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Disinfection of Water Using Photo Catalyst; Titanium Dioxide (TiO2)

Priyanka Patil
P.G. Research Scholar
Veermata Jijabai Technological Institute
Mumbai (M.S.) [INDIA]
Email: priyaankapatil10.6@gmail.com

Abhaykumar S. Wayal
Head & Associate Professor,
Civil and Environmental Engineering Department
Veermata Jijabai Technological Institute
Mumbai (M.S.) [INDIA]
Email: aswayal@vjti.org.in

ABSTRACT

Water purification was acquired using sunlight as the germicidal source, TiO_2 as a photocatalyzing agent, aluminum sulphate (alum) as a coagulant and MPN test to get bacterial count. Sunlight possesses a potential water disinfection property however period of irradiation required is lengthy. The efficiency of sunlight disinfection was significantly improved by the presence of powdered TiO_2. It has been observed that generation of hydroxyl free radicals (OH^- highly reactive species) in oxidation reaction by the photoactivation of TiO_2.The presence of powdered TiO_2 increased water turbidity, and even after leaving the sample to settle for a reasonably long time. This turbidity removed by the addition of alum and then allow it to settle. It is worthwhile noting, however, that the presence of alum alone did not change the solar disinfection capacity. This study gave optimum dose of TiO_2, optimum alum dose and contact time of complete disinfection of water.

Keywords:— *Water purification, Photocatalysis, Titanium Dioxide.*

I. INTRODUCTION

The World Health Organisation (WHO) estimates that 1.1 billion people is getting safe drinking water. Only about half the world's population can turn a tap on in their homes to get running water (Fadhil M. Salih 2014). For the other half, their water supply is often not treated and can carry harmful microorganisms.

Water is one of the main sources of disease transmission, which leads to about 6 million deaths per year. Accordingly, intensive investigations have been conducted and a number of solutions have been put into effect. Particularly, this problem has been under serious consideration by both WHO and UNICEF all over the world. In addition, other institutions consider water purification problem worldwide, and a number of solutions have been suggested (Salih 2014).

Among the many means of disinfection currently in use, sunlight has been suggested as having a promising role in improving water quality particularly in those regions that enjoy a conducive climate. To minimize water transmitted diseases, a cheap, accessible method of water purification is required. Among the methods of disinfection, sunlight has been having a promising role in improving water quality((Fujioca *et al*. 1981; Ciochetti and Metcalf 1984; Davies and Evison 1991; Conroy *et al*. 1996; McGuigan *et al*. 1998; Mcguigan *et al*. 1999; Reed, *et al*. 2000).

Chlorination is a commonly used for water disinfection to kill pathogen in water treatment plants. However, there are several disadvantages. During chlorination, harmful compounds known disinfection byproducts (DBP) are produced in water. DBPs contain carcinogens (i.e. trihalomethanes (THMs) and haloacetic acids (HAAs)). Therefore, alternative means of disinfection have been investigated and sunlight has been suggested as having an important role in disinfecting water. Sunlight is accessible, and does not require a large capita**.** However time required for such treatment is unreasonable. (V. Scuderi *et al.* 2015)

Research into environmental purification by using photocatalysts has produced a number of advances. Researches are increasing on the study of the development of photocatalysts for water purification by photosensitive oxide materials, like TiO_s. The concept of water disinfection involves the utilization of solar energy to oxidise water molecules for the production oxidising radicals, which attacks on cell membrane of micro-organisms in water. Titanium dioxide is used due to its high photocatalytic activity. (Saliby *et al.* 2014)

A photosensitive TiO_2 suspended in water reduced the time of light exposure required to induce disinfection. Similarly, TiO_2 was almost as effective as the powdered form. The effectiveness of semiconductors depends on their concentration and light intensity. However using TiO_2, would impose turbidity, hence alum is used (Salih 2014).

II. Titanium Dioxide

TiO_2 is the most commonly used semiconducting photocatalyst and one of the most studied nanoparticles for environmental applications.

