

Article

A Floatable and Highly Water-Durable TiO₂-Coated Net for Photocatalytic Antibacterial Water Treatment in Developing Countries

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Abstract: A TiO₂-coated net with photocatalytic antibacterial properties that purifies water for practical use in developing countries was fabricated. The TiO₂ particles were modified with a silane coupling agent, aminopropyltriethoxysilane or hexadecyltrimethoxysilane, to improve particle dispersibility. The net comprises three layers: a TiO₂-silicone photocatalyst layer, a silicone layer to protect the net substrate from the oxidizing power of TiO₂, and a polypropylene net substrate. The net is flexible and light enough to float on the surface of water. By modifying the surface of the TiO₂ particles, we succeeded in preparing a highly water-durable photocatalyst coating that can be maintained for 49 days of outdoor exposure. The inactivation of *E. coli* by the TiO₂-coated net under 1.0 mW/cm² of UV irradiation was confirmed. Furthermore, the antibacterial properties were investigated under natural sunlight. The number of *E. coli* decreased from 320,000 to 10 CFU/mL under natural sunlight in just 2 h. The results showed that the photocatalyst-coated polypropylene net effectively eliminates *E. coli* from water, reducing the risk of infectious diseases.

Keywords: photocatalyst; natural sunlight; water purification; polypropylene; bacteria; silane coupling



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1. Introduction

Drinking water in developing countries is often polluted with bacteria such as *E. coli* [1]. Presently, 892 million people worldwide do not have access to safe water, and a solution to this problem is urgently required [2]. Polluted drinking water leads to a high risk of water-borne diseases such as diarrhea, cholera, typhoid fever, hepatitis A, amoebic and bacillary dysentery, and other diarrheal diseases [3]. Accordingly, various water purification systems and technologies have been proposed. However, securing a safe supply of drinking water generally requires great cost and labor.

Chlorination is the most common chemical water treatment method [4]. However, this involves the risk caused by the formation of chlorinated byproducts, such as trihalomethanes and other organohalides, resulting from the reaction of chlorine with organic matter [5]. Furthermore, when used in irrigation, chlorine is often phytotoxic [6]. Membrane technologies are considered very practical means of water purification owing to their excellent and stable performance [7]. However, the initial and running costs for such membrane systems are high, making them impractical for developing countries. Conversely, sunlight, which is free and abundant, has been used as an agent for water disinfection in rural areas of developing countries, which are among the sunniest in the world. The principle behind the solar disinfection (SODIS) method depends on irradiation by the UV

region of sunlight to increase the temperature of water and the production of reactive oxygen species therein by UV-A photosensitization of dissolved oxygen [8,9]. However, long irradiation times are required, and low irradiation intensity allows the regrowth of bacteria after solar treatment because of photorepair mechanisms [10]. Accordingly, this study focuses on the photocatalytic disinfection of drinking water.

Photocatalytic technology is based on the interaction of light with suspended semiconductor nanoparticles, typically TiO_2 , to produce highly oxidative species ($\bullet\text{OH}$ radicals and H_2O_2) from the adsorbed water molecules. $\bullet\text{OH}$ radicals are highly active for both the oxidation of organic substances and the inactivation of bacteria and viruses. Accordingly, the photocatalytic inactivation of bacteria such as *Escherichia coli*, *Salmonella typhimurium*, *Serratia marcescens*, and spores of *Clostridium perfringens* as well as the lactobacillus phage PL-1 virus has been reported [11]. Furthermore, a photocatalyst can degrade the toxins in water that bacteria produce [12].

Powder photocatalysts are commonly used for the photocatalytic sterilization of water. Such powders can disinfect water effectively because the photocatalyst is well dispersed in the system, thus having both effective contact with bacteria and exposure to the photoirradiation energy. However, the water and photocatalyst need to be separated after the reaction, necessitating separation technology that is expensive to set up and run and therefore not affordable in developing countries. Therefore, some form of photocatalyst immobilization is required to simplify the process and decrease its cost.

Flat-panel- and tube-type reactors have been used for sterilization in past research [13,14]. A flat panel-type reactor such as photocatalyst-coated glass is easy to use, but the reaction area depends on the reactor's surface area, so a large substrate is required. In tube-type reactors, the photocatalyst is packed in a glass tube. The number of photocatalyst-packed tubes can be easily increased or decreased depending on the concentration of contaminants and the volume of water, allowing effective sterilization [15]. However, a lot of equipment is required, incurring additional shipping costs.

In our research, we have developed a net-type photocatalytic reactor that floats on the surface of the water and removes bacteria. The net-type substrate has a larger photocatalytic surface area than panel-type reactors because both sides of the surface can be used. Furthermore, we aimed to achieve weight and cost reduction by using a cheap plastic substrate, i.e., polypropylene.

Coating polypropylene with TiO_2 constitutes a major cost reduction because both materials are inexpensive. However, there are several challenges to be overcome when coating polypropylene with TiO_2 . First, the melting point of polypropylene is low (under $200\text{ }^\circ\text{C}$) [16], so the drying temperature employed after coating must be low. Therefore, it is impossible to anneal TiO_2 at high temperatures ($<450\text{ }^\circ\text{C}$), which is typically used to achieve crystal growth and the removal of organic groups to create a strong and durable layer [17]. Secondly, the substrate material can be decomposed by the oxidizing power of TiO_2 itself [18]. Thirdly, the deposition of TiO_2 nanoparticles onto fabrics is highly challenging because of the lack of chemical bonding between fabrics and TiO_2 nanoparticles [19]. Finally, the underwater durability of such systems with long-term use has not been investigated.

