator for 16 h to reach the stationary stage (10^9 colony forming unit (cfu)/mL). The cultures were then aseptically centrifuged and washed three times with phosphate buffer solution (PBS, pH 7.4). Finally, the cell concentrations were adjusted to 1.5×10^7 cfu/mL in each reaction. To prevent contamination, all Milli-Q water (Millipore, USA), PBS solution, and pipette tips were autoclaved (121 °C for 20 min) before use.

The photocatalytic inactivation procedures followed the method reported by Zhang et al. [23]. Briefly, TiO_2/UVA photocatalytic inactivation was conducted in air-tight glass flasks with 100 mL mixture of PBS and bacterial cells. UVA lamp (Cole-Parmer, USA) with intensity of 0.22 mW/cm^2 was used as the lighting source. Samples were collected at different time intervals (0, 5, 20, 40, 60 and 80 min). The inactivation efficiency was evaluated by monitoring the bacteria survival using viable plate count method [23] while the DBP formation was evaluated using U.S. EPA Method 551.1 mentioned in the next section. The effect of pH (5 and 8), TiO_2 dosage (100 and 250 mg/L TiO_2, P-25, Degussa Corporation, Germany) and bromide concentration (0, 20 and 65 mg/L) on the disinfection efficiency and DBP formation was investigated.

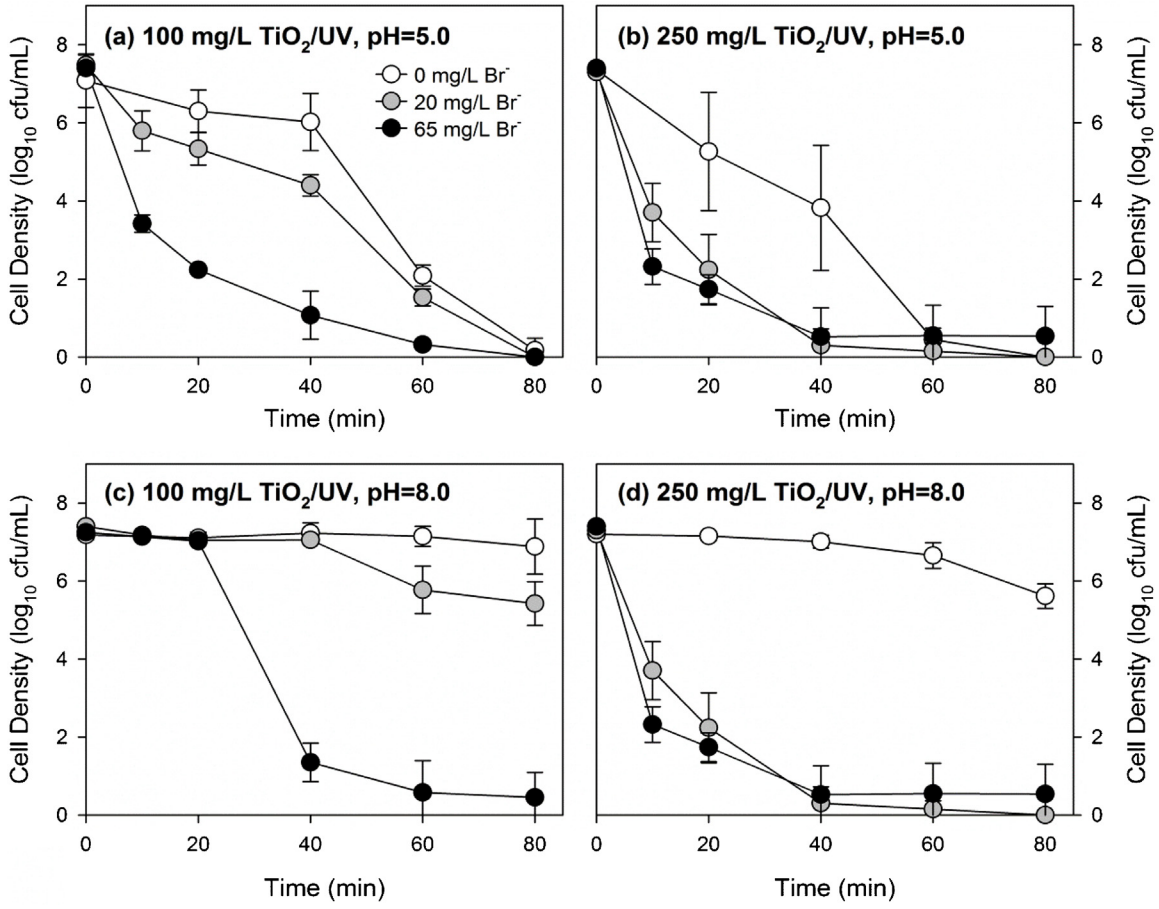

Fig. 1. Inactivation of *E. coli* K-12 in TiO_2/UVA system under different pH, bromide concentrations and TiO_2 dosages.