TiO_2 photocatalysis is believed to act by the following mechanism-

i. When TiO_2 is illuminated at wavelengths of light less than 388 nm, an electron is excited from the valence band to the conduction band, leaving an electronic vacancy called hole (h_{vb}^+) in the valence band (Fig. 1)

ii. This hole then reacts with OH- ions in water and tends H_2O molecules to produce hydroxyl radicals (OH), one of the most powerful oxidizing agents known.

This photocatalytic oxidation process has been shown to successfully degrade a wide variety of organic contaminants, including trichloroethylene, THMs, pesticides, polychlorinated biphenyls (PCBs), and polyaromatic hydrocarbons (PAHs), into nontoxic compounds such as simple mineral acids, carbon dioxide, and water (Saliby *et al.* 2014). As a result, if TiO_2 photocatalysis is used to treat drinking water, it has the potential to degrade raw water contaminants as well as DBPs as they are being formed.

In addition, sunlight (which starts at a wavelength of 300 nm) can be used as the light source, which could allow this method to be a potentially inexpensive technique for degrading organic contaminants and disinfecting drinking water.

TiO_2 proved to be more safe and economical for treatment compared to chlorination, as it doesn’t gives DBP and can also treat organic pollutants at low capital investment.

For example, TiO_2 catalysts can be recycled indefinitely, requiring no additional chemical treatment, thus making its large-scale use (Matsunaga *et al*. 1985; Martiny 1988; Matsunaga *et al.* 1988; Watts *et al.* 1994; Bekbolet and Araz 1996; Herrera Melian 2000, Salih 2002).

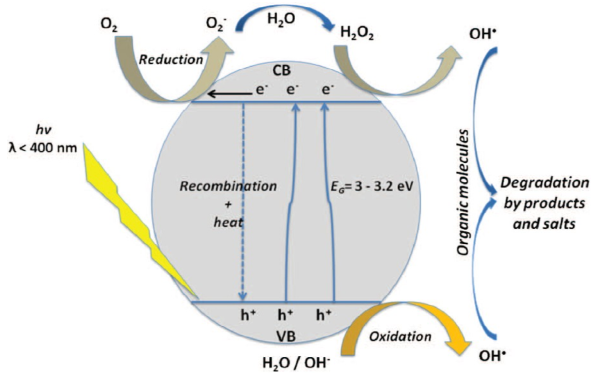

Figure 1: A Scheme of Photo-induced reactions occurring in the bulk and at the surface of a spherical TiO_2 particle (Saliby et al. 2014)

III. Literature Survey

Water purification is complicated procedure. It involves a number of steps, which are required in order for the purified water to meet the guidelines for potable drinking water. There is a continuous need to improve the procedure and to increase its efficiency.

Solar disinfection is limited by a number of factors that affects its efficiency. Usually exposure is relatively lengthy though the procedure is very simple. Attempts to reduce time of exposure have shown a noticeable success ((Fujioca *et al*. 1981; Ciochetti and Metcalf 1984; Davies and Evison 1991; Conroy *et al*. 1996; McGuigan *et al*. 1998; Mcguigan *et al*. 1999; Conroy et al. 1999; Reed, *et al*. 2000). However, further investigation is required to improve it. TiO2 can increase disinfection efficiency (Matsunaga *et al*. 1985; Martiny 1988; Matsunaga *et al*. 1988; Watts *et al*. 1994; Bekbolet and Araz 1996; Herrera Melian 2000, Salih 2002). It reasonably enhances disinfection. This enhancement was attributed to that the presence of TiO2 during exposure induced cell membrane damage, which leads to leakage of cellular components (Saito *et al*. 1992). The membrane damage is believed to be initiated by OH^- (Saito *et al*. 1992; Ireland *et al*. 1993; Salih 2002), which is produced by the photo reactivation of TiO2.

Titanium Dioxide is used as a catalyst which means it do not take part in the reaction and remained back in solution after reaction as it is insoluble in water it tends to settle down. Even though if accidently it get consumed by users, the toxicological data by using literature regarding the effects of TiO_2 as food additive is studied.

