Journal of Fiber Bioengineering and Informatics 14:1 (2021) 53–66

Cite as: A. Mahmood et al.
doi:10.3993/jfbim00364

TiO_2 Based Photo-Catalysis for Virus Disinfection ⋆

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Abstract

This review considers the current literature that is focused on the interface nanostructure/cell-wall microorganism to understand the annihilation mechanism. In this report, photocatalysis is discussed for viral disinfection including TiO_2 photocatalysis and other metal-containing photocatalysis. TiO_2 based materials and its composites, metal-TiO_2 systems, TiO_2 heterojunction systems with other semiconductors, and TiO_2 systems with graphene and other carbonaceous materials are discussed in detail. Some practical uses of titanium dioxide for photocatalytic disinfection processes for the effective prevention/eradication of microorganisms, considering the resistance that the microorganism could develop without the appropriate regulatory aspects for human and ecosystem safety are also discussed.

Keywords: Nanostructure; Microorganism; Photocatalysis; TiO_2; Heterojunction; Composites

1 Introduction

Many illnesses including fever, heart problems, hepatitis, paralysis, respiratory infections are caused by viruses. Viruses have a less infectious quantity of < 10–10^3 particles in comparison with bacterial pathogens and a significant high illness risk of 10-10 000 times under a similar level of exposure [1]. Unfortunately, viruses are difficult to be physically removed due to their small sizes and unique surface properties [2]. Following section describes some disinfection techniques.

Free chlorine is the most commonly used for water treatment and has good viral inactivation properties. The main drawback of chlorination is the formation of mutagenic and carcinogenic disinfection byproducts (DBPs). These DBPs contribute to the recontamination and salting of fresh water sources [3]. Another commonly used disinfection method is the ozonation. It is also unstable in water and undertakes reactions with some water matrix components. The main advantage of ozone is that it decomposes into hydroxyl radicals (·OH), which are strong

⋆Project supported by the Ministry of Education, Youth and Sports of the Czech Republic and the European Union - European Structural and Investment Funds in the Frames of Operational Programme Research, Development and Education - project Hybrid Materials for Hierarchical Structures (HyHi, Reg. No. CZ.02.1.01/0.0/0.0/16_019/0000843).

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oxidants in water [4], that make the ozonation more effective than Cl_2 against bacterial cells and viruses [5]. Like chlorination, ozonation can also produce DBPs in the presence of organic matter e.g. aldehydes, carboxylic acids and ketones [6]. In recent years, germicidal UV has gained more attraction for water disinfection, as low-pressure UV creates practically no disinfection byproducts [7]. UV according to irradiation wavelengths are divided into UVA (315-400 nm), UVB (280-315 nm), UVC (200-280 nm) and vacuum UV (VUV) (100-200 nm). For microorganism inactivation, UVC is the most effective one. UVC light destroys irradiated DNA, directly inducing pyrimidine and purine dimers and pyrimidine adducts. UVC intensity of 7 mJ/cm^2 inactivates bacteria cells by 99% for water disinfection. The susceptibility of protozoa to UVC damage is similar to that of bacteria; thus, 99% inactivation for Cryptosporidium can be achieved at 5 mJ/cm^2 [8].

2 Photocatalysis for Viral Disinfection

According to general description of thermal catalysis, photocatalysis is a process in which speeding up of a photoreaction takes place by the presence of a catalyst, which shows that both light and a catalyst are needed to cause or to accelerate a chemical transformation [8]. As the photoreaction takes place in more than one homogeneous medium, it is usually called "heterogeneous photocatalysis".

Semiconductor photocatalysis has been used for inactivation of organic pollutants and has gained attraction by the researchers [9]. Among the first developers of photocatalytic viral disinfection were Sjogren and Sierka, who carried out TiO_2 based photocatalysis to inactivate Escherichia virus MS2 [10]. Subsequently many researchers has carried out disinfection of water by TiO_2 and TiO_2 based photocatalysis [8]. In order to achieve more antiviral effects, metal based photocatalysts are also being used. Metal-free photocatalysts are also gaining interest from researchers as these are found ample in nature and are low cost, sustainable and safe.

Cho et al. [10] discovered different inactivation kinetics of bacteria and viruses and observed that the virus MS2 was stronger than the bacterium E. coli due to the difference in the surface structures of both. It was learned that intensive oxidation was required to denature the virus structure. Fujishima and Honda [11] carried out the photocatalytic splitting of water on TiO_2 electrodes and this led to the beginning of heterogeneous photocatalysis [8] subsequently leading to the marvelous research activities to understand the fundamental process of heterogeneous photocatalysis [12]. Many researchers have observed the effectiveness of TiO_2 photocatalysis for water disinfection [13].

Rapid recombination of charge carriers is the main disadvantage of TiO_2 which lowers its photocatalytic behavior. To overcome this, many techniques such as the morphological control and the formation of heterojunction systems with other components like metals, semiconductors and carbonaceous materials have been adopted [9]. Several studies indicated the alteration means such as single doping, co-doping and impregnation with different metal and non-metal ions to increase TiO_2 photocatalytic performance and photoactivity in the visible light region [14, 15].

3 Fundamental Mechanism for TiO_2 Photocatalysis

Titanium dioxide (TiO_2) in heterogeneous photocatalysis has been gaining interest from researchers in recent years [16]. Nanocrystalline TiO_2 is found in three major polymeric forms