# Solar Disinfection of Drinking Water with Polyethylene Terephthalate Bottles Coated with Nano-Titanium Dioxide

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***Abstract—*** *Water disinfection processes in the presence of titanium dioxide as a photo-catalyst material provide an interesting route to destroy contaminants, being operational in the UV-A domain with a potential use of solar radiation. In recent years, advanced oxidation processes (AOP) have been developed to meet the increasing need of an effective wastewater treatment. AOP generates powerful oxidizing agent hydroxyl radicals which completely destroy the pollutants in waste water. Solar disinfection of drinking water with polyethylene terephthalate (PET) bottles coated with photo-catalyst* $TiO_2$ *has been shown to be very effective. The study is based on comparison between three systems for treating contaminated water samples using PET bottles. First system was a PET untreated bottle, the second system was a PET bottle coated with black paint on its outer surface. Finally the third system was a PET bottle coated also with a black coat on its outer surface and its inner part was treated with citric acid solution to enable np-*$TiO_2$ *to cover the surface later on, then 0.2 g of np-*$TiO_2$ *powder (of particle size <25 nm, Sigma-Aldrich) was added. The total bacterial accounts were determined to monitor the effect in the three systems. The experimental results have shown that disinfecting water with merely UV was less effective than combining the bottle with heat effect, and adding* $TiO_2$ *film was further more benefited. This work can be applied in rural areas, with no technical support or need for expensive/dangerous chemicals for drinking safe water even if is stored for two days*

.***Keywords— Water disinfection, Photo catalyst, Titanium dioxide, UV Radiation, Solar Radiation.***

## I. INTRODUCTION

Over 30% of the population in developing countries is in need of access to safe drinking water, [1]. It is estimated that 1.1 billion people (17% of global population) lack to access to safe drinking water and 2.6 billion people (42% of global population) lack access to proper sanitation facilities (World Health Organization/UNICEF 2005),[2,3]. To reduce these numbers, there are some methods for water disinfection like chlorination, boiling and Pasteurization. Chlorination is practical for small communities but is difficult to implement at the point of use. Boiling and Pasteurization are effective in removing bacteria, yeasts, molds, and protozoa from drinking water. Both methods require heating to elevated temperatures-65$^o$C for pasteurization and 100$^o$C for boiling-for short periods of time. Pasteurization can be effectively done by solar cookers (Ciochetti & MetCalf, 1984, [4]). Boiling usually requires burning biomasses which is discouraged because it promotes the destruction of local forests that are used for other purposes. Neither boiling nor pasteurization eliminates the chemical contaminants- which increase the risk for cancer, liver and kidney problems, and nervous and reproductive systems problems, [2]. And also other conventional methods like slow sand filtration which needs large land area, manual cleaning of filters and water with low turbidity levels. In addition organic pollutants aren't fully removed from the water using this technique, [2]. Other conventional technologies used to disinfect water are: ozonation, and artificial UV radiation. These technologies require sophisticated equipment, are capital intensive and require skilled operators, [5, 6, and 7].

An alternative treatment option Solar Water Disinfection (SODIS) was developed as an inexpensive alternative. SODIS reduces pathogens by exposing water-filled plastic bottles (mainly polyethylene terephthalate or PET) to sunlight. SODIS is primarily used to disinfect small volumes of water (<2 liters/bottle) and depends only on sunlight for disinfection, making it ideal for rural areas, Individuals expose clear plastic PET bottles filled with contaminated water to full sunlight for 8 hours. The UV radiation in the solar spectrum disinfects water by inactivating bacteria DNA [2,8,9]. Fig.1 represents the SODIS process.

*Fig.1: Depiction of SODIS [2].*

However, bacteria have a self-defense mechanism, the ability to perform enzymatic DNA repair, which can result in bacterial reactivation. Therefore, while bacteria count directly after disinfection may reveal very low bacteria concentration, the bacteria with time may return in large numbers, [8]. Also it does nothing to mitigate inorganic or organic chemical waste that may be present in water. In addition, several variables including water turbidity (a measure of water clarity), total solar radiation, and ambient air temperature affect the disinfection process. It has been also suggested that the efficacy of SODIS is related to the amount of dissolved oxygen in the water at the time of treatment [2,10]. Paper mill wastewater is treated by solar photocatalytic oxidation with synthesized nano $TiO_2$. The results showed that $TiO_2$ in the presence of solar light can be employed as an effective photocatalyst for the removal of chemical oxygen demand from the wastewater but in optimized conditions. A reduction of 80% of total suspended solids from the wastewater was also obtained at the same operating conditions. The experimental results had also shown that the non-biodegradable substances can be very effectively degraded by the solar photocatalytic treatment [11].

In order to increase the efficiency of the SODIS process, solar photo catalytic disinfection (AOP) was developed using titanium dioxide ($TiO_2$) as a photocatalyst. This method promises to increase the rate of disinfection of microorganisms while eliminating organic pollutants, such as fertilizers herbicides and pesticides. Titanium dioxide works much like SODIS in that it, too, generates hydroxyl radicals, peroxides and super-oxides. Figure 2 shows the mechanism of work of $TiO_2$.

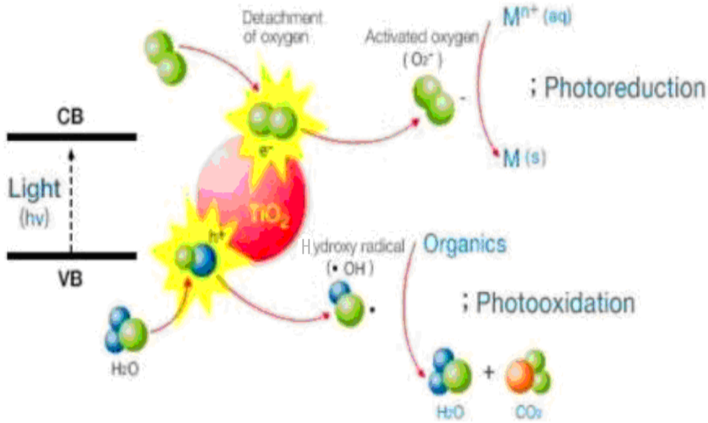



*Fig.2: Photo -reduction and Photo-oxidation with Titanium Dioxide [2].*

## II. THEORETICAL ANALYSIS

If a photon promotes an electron from the valence band to the conduction band a "hole" with a positive charge is left in the valence band:

$$TiO_2 + hv \longrightarrow TiO_2 . (e_{cb}^{-} + hole_{vb}^{+}) \quad (1)$$

The superoxide radical is formed by the addition of a single electron:

$$O_2 + e_{cb}^{-} \Rightarrow O_2 \quad (2)$$

Hydrogen peroxide is formed during the reaction:

$$2 O_2^{\bullet -} + 2H_{aq}^{+} \longrightarrow H_2 O_2 + O_2 \quad (3)$$

The OH radical is formed from either the reaction of water with an electron hole:

$$H_2 O + TiO_2 (hole_{vb}^{+}) \longrightarrow OH^{\bullet} + H^{+} \quad (4)$$

or through the reaction of a hydroxide ion with a hole:

$$TiO_2 (hole_{vb}^{+}) + OH_{adc}^{-} \longrightarrow OH^{\bullet} + TiO_2 \quad (5)$$

From equations (1-5), due to the presence of highly reactive oxidizing species, water can be disinfected from pollutants and chemicals and organisms as well effectively, [2].

However, the photo-oxidation and photo-reduction capabilities of AOP are superior to those of SODIS for the destruction of E. coli bacteria, and organic chemical effluents, [2, 8, 11, 12, 13]. The evolution of structure and microstructure as well as charge separation for a series of highly reactive nano crystalline $TiO_2$ photo-catalysts is certified by the degradation-mineralization of various model pollutants under UV light [14].

This work aims to make a study on SODIS-AOP technique and making it simple to be applied in rural regions and to study the storage of the disinfected water to determine the safety period of using the disinfected water with this technique water. Such remote communities typically suffer from fecal contamination of transient water sources, rather than chemical or radiological contaminants. To address this problem a low-cost continuous-feed water treatment facility has been designed and developed. The facility utilizes solar (UVA) radiation to treat pathogens. Additionally, the facility is designed such that it can be manufactured in-situ from limited or improvised resources at low capital and maintenance costs. The system is modular so that multiple systems can be used to increase water treatment capacity as required. Testing indicates that 3 modules of the design can treat 34L of water in 4 hours producing a 4-log reduction in E. Coli (from $8 \times 10^5$ CFU/ml) with a residence time of less than 30 minutes [15] .

## III. EXPERIMENTAL PROCEDURE

The study is based on three systems for treating contaminated water sample using PET bottles. First system was a PET untreated bottle, the second system was a PET bottle coated with black paint on its outer surface. Finally, the third system was a PET bottle coated also with a black coat on its outer surface and its inner part was treated with citric acid solution to enable np-$TiO_2$ to cover the surface later on, then 0.2 g of np-$TiO_2$ powder (of particle size <25 nm, Sigma-Aldrich) was added and the bottle was shaken manually and carefully to make a thin film on a half of the bottle. Then the bottle was washed twice with distilled water, so the extra loose powder is removed, [2].

The three bottles were exposed to the sun light for half an hour before usage to guarantee their sterilization before conducting the experiment, and then they were filled with water sample contaminated with bacteria.

