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Advanced Photo-Oxidation Process for Treatment of River Water Pollutants and Pathogens

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Abstract: *Water is a fundamental resource for human civilisation, yet there is a critical water shortage happening all across the world in the twenty-first century. In some areas of underdeveloped nations, people drink water that has been extensively polluted and comes from rivers that are home to deadly diseases. Microbial infections in drinking water can cause illness and increase the prevalence of disease. There are several treatment methods available to remove microorganisms from drinking water. This study suggests employing two techniques, photocatalytic semiconductor and photo Fenton, as an enhanced oxidation process to get rid of diverse water impurities and offer a reliable water treatment approach. A test on samples of river water was undertaken, and the analysis of a number of parameters was used to determine how well the test had removed contaminants and pathogens. The physiochemical criteria were used to evaluate the reaction and determine the properties of safe water using both approaches. The two techniques effectively eliminated between 80 and 100 percent of the contaminants that were detected in the river sampled. Variations in Titanium Dioxide concentration correlated with changes in reactivity and degradation rates. Results showed that light absorption was reduced dramatically as titanium dioxide concentration rose to saturation. Besides, the rate of degradation was directly correlated with light intensity.*

Keywords: *Photo Fenton, Photocatalytic Semiconductor, Advanced Oxidation Process, Water Disinfection*

1. Introduction

Despite the fact that the globe has greatly evolved thanks to new technologies, there are still some nations in modern society where the demand for water is great. Water is essential for all forms of life, from industry to agriculture, but it is also essential for the health of the natural world. Therefore, it is crucial that the water be pure and devoid of impurities. A clean water supply has historically been a successful means of eradicating many different diseases. Due to factors including industrial and agricultural expansion, population growth, an increase in the average lifespan, and the long-lasting drought brought on by global warming, clean water sources are becoming increasingly scarce while demand is rising sharply in many parts of the world. One example of a short-term remedy being employed at the time to address this issue is an increase in the capacity for rainwater harvesting.

Unfortunately, both humanity and changing nature greatly pollute water. The food chain is impacted by contaminated water in a number of ways. Pollutants like lead and cadmium, which are frequently consumed by small animals, are then consumed by fish, disrupting the food chain at subsequent levels.

Point-source pollutants and non-point-source pollutants are two different categories of water contaminants. Non-point sources are the indirect releases of toxic substances into the environment, typically as a result of environmental changes, while point sources are the direct releases of poisonous substances into water bodies. Technology makes it simpler to monitor and manage point source pollution, whereas non-point source pollution is far more difficult to manage, for example, using ozone or UV treatment of water. The majority of the undesirable components in lakes and streams are caused by non-point sources of pollution.

2. Literature Review

2.1 Solar Photo-catalyst Properties

The development of advanced oxidation processes (AOPs) and substantial advances in wastewater technology are the results of various investigations. Due to their capacity to produce hydroxyl radicals (OH), AOPs are processes that allow the oxidation and breakdown of organic chemical compounds in a hydrous solution. Non-

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photochemical and photochemical processes are the two categories under which advanced oxidation processes (AOPs) fall. They can be utilised individually or in combination with many other types of conventional wastewater.

There are many types of AOPs, but the best one so far is photocatalytic oxidation (PCO), which involves the destruction of organic compounds by the shining of ultraviolet light or sun light onto a catalyst (for example Titanium Dioxide (TiO_2), Zinc Oxide (ZnO), Iron Oxide (FeO_3)) while at the same time avoiding the introduction of other chemicals. In this context, it could be said that a brand-new material should be used to destroy the unwanted constituents (fungus and bacteria) into non-harmful products with the help of solar light and UV lamps which will be used to excite the catalyst. Among the different types of catalyst, Titanium Dioxide (TiO_2) is by far the best for water treatment at present. TiO_2 is stable, affordable, environmentally-friendly, sustainable and nontoxic.

Titanium dioxide is advantageous for usage in locations like schools, restaurants, clinics, and hospitals because it produces hydroxyl radicals when exposed to light, which eliminate germs like bacteria and fungi. This catalyst greatly accelerates the photocatalytic reaction without producing an end product, which is a key component of its appeal (Wubbels, 1983). Additives are unneeded and help a wide range of pollutants that foul water at room temperature to photodegrade. Titanium dioxide has some drawbacks, including post-recovery particles or the inability to separate particles, as well as a limited adsorption capacity (Chekir et al., 2012). TiO_2 has been the most promising catalyst due to the following reasons:

- TiO_2 catalyst does not output any toxic products unlike other semiconductor catalysts.
- TiO_2 operates at ambient pressure and temperature.
- The mineralisation of parents is complete leaving no secondary pollution.
- Low operation cost.