To address these problems, we explored the use of a binder blending method and surface modification of the TiO_2 particles. Binder blending was explored using a mixture of TiO_2 sources (TiO_2 sols or nanoparticles) and polysiloxane, which can be dried and form layers at low temperatures, as the binder [20]. The net comprises three layers, namely, a TiO_2 -silicone layer as the photocatalytic coating, a silicone resin layer to protect the substrate from the oxidizing power of TiO_2 , and the plastic substrate. Several methods of surface hydroxylation, such as oxygen plasma [21], alkali hydroxides [22], and UV irradiation [23], have been established to improve adhesion between such layers. Furthermore, durability improvement by modifying the TiO_2 surface with a silane coupling agent has been reported [19]. Chen and Yakovlev [24] confirmed the surface modification of TiO_2 nanoparticles with organosilanes by Si–O–Ti bond formation. The active functional groups

grafted onto the particles increase the possibility of chemical bond formation between the modified particles and the binder, thereby improving adhesion strength. Accordingly, we fabricated the TiO₂ layer by mixing silane-modified TiO₂ particles in silicone resin (methyl phenyl polysiloxane). The net was dip-coated first with silicone then with the TiO₂-silicone layer. O₂ plasma treatment was adopted to improve the wettability of the silicone layer.

Overall, we aimed to create a TiO₂-coated net that has high water durability and bactericidal activity. The net is designed for practical and economically efficient water treatment in developing countries.

2. Materials and Methods

2.1. Materials

Ethanol, formic acid, toluene, isopropanol, methylene blue, NaH₂PO₄, Na₂HPO₄·12H₂O, and NaCl were purchased from FUJIFILM Wako Pure Chemical Corp. (Osaka, Japan). 3-Aminopropyltriethoxysilane (APTES) and silicone resin KR-255 (methyl phenyl polysiloxane) were obtained from Shin-Etsu Chemical Co., Ltd. (Tokyo, Japan). Hexadecyltrimethoxysilane (HDTMS) was acquired from Sigma-Aldrich Japan KK (Tokyo, Japan). TiO₂ Degussa P25 was purchased from Evonik (Eseen, Germany). Polypropylene net (PP-#16) and polypropylene plates were obtained from AS-ONE (Tokyo, Japan). *E. coli* DH5 α was provided by the Higami Lab at the Tokyo University of Science, Faculty of Pharmaceutical Sciences. Nutrient broth and nutrient agar were acquired from Nissui Pharmaceutical Co., Ltd. (Tokyo, Japan).

2.2. Surface Modification of TiO₂

First, 5.0 g of the silane coupling agent (APTES or HDTMS) was hydrolyzed in a mixture of 2.0 g of deionized water (generated by Direct-Q UV3 (Merck Millipore, Darmstadt, Germany)), 300 mL of EtOH, and 0.3 g of formic acid. After stirring for 30 min, 5.0 g of TiO₂ particles (P25) was added. P25 is a TiO₂ that has a crystalline composition of 78% anatase and 14% rutile, calculated from XRD calibrations with varying mixtures of rutile and anatase, and Ohtani et al. assumed that the remaining 8% was an amorphous phase [25]. The mixture was kept under reflux at 80 °C for 5 h. After that, dispersed particles were separated from the solvent by centrifuge (10 min at 12,000 rpm) followed by washing with ethanol for three cycles to remove excessive silanes. Once the process was finished, the modified particles were dried in an oven at 60 °C for 24 h, and Fourier-transform infrared (FTIR) spectra were recorded using an FT/IR-6600 spectrophotometer (JASCO, Tokyo, Japan). Hereafter, we denote HDTMS-modified TiO₂ and APTES-modified TiO₂ as HDTMS-TiO₂ and APTES-TiO₂, respectively.

2.3. Photocatalyst Coating

The TiO₂-silicone resin composite layer was deposited on the polypropylene by dip-coating. First, the silicone resin (methyl phenyl polysiloxane) protective layer was deposited by dip-coating. The silicone resin solution was diluted to 5 wt% with toluene to control the solid content, and the resulting mixture was stirred magnetically for 30 min. The polypropylene net was cleaned by 15 min of ultrasonication in isopropanol, and UV-O₃ surface treatment was conducted for 15 min using a UV-Ozone Cleaner UV253E (Filgen, Tokyo, Japan). Once the surface was cleaned, the silicone resin was deposited using a micro dip-coater (MD-0408; SDI, Tokyo, Japan) at a withdrawing speed of 15 mm/s. After the coating processes, the net was placed in a muffle furnace (KDF-S70; Denken-Highdental, Kyoto, Japan) and dried for 20 min at 100 °C.

Then, the silicone-coated net was treated with O₂ plasma (RF power: 100 W, 3 min) using a parallel plate reactive ion etching system (RIE-10NR; Samco, Tokyo, Japan) to improve surface wettability. Plasma was generated under a pressure of 20 Pa and an O₂ gas flow of 10 sccm.

Finally, TiO₂ particles, APTES-TiO₂ particles, and HDTMS-TiO₂ particles were dispersed in the silicone resin solution prepared above at a loading of 5 wt% and dip-coated onto the protective layer to form a photocatalyst layer (withdrawing speed, 15 mm/s). After the coating processes, the net was placed in an oven and dried for 20 min at 100 °C. A cross-sectional schematic image of the prepared net is shown in Figure S1. As a reference, a photocatalyst-coated polypropylene plate was also prepared in the same way.