## IV. RESULTS AND DISCUSSION

The bacteriological examination was conducted on water samples to examine three different parameters UV, heat, and photocatalytic oxidation with np-$TiO_2$. These parameters include the total bacterial counts/ml. the sample was free from Aerobic and Anaerobic bacteria. The parameters expect of total bacteria counts didn't disappear at 33ºC, 51ºC in case of using untreated PET bottles with a thin film of np-$TiO_2$.

To evaluate the effectiveness of the three systems of treating the infected water, table (1) shows the data if the bacteriological analysis and the effect if the solar energy (UV and heat) and the effect of photocatalytic oxidation by np-$TiO_2$ thin film removing bacteria. To achieve this aim, total bacterial counts were determined to monitor the effect of UV in case of untreated PET bottle, the effect of heat (and UV) in case of the half black PET bottle, and finally the effect of the photocatalytic oxidation in case of the half black PET bottle treated with thin film of np-$TiO_2$.

*Table.1: The effect of the solar energy and the photocatalytic oxidation by np-$TiO_2$ thin film on the total bacterial counts (CFU/ml), at 37 ºC of the atmosphere*

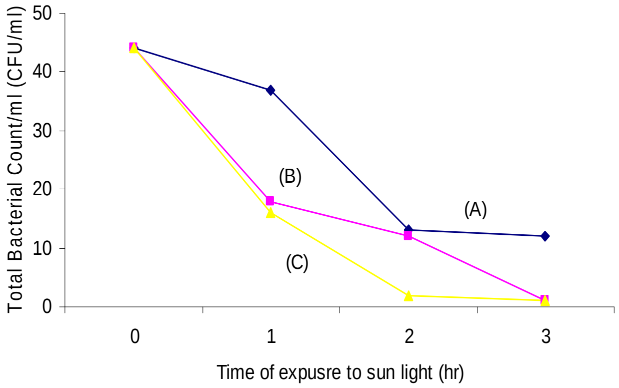
| ***Sample*** | ***(A) Untreated bottle (CFU/ml)*** | ***(B) Half black bottle (CFU/ml)*** | ***(C) Half black-$TiO_2$ thin film treated bottle (CFU/ml)*** | ***Sample Temperature (ºC)*** |
|---|---|---|---|---|
| **Exposure time** | the total bacterial count/ml | | | |
| 0hr | 44 | 44 | 44 | 25 |
| After 1 hr | 37 | 18 | 16 | 37 |
| After 2 hrs | 13 | 12 | 2 | 45* |
| After 3 hrs | 12 | 1 | 0 | 51* |
| **Efficiency of Bacterial Removal (%)** | 72.7 | 97.7 | 100 | |

* In case of the untreated bottle temperature of the sample was steady at 33 ºC.

In table (1), the sample at room temperature 25ºC, was 44 CFU/ml as starting the experiment, while the bacterial counts for the untreated bottle after exposure to the sun, at 33ºC (for water, but for the atmosphere was 37ºC) were, 37, 13, and 12 CFU/ml, although in case of using the half black bottle, the bacterial counts were 18 at 37ºC, 12 at 45ºC, and 1 at 51ºC. However, the bacterial counts for the half black bottle treated with np-$TiO_2$ thin film were 16 at 37ºC, 2 at 45ºC, and 1 at 51ºC.

By increasing time of exposure to UV light, for all the systems, the bacterial counts were dropping gradually, but in the second system it dropped faster due to the heat caused by the half black side of the bottle, and dropped faster in the third system due to the effective photocatalytic oxidation by np-$TiO_2$ thin film.

From table (1) it is obvious that the treatment of np-$TiO_2$ to the PET bottle was superior to the other systems in this study, due to the effectiveness of the photocatalytic oxidation process occurred by the $TiO_2$ nano particles exposed to UV light, fig.3 shows the total bacterial counts for the three times against time.




*Fig,3: Total bacterial counts/ml against time, A: untreated bottle, B: half black bottle, C: half black and half $TiO_2$film bottle.*

After storing these samples for 48 hours and again conducting them for determining the total bacterial counts, the results discovered the following data in table (2). From table (2) another criterion was added to this study, revealing that the np-$TiO_2$ treated PET bottle system was still superior to the other systems, and so it adds to the benefits of using np-$TiO_2$ thin films in water treatments as its sterilizing effect lasted to a longer period of time.

## V. CONCLUSION

As a final result of this study, the experimental results show acceptable agreement with previous studies [have reference] one can conclude that the UV for three hours is not enough in killing all bacteria, but by photocatalytic reaction that was guaranteed in two hours. This work can be applied in rural areas, with no technical support or need for expensive/dangerous chemicals for drinking safe water even if is stored for two days.

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