Disinfection of Natural Water using Titanium Dioxide

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ABSTRACT

Titanium dioxide in the presence of UV light has sterilizing ability and can be used for water disinfection. This study focuses on the evaluation of disinfection efficiency of TiO_2/UV for natural water. Titanium dioxide nanomaterial was synthesised and annular photo reactor was fabricated for conducting all the experiments. Disinfection of the Ganga canal water was done with (i)UV-C, (ii)TiO_2 and (iii) TiO_2 in the presence of UV-A. TiO_2 was used both in slurry as well as in immobilised form. Experiments were conducted both in batch and continuous mode. Disinfection efficiency increased with increase in irradiation time.

Keywords: disinfection by-products, nanomaterial, reactive oxygen species, fixed bed reactor

1. INTRODUCTION

The primary goal of water treatment is to ensure that the water is safe to drink and does not contain any disease-causing microorganisms. Disinfection of water is done to kill pathogens and render it safe for drinking. The most common techniques used for water disinfection are chlorination, ozonation and UV-C radiation. Various disinfection by-products are formed during their use. These disinfection by-products can be carcinogenic in nature. Disinfection of water through titanium dioxide (TiO_2) photocatalysis can act as an alternative technology. Titanium dioxide is a semiconductor excitable under UV radiation (UV-A range), generating an electron–hole pair. The antibacterial activity of TiO_2 is related to reactive oxygen species (ROS) production, especially hydroxyl free radicals and peroxide formed under UV-A irradiation via oxidative and reductive pathways, respectively. Reactive oxygen species formed during photocatalysis cause damage to various cell components leading to biocidal activity. Therefore, titanium dioxide nanoparticles in presence of UV lamp can be used for disinfection of water. Reducing the size of the materials to the nano scale produces tremendous increase in disinfection capacity due to the greater surface area and contact efficiency. However, TiO_2 is not easily separable from water. TiO_2 was immobilised on glass beads, thus eliminating need for post treatment separation.

2. MATERIAL AND METHODS

Synthesis of titanium dioxide nanomaterial. TiO_2 nanoparticles were synthesized from sol-gel technique. Titanium (IV) isopropoxide (TTIP) was used as precursor. TTIP (25ml) was dissolved

in absolute ethanol (25ml) and distilled water (10ml) was added to the solution. The solution was vigorously stirred for 30 min in order to form sols. After aging for 24 hrs, the sols were transformed into gels. Gels were dried under 120˚C for 2 hr to evaporate water and organic material to the maximum extent. The dry gel was sintered at 450˚C for 2hrs to obtain TiO_2 nanoparticles [1, 2]. Heat attachment method was used for immobilization of TiO_2 [3].

Characterization of TiO_2 Nanoparticles. *Scanning Electron Microscopy (SEM):* FE-SEM was done at Institute Instrumentation Centre, IIT Roorkee. Size of the nanoparticles synthesized was found to be 15-20nm as shown in figure 1.

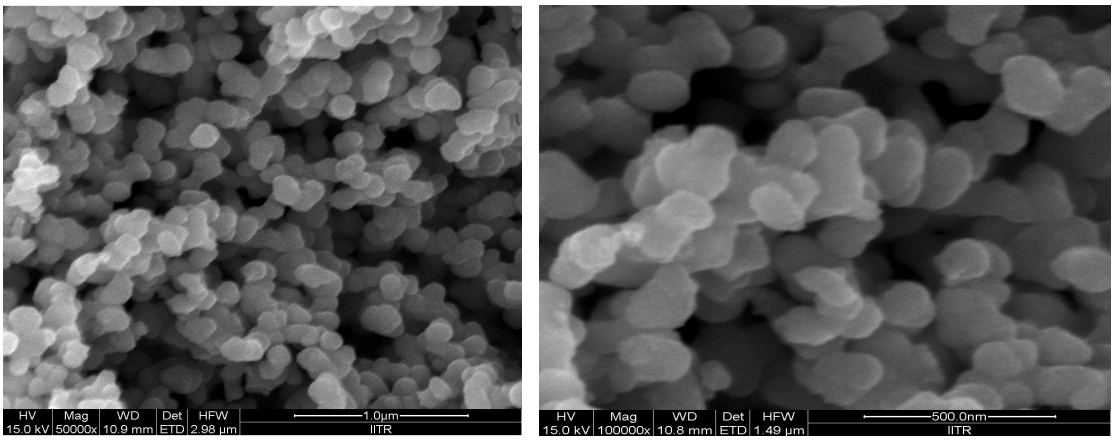


Figure 1 – FE-SEM images of sol-gel synthesized TiO_2 nanomaterial

Transmission Electron Microscopy (TEM): TEM images also tell us the grain size of synthesized nanomaterial. Average size was 20nm as shown in figure 2.