Titanium dioxide is known as "The environmental knight" due to its limited toxicity, inertness, and biocompatibility. The lethal dose at 50% concentration (LD_{50}) of titanium dioxide is greater than 10g/kg, and approved by Food and drug Administration (FDA). The FDA and Environment Protection Agency (EPA) have specified 50 μg/kg body weight/day of nano- TiO_2 ($nTiO_2$) as safe dose for humans (Title 21, volume 1, revised as April, 2014). Moreover, the European Expert Committee on Food Additives of the Food and Agriculture Organization/World Health Organization (JECFA), and the European Food Safety Authority (EFSA)'s Scientific Panel on Food Additives, Flavoring, Processing Aids and Materials in Contact with Food have approved the daily intake of nano-TiO_2 in general food stuff (Syed *et.al* 2017).

IV. Materials and Method

Samples were collected according to guideline recommended for sampling, IS-13969-2004. Ground water was used for testing as it was found contaminated. The area of study was selected as per convenience of collection of sample.

MPN test was used as the test to determine bacterial count. Tubes were incubated at 37°C for 24 hours and bacterial count was scored. Nephelometer was used to determine turbidity.

Solar exposure was usually made during a period extending from about 11 am to 1 pm. The selection of this period was based on sunlight intensity that was at its highest and the rate was almost consistent over the entire exposure period.

Photosensitive semiconductor, TiO_2 (anatase, crystal powder), was used as the photooxidizing agent. TiO_2 powder was first suspended in water.

Experiment was carried out in 3 sets-

i. Determination of optimum dose of alum.

A sample was collected and 3 tests with TiO_2 dose of 1.5 g/l, 2 g/l and 2.3 g/l were added in beakers containing 400 ml sample. For each test alum was added at concentration ranging between 40 to 120 mg/l, to samples irradiated for 120 minutes (prior to sunlight exposure).

Samples were then stored for 3 hours and their turbidity was checked. The effect of alum on turbidity produced by TiO_2 was studied and changes in turbidity of the supernatant were determined.

ii. Determination of effect of alum dose in disinfection process

The effect of alum in the disinfection process was studied by irradiating 5 different samples in presence and absence of optimum alum dose in the sample containing 0.5 g/l TiO_2.

iii. Determination of optimum dose of TiO_2 dose.

Beakers containing 400 ml sample, TiO_2 dose and optimum alum dose obtained in first set of experiment were exposed to sunlight for varying dosages from 0.5 g/l to 2.3 g/l for irradiation period chosen.

Reduction in MPN count in the presence of TiO_2 and optimum alum dose (obtained from first set of experiment) was determined to get complete disinfection.

V. Result and Discussion

Turbidity of the suspension with TiO_2 is very hard to remove by the conventional methods. However, the presence of alum at a concentration of as low as 40 mg/1 gradually removed turbidity in about 3 hours at room temperature. A plot representing the changes in turbidity is given in figure 2. Test 1, Test 2, Test 3 shows 3 different tests on same sample source collected freshly with TiO_2 dose 1.5 g/l, 2 g/l and 2.3 g/l respectively.

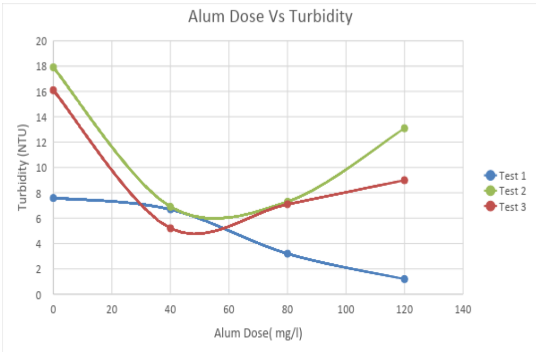

Figure 2: Plot of Alum dose vs Turbidity.

The effect of alum was studied in alum solutions of 40 mg/1. Moreover, alum did not induce any change in photosensitivity when sunlight exposure was carried out in the presence of alum of 40 mg of alum ml/1 as shown in Figure 3.