2.4. Durability Test

The durability of the photocatalyst layer was examined both in the lab and under actual sunlight. In the lab test, its durability under water flow and strong artificial sunlight was evaluated. During the water durability test, sample nets were fixed in water that was stirred using a magnetic stirrer set at 500 rpm for 24 h. During the photodurability tests, sample nets were floated in water under artificial sunlight XC-100 (SERIC, Saitama, Japan) for 16 h. The UV intensity ($\lambda = 310\text{--}380$ nm) of the artificial sunlight as measured using a UV power meter C10427 (Hamamatsu Photonics, Shizuoka, Japan) was 4.0 mW/cm².

The durability under real-world conditions was evaluated by floating the photocatalyst net in tap water under natural sunlight. Tap water was put into a bucket and set on the roof of a building at the Tokyo University of Science (Noda, Chiba, Japan) from 1 July 2022 to 19 August 2022. During the test period, tap water was added to the bucket every week to maintain the water volume. The solar radiation time is estimated to be 316 hours based on data from the Japan Meteorological Agency in Japan [26].

The durability of the photocatalyst layer was determined by scanning electron microscopy/energy dispersive X-ray spectrometry (SEM/EDX) observation using a JCM-6000 (JEOL, Tokyo, Japan) and from the difference in photocatalytic activity before and after durability tests. Photocatalytic activity was evaluated by the decomposition of Methylene Blue (MB). Sample nets were floated in a petri dish containing 50 mL of aqueous MB solution (2.0×10^{-5} mol/L) in the dark for 8 h, followed by illumination. FL15BL-B (Panasonic, Osaka, Japan) was used as a light source, and the UVA irradiation intensity was adjusted to 1.0 mW/cm². The absorption spectrum of the MB solution was monitored using a UV-Vis spectrometer (UV-1800; Shimadzu, Kyoto, Japan), and photocatalytic activity was estimated from the change in the absorption peak intensity of MB.

2.5. Photocatalytic Sterilization of Water Containing Bacteria

The antibacterial properties of the samples were evaluated against *E. coli* DH5 α cells, which were precultured by shaking in nutrient broth in an incubator (Tokyo Rika Kikai, Tokyo, Japan) at 37 °C for 18 h. From the main culture, the bacterial suspension was inoculated into a new nutrient broth and shake-cultured in an incubator at 37 °C for 2.5 h. NaH₂PO₄ (3.09 g), Na₂HPO₄·12H₂O (8.77 g), and NaCl (37.98 g) were added to 500 mL of ultrapure water to prepare 10 \times phosphate-buffered saline (PBS). Then, 50 mL of 10 \times PBS was added to 450 mL of ultrapure water to prepare 1 \times PBS, which was used as a bacterial suspension for intact *E. coli* cells. Bacteria cells were harvested by centrifugation at 3500 rpm for 10 min and then washed three times with 1 \times PBS to remove broth residues. The cells were resuspended in 1 \times PBS to achieve an OD₆₆₀ value of 1.0. The experiments were performed using a glass container as shown in Figure S2. Ultrapure water and the bacterial suspension ($3.2\text{--}7.6 \times 10^6$ CFU/mL) were added to the container at a ratio of 9:1. The water depth was set to 20, 30, or 40 mm. The photocatalyst net covered the water surface. The reaction suspension was illuminated with a black light for 3 h.

The standard plate-count technique was used to determine the number of microorganisms present. First, 100 μ L of a diluted suspension by 1 \times PBS was spread over the surface of nutrient agar, which was then incubated at 37 °C for 24 h. After incubation, the number of viable colonies was counted with a colony counter, and the average number of colonies was calculated. A control suspension without the net and a suspension with an uncoated polypropylene net were also evaluated with a water depth of 20 mm. The photocatalytic experiments were carried out under UVA and natural sunlight irradiation.

Blacklight FL15BL-B was used as the light source, and the irradiation intensity of UVA was adjusted to 1.0 mW/cm^2 . The sterilization test using sunlight was started from 1:45 PM to 4:45 PM on September 21st and 1:30 PM to 3:30 PM on October 4th, 2022. The water depth was set to 20 mm, and the container size was $9.6 \text{ cm} \times 9.6 \text{ cm}$. The UV intensity of the sunlight was measured every 30 min.

3. Results and Discussion

3.1. FTIR Spectra of Surface-Modified TiO_2

To determine whether the TiO_2 surface was modified, the transmission FTIR spectra of APTES- TiO_2 and HDTMS- TiO_2 were examined (Figure 1). In the spectrum of TiO_2 , the peaks below 700 cm^{-1} are assigned to Ti–O and Ti–O–Ti bonds in titania [24]. The stretching vibration of absorbed water as well as surface hydroxyl groups (–OH) on the TiO_2 nanoparticles was confirmed by the broad absorption band between 3400 and 3200 cm^{-1} and the low-intensity peak at 1640 cm^{-1} [24]. After surface modification by the two types of organosilane, as presented in the spectra of APTES- TiO_2 and HDTMS- TiO_2 , the absorption peaks representing the stretching vibrations of – CH_3 , – CH_2 , and the C–O bond, respectively, appear at approximately 2925 , 2854 , and 1467 cm^{-1} . The stronger peak intensity for HDTMS reflects the long-chain hydrophobic alkyl groups of HDTMS [27]. Furthermore, the peak corresponding to the Si–O–Si bond is observed at approximately 1040 cm^{-1} , confirming the condensation reaction between silanol groups [28]. As shown in Figure 1, the N–H bending vibration of primary amines (– NH_2) is observed as a broad band in the region of 1605 – 1560 cm^{-1} [24]. The appearance of these bands indicates that the amine functional groups in the organosilane are grafted onto the modified particle surface. These results confirm that the modification of TiO_2 with silane coupling agents was successful.