Figure 1 depicts the TiO_2 photocatalytic degradation cycle. Through this interaction, different chemical compounds in contact with the titanium dioxide continuously degrade until they become harmless. Photo catalysis has a nearly permanent impact.

2.2.1 TiO_2 Water Disinfection Processes

Titanium dioxide (TiO_2), a compound semiconductor, naturally becomes a potent oxidant when exposed to any type of light, including UV rays or the sun (see Figure 2). The majority of naturally occurring or artificial substances can degrade with titanium dioxide (TiO_2), even at low concentrations, according to its peak oxidation properties (Castellote and Bengtsson, 2001).

Many electrons are concentrated in the bound region of semiconducting composites or compounds. To excite these electrons, a level of energy of at least 3.2 electron volts (eV) must be created. A quantum of light (hv) having a wavelength of less than or equal to 390 mm can provide the energy (3.2 eV). TiO_2 catalyst particles generate a hole (h^+) and charged linked electrons that are dissociated from the ion when exposed to UV radiation and sunshine. Free electrons (e^-) are what these are known.

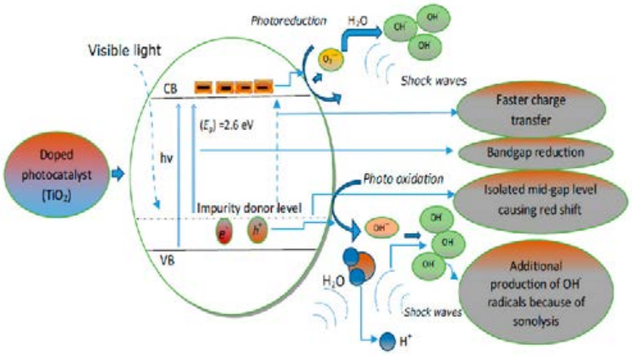

Figure 1. Light Radiating onto TiO_2 Causing Decomposition
Source: Adopted from Panda and Manickam (2017)

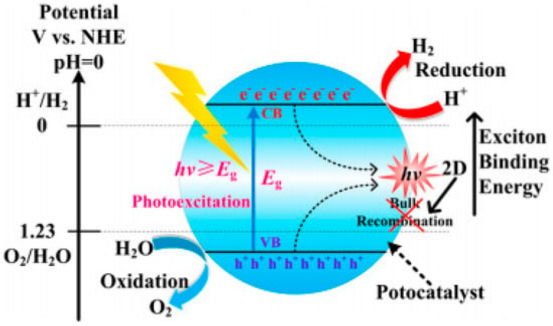

Figure 2. Photo Catalysis Operation on the Surface TiO_2
Source: Adopted from Su et al. (2018)

Once exposed to ultraviolet light (UV), TiO_2 valence band (vb) electrons (e^-) get excited and make their way to the conduction band (cb), thereby abandoning the hole (h^+), which has a positive charge (Mills et al., 1997). The excitement of valence band electrons under UV light, causing their movement from the hole to the conduction band, is termed photo-excitation and can be expressed as this reaction

$$TiO_2 + hv \gg TiO_2 + e^- + h^+ \tag{1}$$

Coupled e^- and h^+ from the process can join again to reseal the energy soaked in as heat. Holes (h^+) get into reactions with water (H_2O), forming hydroxyl radicals (OH), and simultaneously, natural compounds are oxidised. In the meantime, electrons also react with oxygen (O_2) to generate superoxide radicals (O_2) and carry out oxidation and the breakdown of organic matter reactions (Kang et al., 2007).

The reactions that form TiO_2 superoxide and hydroxyl radicals are as follows:

$$TiO_2(h+vb)+H_2O \gg OH^- + H^+ \quad (2)$$

$$TiO_2(h+vb)+OH^- \gg OH \quad (3)$$

$$TiO_2(e-cb)+O_2 \gg O_2^- \quad (4)$$

Where: *vb* is the valence band and *cb* is the conduction band.

According to Legrini et al. (1993), additional superoxide and hydroxyl radicals are produced, interact with contaminants, and experience oxidation, which causes them to decompose into water (H_2O) and carbon dioxide (CO_2). Due to the potent oxidising agents generated throughout the process, the TiO_2 photo catalytic process is an effective method for removing microorganisms and dissolving organic contaminants. TiO_2 is a much better and faster way to reduce microorganisms in wastewater because it has an excessively large surface area overall for the reaction. The main issue with this method, which adds to its complexity and time requirements, is the requirement to filter out more TiO_2 particles from the water, but this could easily be accomplished (Benjamin et al., 2013).