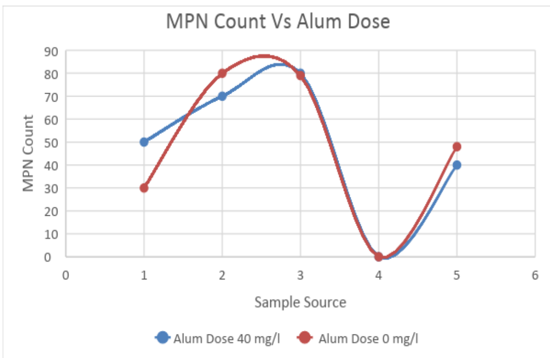

Figure 3: Plot of Effect alum in Disinfection.

From an experiment, Bacteria deactivation. Water exposed to sunlight experienced exponential loss in MPN count with the exposure obtained by conducting MPN test. When TiO_2 2.3.g/l was present, further reduction was observed. Alum dose of 40 mg/1 was present during sunlight exposure for settlement of TiO_2 particles. A plot representing disinfection at various dosages is shown in figure 4.

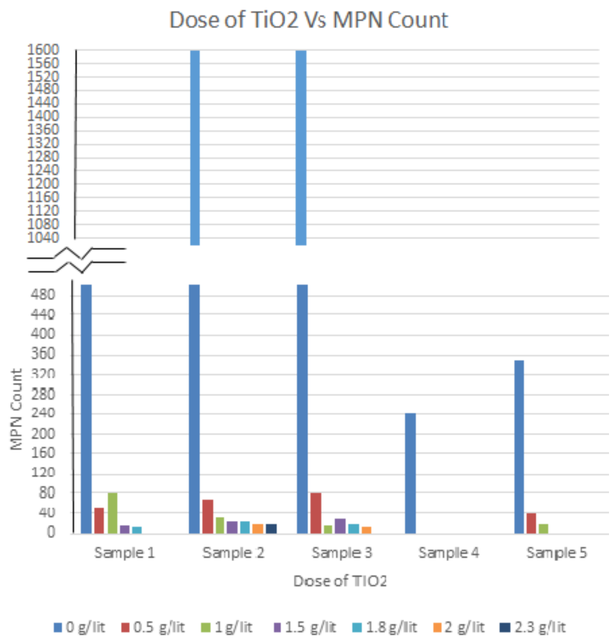

Figure 4: Plot of Disinfection of water with different TiO_2 Dose.

The presence of alum enhanced the clearance of turbidity particularly in the presence of TiO_2 (Figure 2). As TiO_2 is insoluble in water alum was added for coagulation, optimum dose of alum is obtained 40 mg/l. Thus optimum dose of alum is 40 mg/l, hence for further experiments this dose is fixed.

Alum was mixed during irradiation, thus question raised that do presence of alum affect the disinfection reaction. Hence test was conducted on 5 different samples with and without alum dose with 0.5 g/l of TiO_2 dose.

It is worthwhile noting, however, that the presence of alum alone did not change the solar disinfection capacity (Figure 3). This showed that alum does not take part as disinfectant or any role in oxidation reaction.

At various dose of TiO_2 disinfection was attempted and for complete disinfection 2.3 g/l of TiO_2 dose was obtained (Figure 4). Thus for this dose water get purified.

VI. Conclusion

Sunlight is an efficient disinfectant. Its efficiency can enhance by the presence of TiO_2. Thus from the study, results reflects that at 2.3 g/l dose of TiO_2 (anatase) at ground water sample source (containing a large quantity of pathogens) complete disinfection was obtained after treatment. Initial concentration of contaminants in water samples was varying at all sources hence this dose was fixed considering the maximum initial concentration of contamination. The dose of alum for coagulation of TiO_2 after disinfection was obtained 40 mg/l. The contact time of disinfection reaction is approximately 5 hours. It is also proved that presence of alum does not affect disinfection process. As photocatalysis technique using TiO_2 as a catalyst removes organic pollutants, heavy metals and nitrates along with bacteria, it is efficient as well as economical method.

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