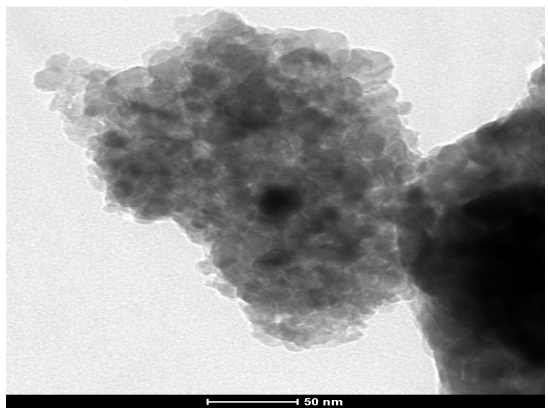
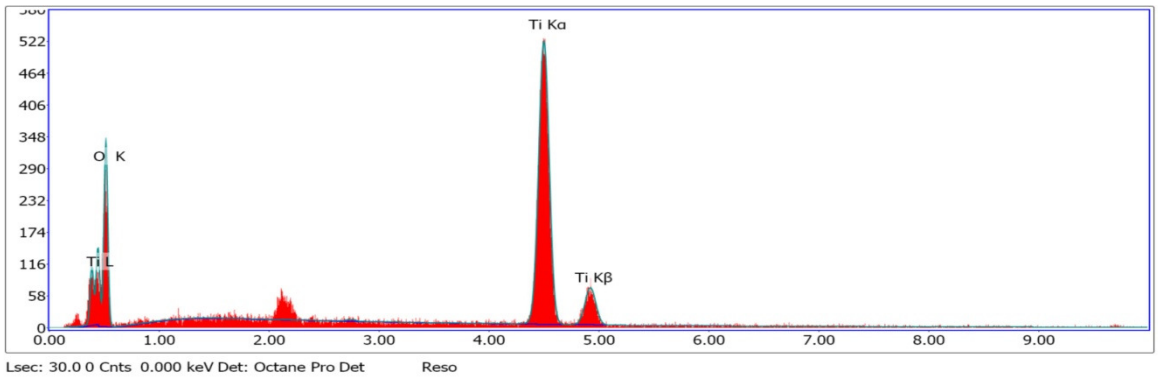


Figure 2 - TEM image of TiO_2 nanomaterial



Energy Dispersive X-ray analysis (EDX): EDX gives us the composition of synthesized nanomaterial. EDX was done at Institute Instrumentation Centre, IIT Roorkee. EDX analysis report of the synthesized material is as shown in table 1.

Table 1: eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %
O K	39.64	66.29	95.31	12.05
TiK	60.36	33.71	397.42	3.01

Photocatalytic experiment. Experiments were done in annular photoreactor. Total coliform and Escherichia coli were tested in inlet and outlet water from photoreactor using colilert-18. The effect of TiO_2 photocatalysis on coliforms was tested in two different reactor configurations. In slurry reactor TiO_2 nanoparticles were added in the powder form and in fixed-bed reactor, TiO_2 nanoparticles coated glass beads of 3-4mm diameter were placed in the whole annular reactor. Schematic diagram of photoreactor and cross-section of the fixed bed reactor is shown in figure 2.4.

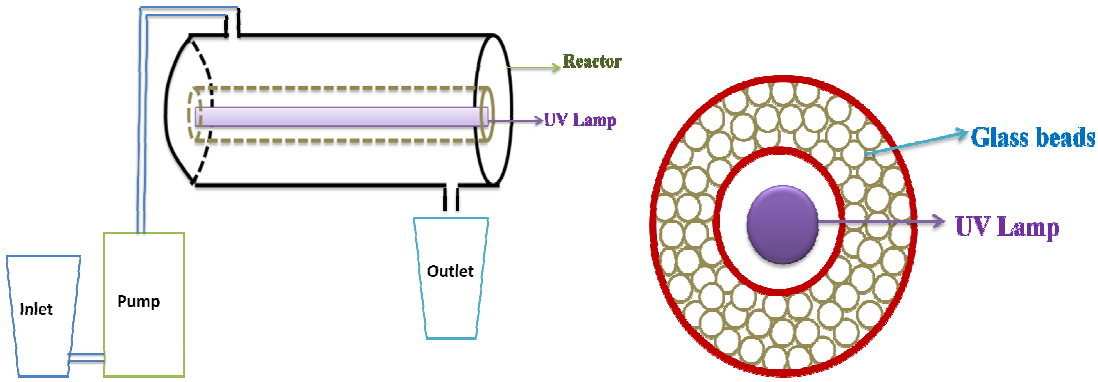


Figure 3 Experimental set up and cross-section of fixed bed photoreactor

3. RESULTS AND DISCUSSIONS

Batch experiment. *UV only*: UV lamp of wavelength 254nm and 365nm were used. Effect of irradiation time on disinfection efficiency was observed by varying time as shown in figure 4.

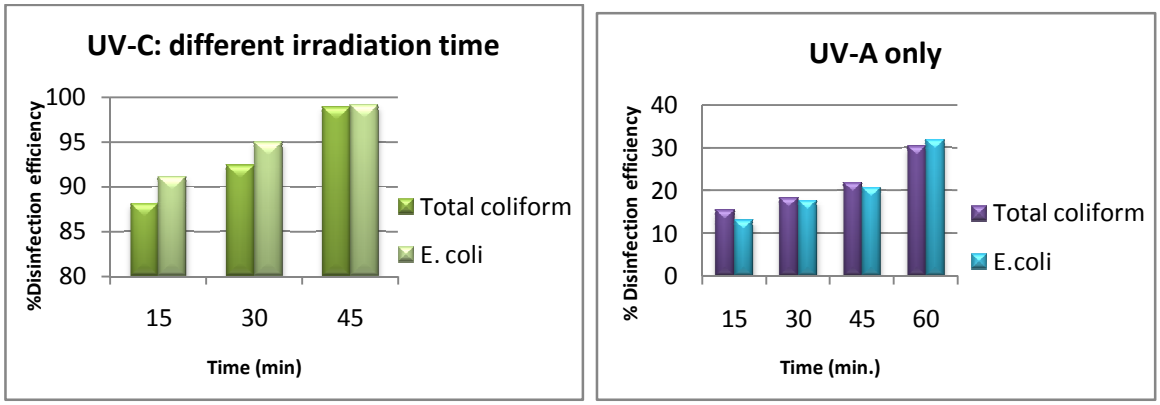


Figure 4 Effect of UV-C and UV-A irradiation time on total coliform and E.coli

TiO_2 only: Inactivation of coliforms was tested after adding 1g/L TiO_2 to Ganga canal water.

UV-A + TiO_2: 1g/L TiO_2 was added to the Ganga canal water and irradiation time was varied from 10 to 120 minutes. Percent disinfection efficiency at different irradiation time was compared with that of TiO_2 alone and is as shown in figure 5.

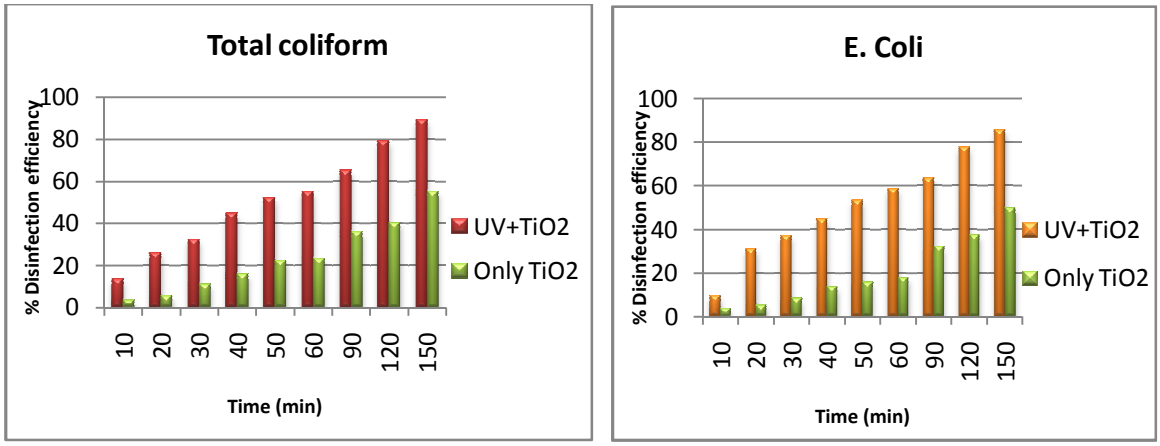


Figure 5 Effect of TiO_2 and UV-A+ TiO_2 after different time on total coliform and E.coli

UV-A + TiO_2- different concentration: Figure illustrates the influence of TiO_2 dose on the rate of cell kill. The proportion of surviving cells after 45 min in each case is shown in the figure 6.

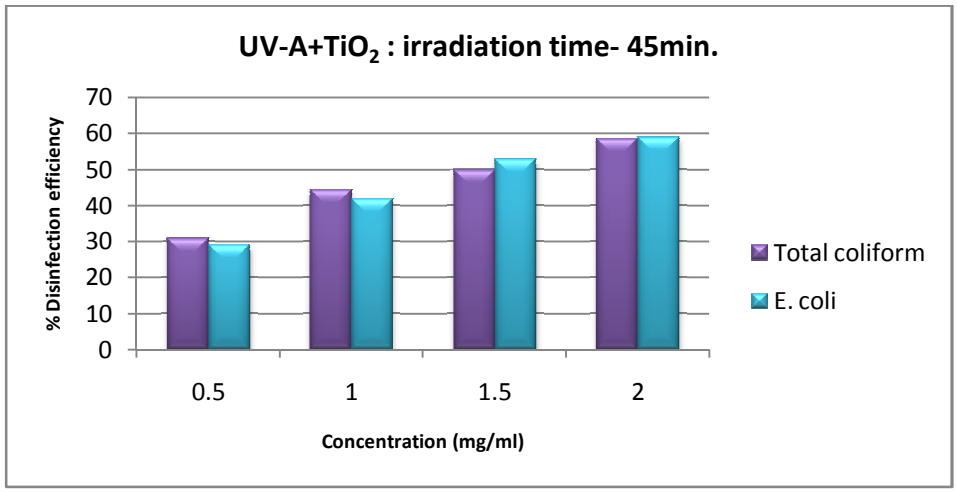


Figure 6 Effect of concentration of TiO_2 on total coliform and E. coli after 45 min irradiation time

Continuous experiment. *UV-C only*: UV lamp of 254nm wavelength was used. Continuous operation was done at different flow rates to observe its effect on total coliform and E. coli as shown in figure 7.

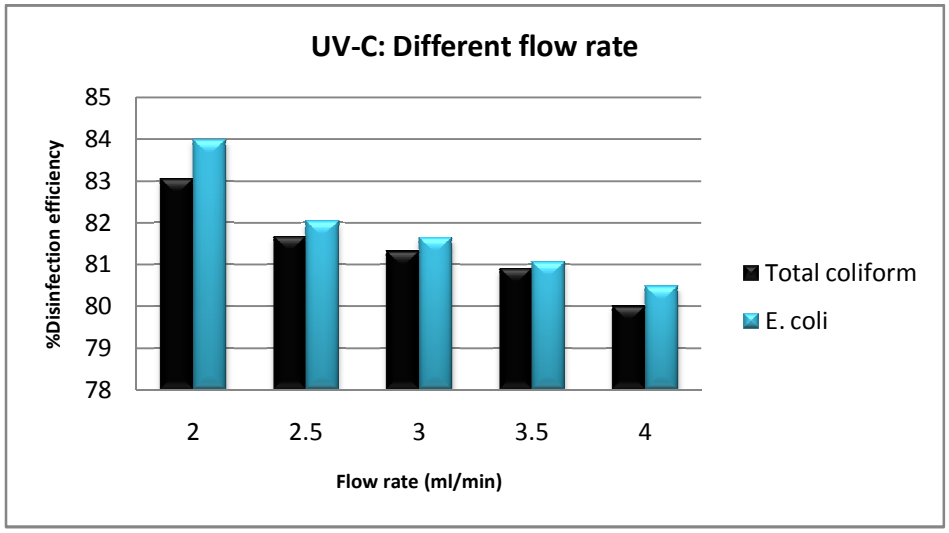


Figure 7 Effect of flow rate on disinfection efficiency

UV-A + TiO_2 immobilized on glass beads: The reactor was filled with TiO_2 coated glass beads and operated at different flow rates. Ganga canal water and Krishni river water was used as inlet and disinfection is as shown in figure 8.

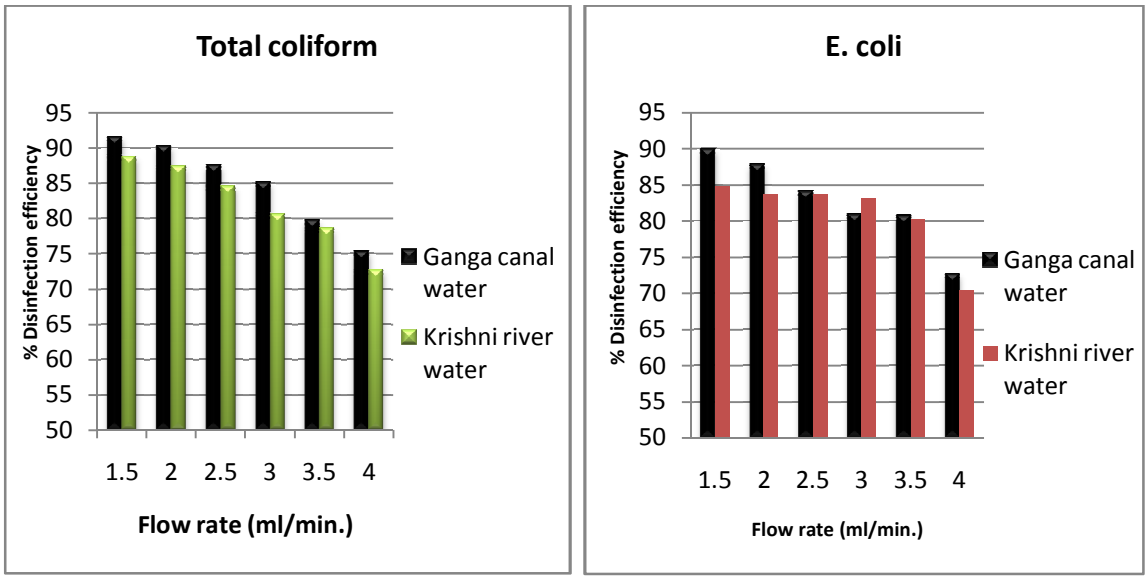


Figure 8 Difference in killing of total coliform and E. coli for Ganga canal water and Krishni water

Contribution of ROS during disinfection: Disinfection takes place due to formation of reactive oxygen species. Methanol (30mM) and tertiary butanol (1mM) were used to estimate the effect of the radical on coliform inactivation during disinfection as shown in figure 9 [4,5].

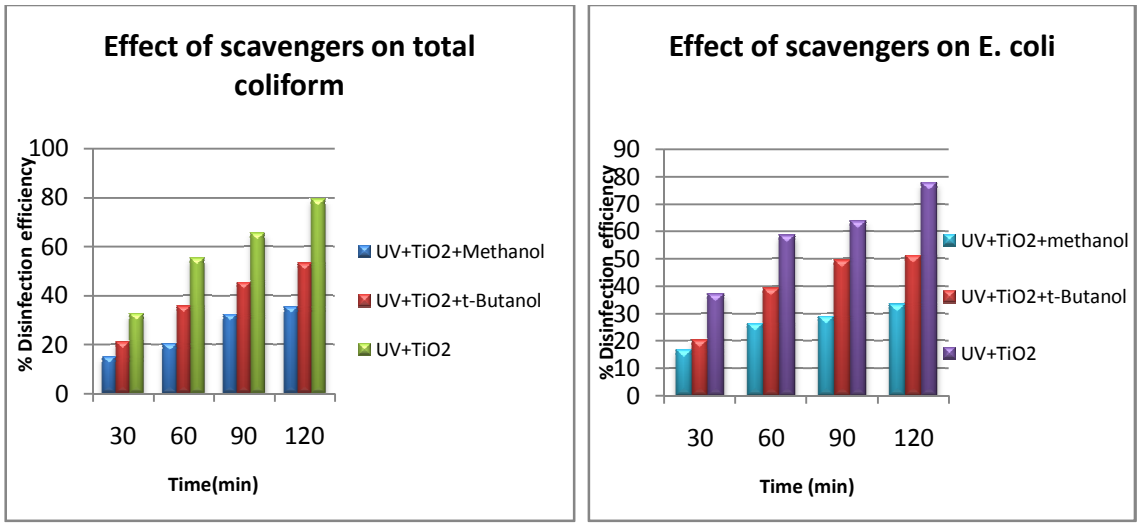


Figure 3.9 - Effect of methanol (30mM) and tertiary butanol (1mM) on total coliform and E. coli

4. CONCLUSION

Disinfection efficiency of UV-C alone is greater than that of titanium dioxide in the presence of UV-A radiation. Disinfection increases with increase in irradiation time and increase in concentration of TiO_2. When flow rate is increased disinfection decreases. Inhibition of disinfection is greater when methanol is added as compared to tertiary butanol. Disinfection efficiency of Krishni river water was lesser than Ganga canal water. Disinfection occurs when titanium dioxide was added to water in absence of light. This shows that not only ROS are responsible for disinfection.

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