2.2 Solar Photo Fenton (SPF) Properties

2.2.1 Levels of Fe^{2+}

Prior research looked at the ideal iron concentrations required for a more efficient SPF response. The investigations examined the amounts of iron in pesticide-containing industrial wastewater. The tests were conducted using different dosages of the substance $7H_2O.FeSO_4$. The outcomes of these tests showed that increasing the concentration of Fe^{2+} to 2.4 mg/L was the ideal dose with a hydrogen peroxide concentration of 10:1 (Alalm et al., 2013).

2.2.2 Hydrogen Peroxide and the Fenton Process

A study looked at the various outcomes of the degrading activity when hydrogen peroxide was added to the sample. The pollutant samples received additions ranging in dosage from 30 mg to 180 mg. The greatest substantial removal activity occurred at a 10:1 ratio, when most contaminants were eliminated in 90 minutes by a dosage of 120 mg.

Too much water would prevent the reaction from proceeding. No additional water was needed. By using hydrogen peroxide, this study has the advantage of lowering the amount of water required for the reaction, which is very helpful when trying to be more affordable (Samet et al., 2012). However, there are many conditions where hydrogen peroxide has not been practical under UV conditions. Water has a very low molar extinction coefficient, and increasing the depth of the water quickly decreases the activity of the UV light energy.

The quantity of pollutants in the water generally affects the degradation. In a UV environment, hydrogen peroxide will be regarded as effective if the pollutants' concentration levels are low (Binnie, 2013).

2.2.2 Time

One study compares the degradation of the contaminants using sunlight against churning the sample to see which is more effective. The results showed that when stirring, 85% of COD was removed in less than half an hour; however, solar energy achieved a greater 91% COD removal rate, but the process took four times as long, or 120 minutes. In addition, churning was less efficient at removing chloropyrifos than solar light, with clearance rates only reaching 83% after 180 minutes of solar exposure compared to 60% after an hour of stirring (Ogier et al., 2008).

2.2.4 Solar Light Compared to UV Light

Previous research seems to suggest that when performing the SPF reaction, the effectiveness of each light source varies. They discovered parallel efficiency in both light forms when examining how the SPF reaction was utilised to discolour liquid tea. However, solar energy was favoured over ultraviolet light since it was less expensive to operate. Since the goal is to conduct the contact in the most cost-effective way possible, this is a crucial factor to take into account. The amount of energy was delivered to the polluted sample over time that was more significant than the reaction time (Sekine et al., 2012).

2.2.5 Improving the SPF Process Reaction

Titanium dioxide could improve the pace at which pollutants degrade in a sample after research into the impacts of adding specific compounds was conducted. The application of TiO_2 enhanced chloropyrifos degradation in the sample water by 27%, an improvement of 10% over the normal SPF response. It was discovered after testing several catalyst concentrations that 1.5-2.0 mg/l of titanium dioxide was the ideal amount (Alalm et al., 2013).

2.2.6 Cost-effective

In developing countries, significant expenditure on water treatment processes is not an option. This reaction needs to be extremely cost-effective. Previous studies have carried out a cost evaluation of the entire reaction and found ways to cut the expenditure. The results of these studies were extremely promising, as a reduction of 83.33% in reagent costs was achieved (Trivedy et al., 2009).

It would be expensive to treat water with advanced oxidation processes (AOPs) alone if the level of pollution is high. The SPF reaction would be adopted to decrease costs in the initial stage of the degradation process. Biological treatments would remove the remaining pollutants. In the preliminary oxidative procedure, the non-biodegradable and toxic compounds in the water would be removed. Subsequently, the remaining intermediates need to be removed with biological treatments (Trivedy et al., 2009).

3. Methodology

3.1 Experiment Procedure

Figure 3 shows the experimental setup for a solar photochemical reactor for both water and wastewater treatment. The setup was to record the photo-fenton reaction's performance when exposed to sunlight through the solar reactor's flowrates. The experiment procedure is as follows:

1) Compare the outcomes based on the levels of iron and sulphates,
2) Using TiO_2 to perform photocatalytic reactions in the presence of solar light,
3) Determine which approach is most efficient by measuring the rate at which contaminants are removed from the surface water system, and
4) Put improvements into practice to boost productivity.

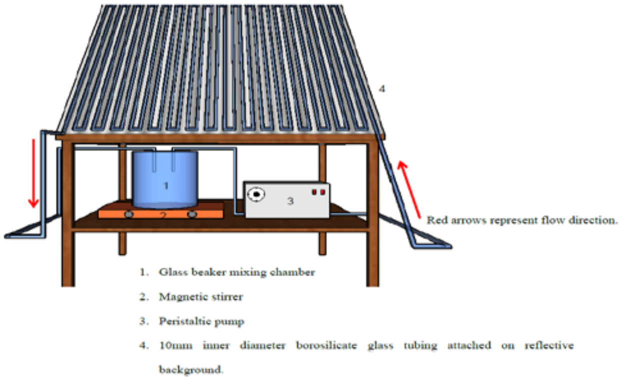

Figure 3. Experimental Setup for Solar Photochemical Reactor for Water and Wastewater Treatment

3.2 River Water Collection and Sampling

The Couva River in Trinidad was sampled twice a week for river water. Utilising technology and contrasting the water collected over a longer period of time are important issues. Any imaginable external effect can result in unexpected readings that can be corrected. For instance, certain pollutants released upstream may alter the water's properties.

