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Long-term and stable antimicrobial properties of immobilized Ni/TiO_2 nanocomposites against *Escherichia coli, Legionella thermalis*, and MS2 bacteriophage

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ABSTRACT

Nickel has been extensively used as a high work function metal because of its abundance, low cost, relatively non-toxic nature, and environmentally benign characteristics. However, it has rarely been extended in a form of immobilized composite, which is a practical strategy applicable for photocatalytic antimicrobial activities. In this study, a composite of nickel and TiO_2 (Ni/TiO_2) was prepared using a photodeposition method, and its antibacterial properties were investigated using *Escherichia coli* (*E. coli*). To optimize Ni/TiO_2 synthesis, the effect of various photodeposition conditions on antibacterial performance were investigated, such as the light irradiation time, metal content, TiO_2 crystalline structure, and presence or absence of electron donors (i.e., methanol). The optimized 2 wt% Ni/TiO_2 exhibited an antibacterial efficiency of 3.74 log within 7 min, which is more than 10-fold higher than that of pristine TiO_2 (2.54 log). Based on this optimized weight ratio, Ni/TiO_2 was immobilized on a steel mesh using an electrospray/thermal compression method, and its antibacterial performance was further assessed against *E. coli*, MS2 bacteriophage virus (MS2 phage), and a common pulmonary pathogen (*Legionella thermalis, L. thermalis*). Within 70 min, all target microorganisms achieved an inactivation that exceeded 4 log. Furthermore, the long-term stability and sustainable usability of the Ni/TiO_2 mesh were confirmed by performing more than 50 antibacterial evaluation cycles using *E. coli*. The results of this study facilitate the successful utilization of immobilized Ni/TiO_2 mesh in water disinfection applications.

1. Introduction

Nanomaterials have garnered increasing attention as effective disinfectants because of their strong antimicrobial properties and environmentally benign characteristics as they are not expected to form harmful disinfection by-products (Marambio-Jones and Hoek, 2010). Recently, several studies have actively reported the use of numerous nanomaterials in the photocatalytic field, including titanium oxide (TiO_2), tungsten oxide, zinc oxide, and cadmium sulfide (Chen and Ye, 2008; Pikula et al., 2020).

TiO_2 is a widely used material that is inexpensive, nontoxic, and stable, while exhibiting photocatalytic properties (Wang et al., 2020). When TiO_2 irradiated with ultraviolet rays; this leads to the excitation of electrons in the valence band to the conduction band, thereby separating the electrons and holes (Seif et al., 2019). However, Ni et al. reported that the rapid recombination rate of electron-hole pairs in TiO_2 greatly prevents the production of ROS (reactive oxygen species) (Ni et al., 2007). Therefore, to promote ROS production, co-catalytic nanoparticles are introduced to trap photo-excited electrons (Yang et al., 2019). Replacing noble metals with abundant and less expensive metals remains as an attractive strategy. Among non-noble metals, nickel is a cost-effective material with high electrochemical stability and low toxicity, which has been extensively applied in various industries such as in the manufacturing of catalysts and batteries (He et al., 2015). Thus,

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