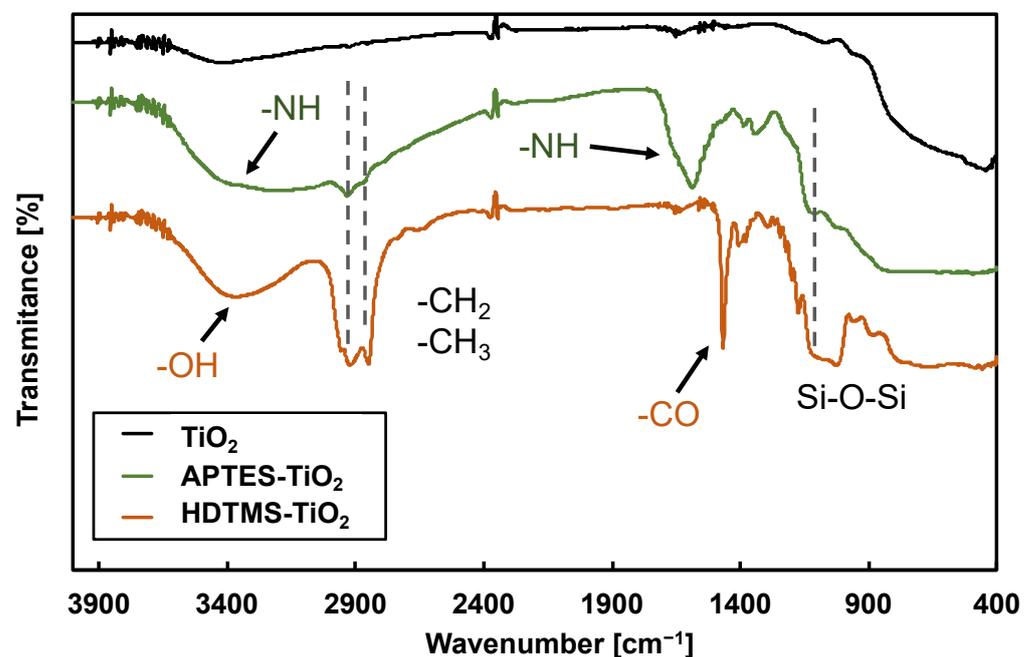


Figure 1. FTIR spectra of TiO_2 , APTES- TiO_2 , and HDTMS- TiO_2 particles.

3.2. Evaluation of Coated Material

The fabricated net maintains its flexibility, even after layer formation (Figure 2a). Furthermore, the net is light enough to float on the water surface (Figure 2b). As shown in Figure 2c, the surface of the net and the intersection of the mesh part are coated to form a TiO_2 -silicone layer. Furthermore, from the higher-magnification SEM image (Figure 2d), a rougher surface than that of the silicone-coated polypropylene net surface is observed (Figure S3). This indicates that TiO_2 particles are attached to the silicone layer in the methyl phenyl polysiloxane polymer. Hydrophilization of a surface by oxygen plasma treatment is

considered to help obtain a flexible but strong surface coating [21]. The hydroxyl groups formed on the surface improve the wettability and introduce dehydration condensation sites, increasing adhesion between the layers. The EDX mappings also demonstrate that Si and Ti are uniformly distributed in the prepared TiO_2 -coated net (Figure 3).

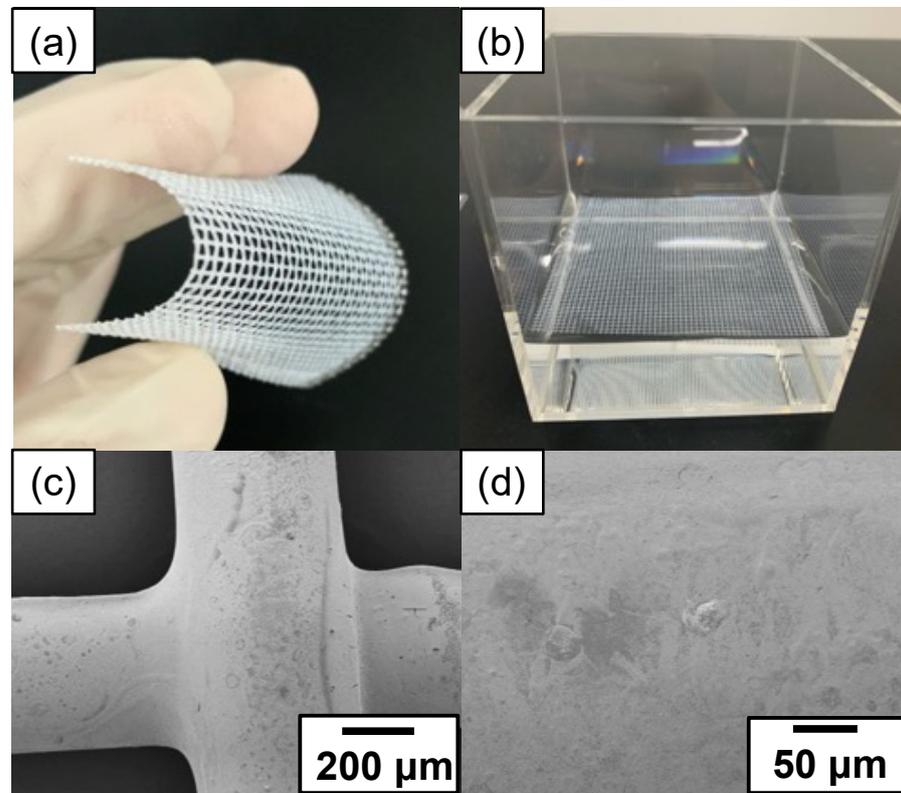


Figure 2. Photographs of (a) a bent TiO_2 net and (b) a net floated on water. (c,d) SEM images of the TiO_2 net surface at different magnifications.