3.3 Water Parameters

There are specific parameters that needs to be calculated to show how effective the reaction has been in removing the pollutants and to assess the integrity of the sample against standards established by the authorities. These parameters measure different elements of the sample to examine if there are any problems in the sample compared to the standardised water.

3.3.1 Phosphates

Phosphate is a crucial element that affects the growth of living things such as plants and animals and is essential for nutrition. It is important to moderate these physiochemical parameters since a high concentration of phosphate can lead to an increase in mineral and organic nutrients, which in turn leads to a reduction in the amount of dissolved oxygen in the water.

3.3.2 *Turbidity*

Turbidity is a measurement of a water sample's ability to transmit light. These tests evaluate the water discharge's quality in terms of residual and colloidal suspension problems. Colloidal matter absorbs light, making the difference in water samples under the same circumstances. Studying the amount of light scattered on a water sample reveals the presence of any colloidal matter.

3.3.3 Colour

The sample water taken from the two water sources can be coloured to identify its age. Specific properties relating to the age of the water would determine the smell and colour of the water sample. Fresh wastewater exhibits a pale grey hue when sampled.

3.3.4 Temperature

Temperature is an important factor when taking hygiene into account. In terms of biochemical reactions, a rise in temperature of 10 degrees Celsius can approximately double the reaction rate of bacteria with the uptake of oxygen, while cooling to low temperatures will destroy living bacteria as, without heat, the bacteria cannot survive. A key factor of temperature in water is that specific constituents (such as the concentration of dissolved oxygen) can be changed at different temperatures due to the ionisation of ammonia elements (Afgan et al., 2007).

3.3.5 Ammonia NH_3

Ammonia is typically found in modest amounts in natural water, but large amounts are extremely damaging to freshwater aquatic life.

3.3.6 Biochemical Oxygen Demand

The Biochemical Oxygen Demand (BOD) is a parameter that is routinely used in various forms of containment for surface and wastewater. This parameter measures the amount of dissolved oxygen to be consumed by the microorganisms within the wastewater sample. This occurs when the organic matter within the sample has undergone biochemical oxidation (Pizzi, 2011).

3.3.7 Chemical Oxygen Demand

The Chemical Oxygen Demand (COD) represents the amount of organic matter within a pollutant sample, which is very sensitive to the oxidation process when undergoing the SPF process. The definition of COD is the ‘total quantity of oxygen required to chemically oxidise the non-biodegradable and biodegradable organic matter'. The organic matter within the sample should be eliminated and transformed into water and carbon dioxide (Gautam, 2015).

3.3.8 pH Value

When determining whether a liquid is acidic or alkaline, the negative logarithm of the hydrogen ion concentration is employed to classify the pH (Letterman, 1999).

3.4 Experimental Methods and Results

3.4.1 River Water Collection

The given equipment was tested to ensure the safety of all those involved in the river water collection, and a risk assessment of the water collected was done in the beginning to account for any potential risks.

3.4.2 Solar Photo Fenton Experiment

All testing was done with 2.4 grams of iron and 12 litres of river water sample. Specifically, Tests 1, 2, 3 and 4 used 24 ml of 30% Hydrogen Peroxide. The piping system for Test 1 was flat, while all the other tests were done at an angle of 45 degrees. Other settings and conditions per test are described as follows:

- Test 1: Sunlight test: Flat piping system with 10:1 ratio.
- Test 2: Sunlight test: 10:1 ratio.
- Test 3: Sunlight test: 5:1 ratio. The difference in the lighting situation has had a substantial influence on the quantity of pollutants.
- Test 4: Sunlight test: 20:1 ratio.
- Test 5: Sunlight test: 10:1 ratio; Hydrogen Peroxide (6%): 24ml. The variation in concentration has dramatically reduced the reaction's abilities to remove the pollutants in comparison with 30% hydrogen peroxide.
- Test 6: Sunlight test: 5:1 ratio; Hydrogen Peroxide (6%): 12ml.
- Test 7: Sunlight test: 20:1 ratio; Hydrogen Peroxide (6%): 48ml.
- Test 8: Sunlight test: 2:1 ratio (Iron: Alum); