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Photocatalytic Disinfection of *Coliform* Bacteria Using UV/TiO_2

Rahmani AR. PhD, Samarghandi MR. PhD, Samadi MT. PhD, Nazemi F

Dept. of Environmental Health Engineering, Faculty of Public Health and Center for Health Research, Hamadan University of Medical Sciences, Iran

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Abstract

Background: There are great interests in photocatalytic oxidation of contaminants using titanium dioxide in recent years. The main objective of this research was to study photocatalytic disinfection of *Coliform* bacteria as water microbial pollution index using TiO_2 and a low pressure UV lamp in a batch reactor.
Methods: The polluted water was prepared by adding a colony of *Coliform* in raw water and in separate stages was contacted with UV, TiO_2 and combination of them and various parameters such as contact time, pH and amount of TiO_2 were studied in terms of their effect on reaction progress.
Results: The results showed that in simultaneous presence of both UV ray and TiO_2, there was the most effective disinfection of *Coliform*. This study showed that 100% of *Coliform* was killed by irradiation for 60-75 min. in the presence of 0.8 gr l^{-1} TiO_2 in pH=7.0.
Conclusion: Based on the results, UV/TiO_2 process may be effectively applied for disinfection of polluted water and can be suggested as a effective purifying method for water disinfection.

Keywords: *Water treatment, Disinfection, Coliform, Photocatalyst, TiO_2, UV*

Introduction

The practice of eliminating harmful microorganisms in water dates back to ancient times. The most common methods for water disinfection are using chemicals, Ozonation, Ultra Violet ray, Membrane Processes etc (1-3).
In the past, the primary emphasis of disinfection was prevention of water-born diseases by controlling some bacteria such as *Coliform*. A new finding made in 1970 resulted in significant reevaluation of this long established disinfection practice was about disinfection by products. This disinfection by products, formed via the reaction between disinfectants and certain organic matters in water, may be harmful to human health. Thus, the new methods for decreasing the side effects of disinfectants must be improved (4-8).
The application of photocatalysis in the treatment of water and wastewater is an interesting alternative and is the object of a great interest over the last years by many researchers (9, 10). In these researches, attention has been drawn toward an alternative technique where the pollutants are degraded by irradiation suspension of metal oxide semiconductor particles such as TiO_2 or ZnO (2, 4, 9). TiO_2 is an excellent photocatalyst for complete mineralization of pollutants in water and wastewater. It has been known as a chemical that is non-toxic, insoluble in water, stable under UV radiation and comparatively cheap (6, 11).
TiO_2 is capable to be activated by UV-light with wavelengths less than 400 nm (6, 11, 12). Light energy from ultraviolet radiation (light) in the form of photons, excites the electrons on the surface of titanium atoms suspended in the contaminated water, moving them from the valence band to the conductance band.

Corresponding Author: Dr Mohammad Taghi Samadi, Fax: +98 811 8255301, E-mail: samadi@umsha.ac.ir

The result of this energy change is the formation of holes in the surface of titanium atom, and free electrons, which are now available to form hydroxide (OH) or other radicals, which can used as a powerful oxidizing agent to convert organic pollutants into CO_2 or inactivated microorganisms (7, 9, 11, 13).
The antimicrobial activity of UV/TiO_2 has been essayed in several microbes including *Enterobacter caloacae* (12), *Escherichia coli* (2, 4, 8, 10-12, 14, 15), *Pseudomonas aeruginosa* (10, 12), *Cyanobacteria* and Unicellular algae (3), *Lactobacillus helveticus* (4), *Legionella pneumophila* (14), *Clostridium perfringens* and *Coliphages* (7).
In this work, we have compared the effectiveness of TiO_2, UV and UV/TiO_2 for the disinfection of *Coliform* bacteria as a water microbial pollution index.

Material and Methods

Bacteria culture and TiO_2

The effect of photocatalytic on disinfection in a batch reactor was tested on *Coliform*. Bacterial sample was taken from polluted water and grown in lactose broth (Merck) on an orbital shaker at 35 ºC for 24 to 48 h until was gotten turbid. From this culture, sample was inoculated into EMB agar (Merck). Plates were incubated at 37 ºC for 24 h. Then for preparation of polluted water, a colony of culture produced in EMB agar was added to 1000 ml water. Most Probable Number (MPN) of *Coliform* in samples was measured as MPN/ 100 ml before, during and after examinations by using the fermentation technique in presumptive and confirmed tests (11, 15)
TiO_2 (Degussa P-25) was used as the photocatalyst in a batch-type reactor was a gift from Aeroxide (Evonik-Industries Germany). The sample used in this particular work had a BET surface area of 50±15 $m^2\ g^{-1}$, an average particle diameter of 21 nm and the density was 130 g L^{-1}. pH (Hach, Sension 5) adjustments in samples were made using 1 N HCl acid (Merck, 37%) and 1N NaOH (Merck 100%).

UV source and light intensity

A 40 W low pressure UV lamp, 0.8 m in length was installed 5 cm above the samples surface and the light intensity was 0.9 J $s^{-1}m^{-2}$ measured by a radiometer at 300 to 400 nm (Hagner EC1-UV-A). All analyze were made according to the standard methods (15).

Experimental Set-up and Measurements

In these experiments, the photochemical cell consisted of sterile 250 ml beakers and magnetic stirrers that used for stirring the samples. The temperature of reactors was controlled at 20 ^{o}C. In the first phase of run, the beakers were filled with 200 ml of polluted water and in separate stages were contacted with UV, TiO_2 and combination of them. In the examinations various parameters such as pH (5.7, 7.0 and 8.1) and amount of TiO_2 (0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 gr L^{-1}) were studied in terms of their effect on reaction process for 60 min, respectively. The polished aluminum was used as the reflective material to protect the samples studied in absence of radiation. In the second phase of run based on the optimal values obtained from the first stage (pH and concentration of TiO_2), the examinations will be repeated for determination of optimal of contact time (0, 10, 20, 30, 45, 60 and 90 min.). In the third phase of run based on the optimal values obtained from the previous stages, the effect of TiO_2 concentration in disinfection efficiency was studied. The disinfection efficiency, *E*, is calculated as:

$$E = \frac{C_i - C_f}{C_i} \times 100$$

C_i and C_f are the initial and final MPN/100 ml respectively. The experimental apparatus as shown in Fig. 1 was set up in Hamadan University of medical sciences in 2008.

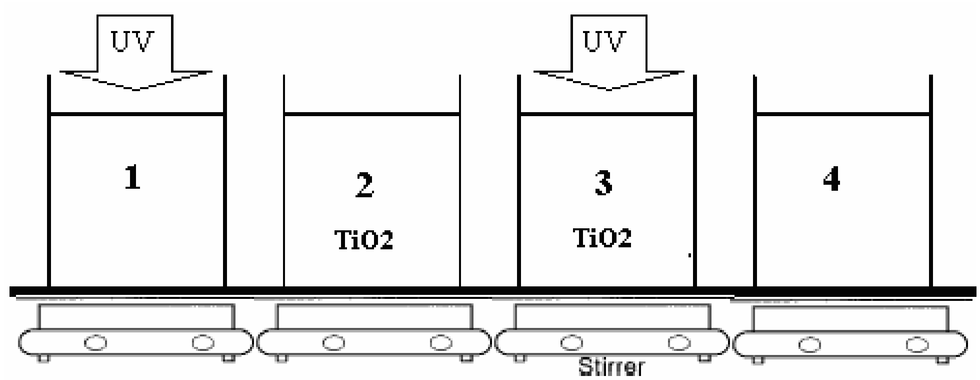

Fig. 1: Schematic diagram of experimental apparatus

Results

The results from examinations as MPN/100ml in pH=5.7, 7.0 and 8.1 as the function of TiO_2 concentration in the studied processes in 60 min. UV irradiation is shown in Fig. 2. It is found that disinfection efficiency is affected by TiO_2 concentration. The results show that the variation on pH has no significant effect on *Coliform* inactivation. The most observed yield is related to pH= 7.0.

The results from examinations in pH= 7.0 and TiO_2= 0.8 gr L^{-1} as the function of exposed time in the studied processes are shown in Fig 3. It is found that *Coliform* removal is affected by contact time. By increasing the contact time, the percentage of disinfection is raised. Presence of TiO_2 in these processes can promote removal rate, remarkably.

The effect of TiO_2 concentration on samples exposed to UV light for 75 min at pH=7.0 is shown in Fig. 4. The *Coliform* removal efficiency decreased gradually with increasing amounts of TiO_2. The maximum reduction was reached at around 0.8 gr L^{-1}. Further increase in concentration caused a continuous rise in the present fraction. Accordingly, a TiO_2 concentration of 0.8 gr L^{-1} was used as the optimum concentration.

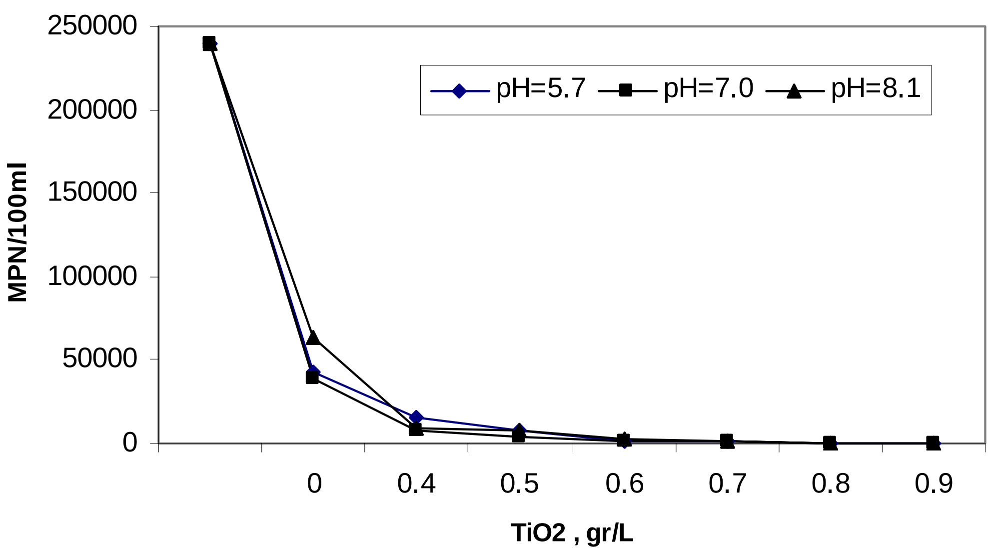

Fig. 2: Effect of TiO_2 concentration and pH on *Coliform* removal as MPN/100 ml: Irradiation time= 60 min

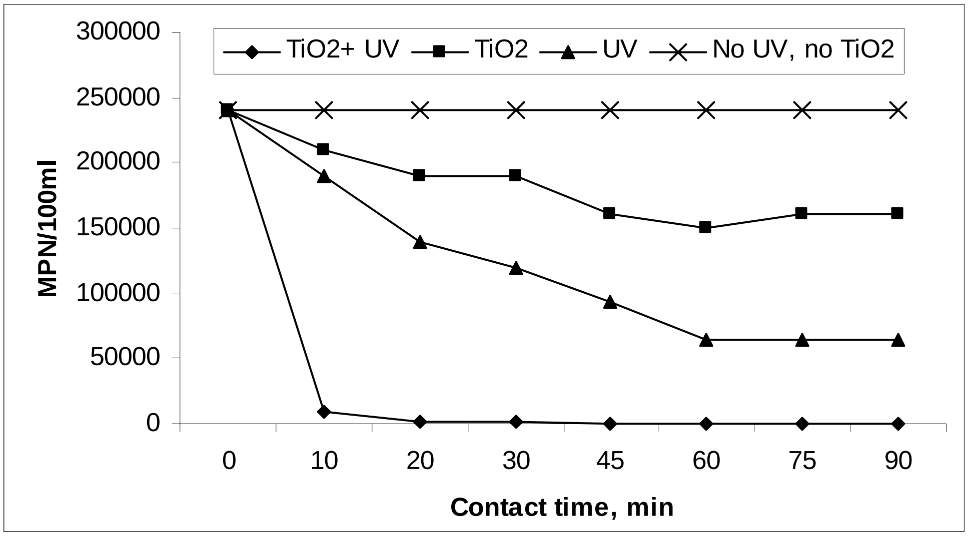

Fig. 3: Effect of irradiation time on *Coliform* removal: TiO_2 = 0.8 gr L^{-1}, pH=7.0