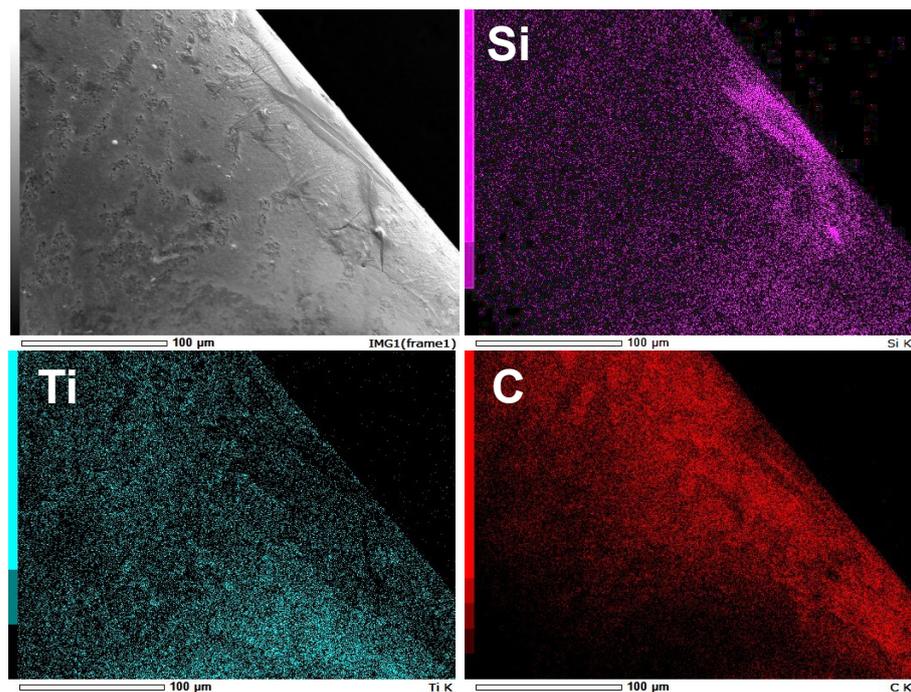


Figure 3. SEM image and EDX elemental mappings of the TiO_2 net.

The difference in reaction rate between the net and plate substrates was measured. Both substrates were cut into 5 cm × 5 cm sections, and the TiO₂ coating followed the procedure in Section 2.3. Photocatalytic activity was assessed by the decomposition of MB. Figure 4 shows that using the net substrate increases the decomposition speed by 140%. This is due to its larger surface area than that of the plate substrate. Furthermore, the net is lighter because of the space between the strings. Considering transport fees, nets are an ideal material for developing countries. Thus, we chose a net substrate for water purification.

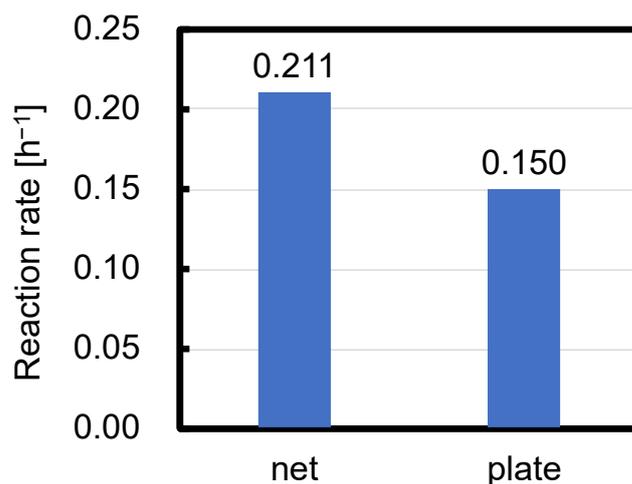


Figure 4. Photocatalytic degradation of MB by a TiO₂-coated net and a TiO₂-coated plate.

3.3. Lab-Scale Durability Test

The durability of the photocatalyst layer under water flow and strong light was tested using three samples. The photocatalytic reaction rate was assessed by the decomposition of MB, and k_{after} (reaction rate after the test)/ k_{initial} (reaction rate before the test) was calculated (Figure 5a,b). After the water flow test, the reaction rate changes of the TiO₂ net, HDTMS-TiO₂ net, and APTES-TiO₂ net were 55%, 74%, and 62%, respectively. Because the TiO₂ particles are coated onto the surface by mixing into silicone resin, MB is decomposed by the surface-deposited and semi-embedded TiO₂ particles. The decrease in reaction rate after the water flow test is due to the shedding of particles from the surface [29]. By modifying the surface of the TiO₂ particles, the functional groups increase the possibility of chemical bond formation between the modified particles and silicone, thereby improving adhesion strength [30]. In the case of HDTMS-TiO₂, the long carbon chains of HDTMS tangle in the silicone chains and physically improve adhesion, thus providing excellent water resistance to the photocatalyst layer.

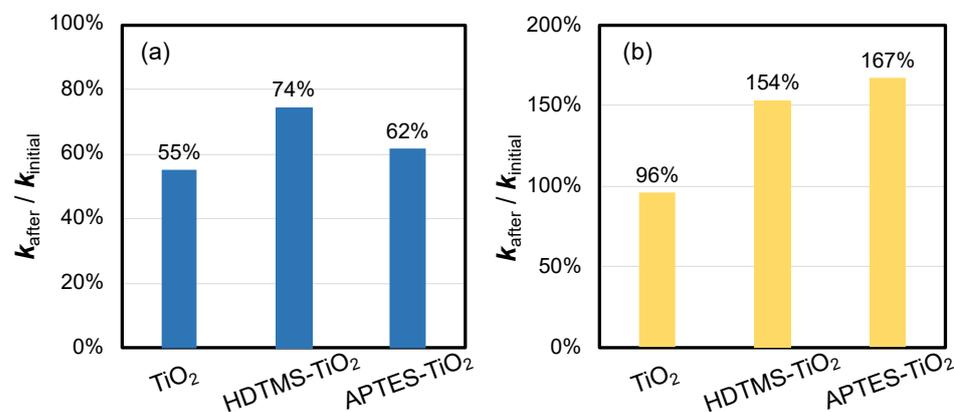


Figure 5. Effect of (a) water flow and (b) strong artificial sunlight irradiation on the photocatalytic degradation of MB.

As shown in Figure 5, after the light irradiation test, the reaction rate changes for the TiO₂ net, HDTMS-TiO₂ net, and APTES-TiO₂ net were 96%, 154%, and 167%, respectively. The TiO₂ coating on the net surface after strong light irradiation (Figure 6) was examined. For the TiO₂ layer, peeling is observed (red arrow in Figure 6a), while the modified TiO₂ does not peel. This indicates that silane modification of the TiO₂ particles improves the strength of the layer. The improvement in reaction rate is thought to be due to the decomposition of residual organic matter in the layer, which increases the number of particles contributing to the decomposition of MB. From these results, we concluded that HDTMS-TiO₂ is most suitable for long-term outdoor use. Therefore, HDTMS-TiO₂ was selected for subsequent experiments.

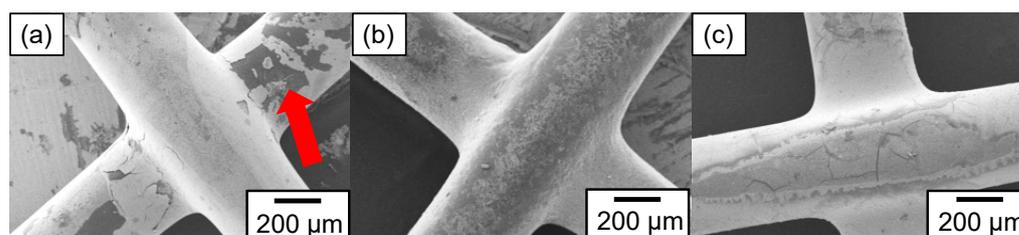


Figure 6. SEM images of the (a) TiO₂ net that TiO₂ layer peeling are observed near the red arrow, (b) HDTMS-TiO₂ net, and (c) APTES-TiO₂ net after strong artificial sunlight irradiation.

3.4. Durability in the Natural Environment

The durability of the HDTMS-TiO₂ net was evaluated on the roof of our university for 49 days. Surface observation by SEM (Figure 7) and the decomposition of MB were evaluated every 7 days. The SEM image demonstrates that the TiO₂ layer remains intact. No layer peeling is observed even after 49 days. Figure 8 summarizes $k_{\text{Day } n}$ (reaction rate at day n ($n = 7-49$)/ k_{initial} (reaction rate before the test). From day 1 to 14, the reaction rate decreases because of the surface pollution that occurs when water is left outside. We confirmed the growth of species such as algae and diatoms both in the water and on the net surface (Figure S4). This is because we placed the water bucket outside for the experiment, and algae and other species can be transported to the water by the wind. In contrast, the reaction rate increased for days 14–49. It was considered that the remaining organic compounds in the layer decompose around the TiO₂ particles, as shown in Section 3.3. These results demonstrate that the net sustains photocatalytic activity over long-term use.

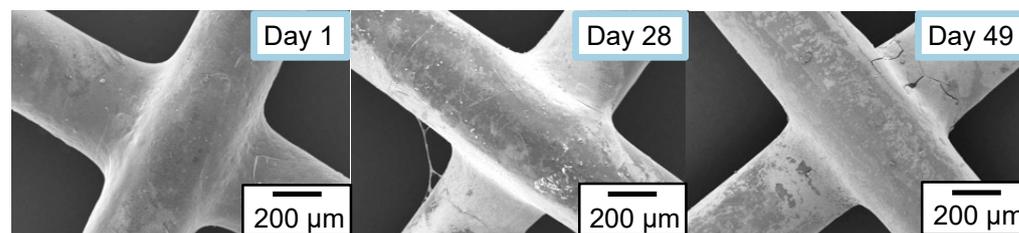


Figure 7. SEM images of the HDTMS-TiO₂ net left outside for 1, 28, and 49 days.

3.5. Photocatalytic Sterilization of Water Containing Bacteria

The antibacterial properties of the TiO₂ net were investigated in the lab using black light (Figure 9). After 3 h of UV irradiation, the survival rate of *E. coli* under UV, with the control polypropylene net (base material), and with the TiO₂ net floating on water depths of 20 mm, 30 mm, and 40 mm were 25.98, 24.25, 3.07, 7.11, and 15.99 %, respectively. The *E. coli* concentrations with and without the polypropylene net under UV irradiation were very similar, demonstrating that the polypropylene net itself has no effect on *E. coli*. Upon increasing the water depth, the survival rate of *E. coli* increases. Sterilization by TiO₂ is due to hydroxy radicals ($\bullet\text{OH}$) generated on the surface of the catalyst, which are highly active for the oxidation of organic substances and the inactivation of bacteria and

viruses [31]. Furthermore, *E. coli* is known to sink in water. In this experiment, the solution was not stirred during irradiation. Therefore, a 40 mm water depth may be too much for sterilization by the TiO₂ net. Therefore, we decided 20 mm is the recommended water depth for using this net in a flat container at home for water sterilization.

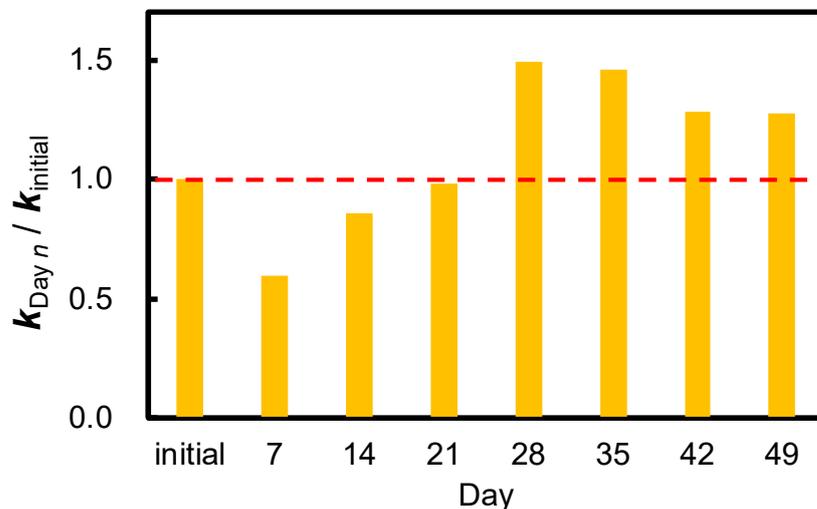


Figure 8. Effects of 49-day outdoor exposure on the rate of photocatalytic degradation of MB.

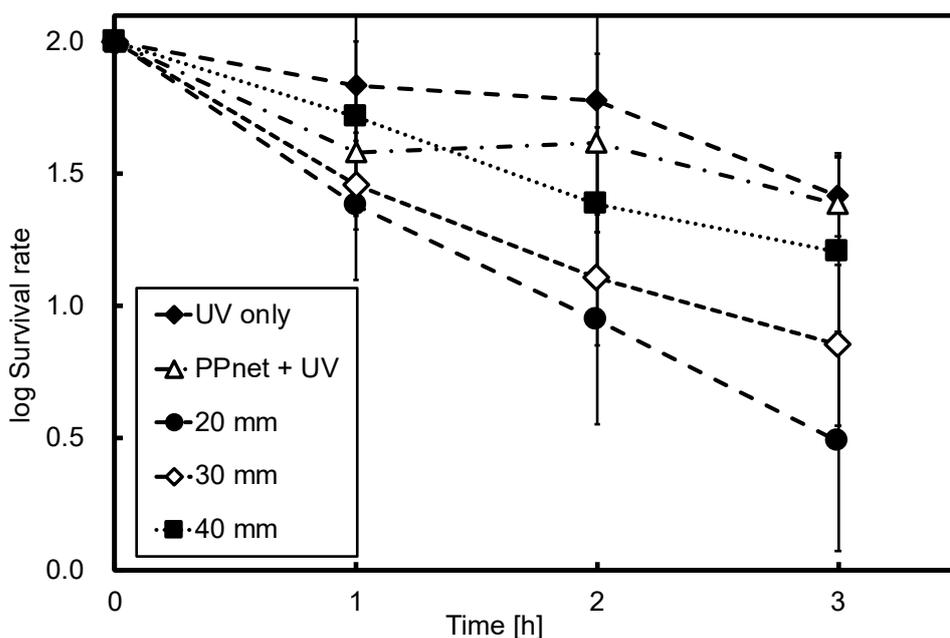


Figure 9. Photocatalytic sterilization of water containing *E. coli* at various water depths.

The antibacterial properties of the TiO₂ and HDTMS-TiO₂ nets were investigated outside under natural sunlight. The starting time was 1:45 pm. It was relatively cloudy on 21 September. A maximum UV intensity of 1.4 mW/cm² was recorded at 1:45 pm. As shown in Figure 10, there were small changes in UV intensity depending on cloud cover. The UV intensity alone was not high enough to sterilize *E. coli*. However, sterilization was confirmed with the photocatalyst net floating on the water’s surface. After 1 h of sunlight irradiation, the survival rates for *E. coli* with sunlight, the TiO₂ net, and the HDTMS-TiO₂ net were 21.62, 1.17, and 1.08%, respectively. These results show that the fabricated photocatalyst net can sterilize *E. coli* in water.

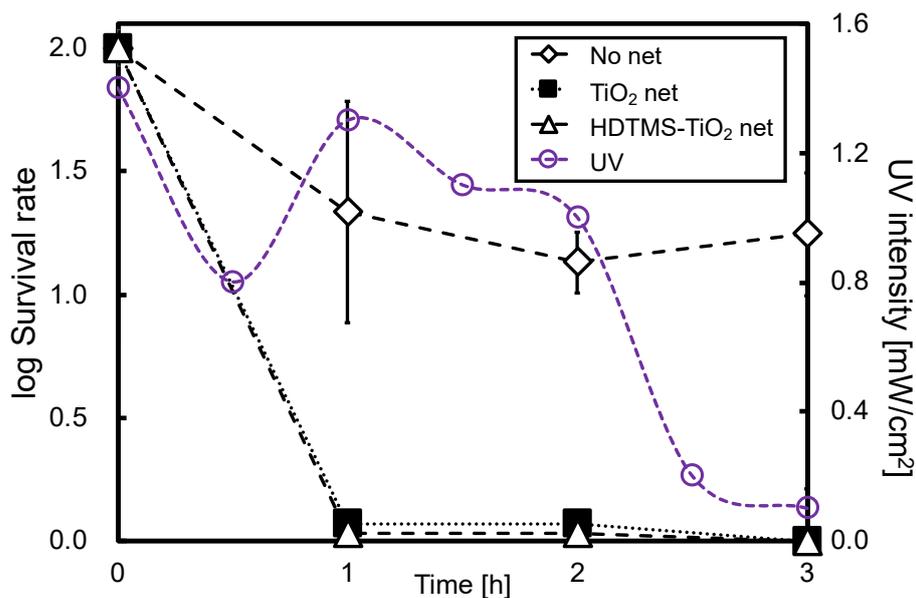


Figure 10. Photocatalytic sterilization of water containing *E. coli* by the TiO₂ net and HDTMS-TiO₂ net under natural sunlight.