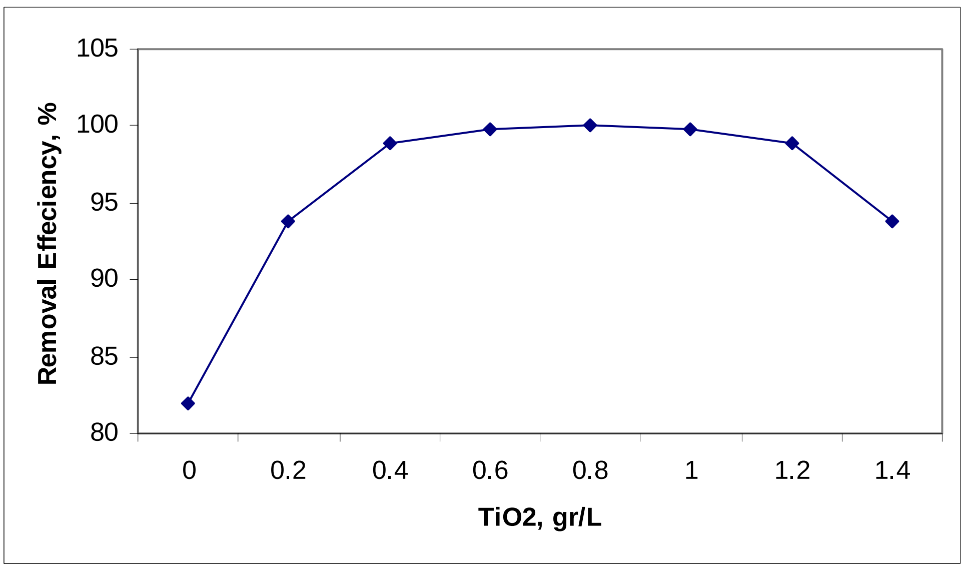

Fig. 4: Effect of TiO_2 concentration on *Coliform* removal as MPN/100 ml:

Irradiation time = 75 min, pH=7.0

Discussion

In this work, the photocatalytic disinfection of *Coliform* by using a low pressure UV lamp intensity of 0.9 J $s^{-1}m^{-2}$ and effects of TiO_2 concentration on 100% reduction time were investigated. The results obtained in this study for the photocatalytic destruction of *Coliform* are discussed below and similar to those reported by several other authors (1, 2, 4, 6, 8, 11-13, 16).

Effect of pH and TiO_2 concentration

The effect of pH on *Coliform* inactivation, as the pH was changed from 5.6, 7.0 and 8.1 in UV/TiO_2 process at 60 min and TiO_2 concentration of 0 and 900 ppm is shown in Fig. 2. The results show that no significant pH effect on *Coliform* inactivation was observed at the pH conditions used in this study. Cho et al. reported that the cell surface charge of *E. coli* has a negative charge character and the TiO_2 particle has a point of zero charge pH of about 6.3. Thus, it was expected that electrostatic repulsion between the TiO_2 surface and *Coliform* at high pH would be higher due to their both having the same negative charge. However, such a trend was not observed. Although the electrostatic interaction at the TiO_2/water interface could be important in many cases of photocatalytic degradation of charged substrates, it is a relatively weak force, which can be dominated by other factors (2, 13, 17).

Effect of UV irradiation, TiO_2 and contact time

The effect of UV irradiation and TiO_2 on removal of *Coliform* shows in Fig. 3. The experiments were done at initial 240000 MPN/ 100 ml, TiO_2 concentration of 800 ppm and pH= 7.0. The experiments were continued up to 90 min. It is obvious that removal efficiency of *Coliform* in the absence of each of TiO_2 or UV irradiation, with time was low, while in the presence of both of them, removal efficiency was increased. The 96% reduction time at an optimal concentration of 0.8 gr TiO_2 L^{-1} was 10 min at 0.9 $Js^{-1}m^{-2}$. It can be concluded from these results that disinfection capability in the aspect of time using both TiO_2 and UV light was more than 4.62 times as that by using only the UV light.

In the presence of both of TiO_2 and UV irradiation, hydroxyl radicals (OH) are produced, which increase the efficiency of the process. In the absence of UV irradiation, it may be TiO_2 particles adsorbed some of microorganisms, which causes low decrease in the amount of *Coliform* with time (8, 10-12, 18).

Effect of amount of TiO_2

Different amounts of TiO_2, from 0 to 1.4 gr L^{-1}, were added to the samples with initial 240000 MPN/100 ml and the results are shown in figure 4 at 75 min UV irradiation time. It can be seen that to some extent, increasing the TiO_2 concentration increased the removal of *Coliform*. In this experiment, maximum disinfection capability occurred at 0.8 g TiO_2 L^{-1}. At higher TiO_2 concentrations (>0.8 gr L^{-1}), the disinfection capability decreases due to the absorption and scattering of UV light by the suspended TiO_2 particles (2, 6, 10, 13).

In conclusion, the results of this study showed that UV/TiO_2 process could be effectively removed *Coliform* bacteria. The 100% removal efficiently at a UV intensity of 0.9 J $s^{-1}m^{-2}$ with 0.8 g TiO_2 L^{-1} was 60 min. This process needed joint action of UV irradiation and TiO_2. Increasing the concentration of TiO_2, first increased the *Coliform* removal efficiency, but further increase in photocatalyst concentration causal resulted in a decrease in process efficiency. Also it is resulted that pH has no significant effect on the disinfection by UV/ TiO_2 process.

Acknowledgements

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