Moreover, logarithmic reduction of *E. coli* was conducted (Figure 11). It was relatively sunny with partial cloudiness on 4 October. The starting time was 1:30 pm. A maximum UV intensity of 3.0 mW/cm² was recorded at 2:30 pm. The initial concentration of the *E. coli* suspension was 3.2–7.6 × 10⁵ CFU/mL. After 2 h of sunlight irradiation, the *E. coli* concentrations for sunlight, the TiO₂ net, and the HDTMS-TiO₂ net were 985, 30, and 10 CFU/mL, respectively. Rincon and Pulgarin [32] observed no bacterial growth (*E. coli* K12) after illumination of a contaminated TiO₂ suspension. However, without a catalyst, the illuminated bacteria recovered their initial concentration after 3 h in the dark. This result shows that even if bacteria are not cultivable at the end of the phototreatment, some are not killed and recover their culture ability after a period in the dark. Thus, it is necessary to use a photocatalyst for the deactivation of drinking water.

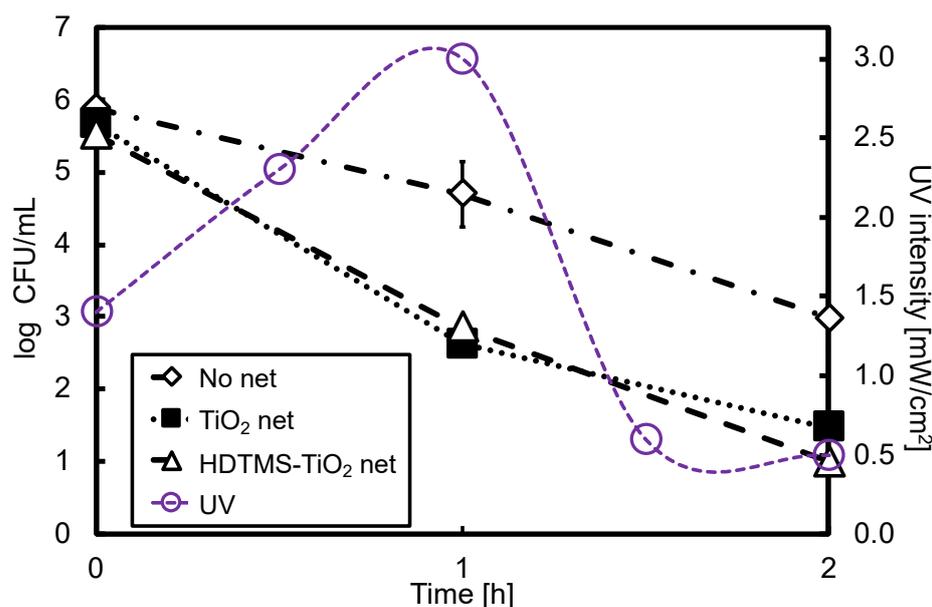


Figure 11. Photocatalytic sterilization (logarithmic reduction) of *E. coli* using the TiO₂ net and the HDTMS-TiO₂ net under natural sunlight.

4. Conclusions

We aimed to create a TiO₂-coated net that disinfects water for practical use in developing countries. The TiO₂ particles were modified with APTES or HDTMS to improve particle dispersibility. By modifying the surface of the TiO₂ particles, we succeeded in preparing a highly water-durable photocatalyst coating that can be maintained for 49 days of outdoor exposure. This represents 316 h of solar radiation [26]. The number of *E. coli* was decreased from 320,000 to 10 CFU/mL under sunlight within 2 h. Because the UV intensity in developing countries is stronger than that in Japan, sterilization by the photocatalyst net will occur more quickly. These results indicate that the photocatalyst net can be used more than 150 times (316 h/2 h). The amount of water that the net can treat depends on the size of the water container. In this study, we set the water depth to 20 mm, and the container size was 9.6 cm × 9.6 cm. Therefore, the amount of treated water was 185 mL. Using a container with a surface area of 1000 cm² and 20 mm in depth, the photocatalyst net can treat 2 L of water, which is the required amount of drinking water for adults per day [33]. Existing water treatments necessitate the incurrence of equipment costs, such as those associated with separation membranes as well as operational expenses. The cost of materials required to fabricate 100 cm² of the TiO₂-coated net was less than USD 1. Dip-coating is distinguished by the ability to apply a thin film and the low loss of coating liquid in contrast to spray coating. These attributes enable the creation of a large TiO₂-coated net with a minimal amount of coating liquid, potentially leading to cost reduction. Additionally, there are no operational expenses associated with this net. As a result, the implementation of the TiO₂-coated net in developing countries may be facilitated. The results we obtained show that the photocatalyst-coated polypropylene net effectively eliminates *E. coli* from drinking water, reducing the risk of infectious diseases.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/w15020320/s1>, Figure S1: Schematic of coated layers; Figure S2: Schematic of the antibacterial test setup; Figure S3: SEM images of the silicone layer coated polypropylene net at different magnifications; Figure S4: SEM images of algae and diatom growth on the HDTMS-TiO₂ net surface.

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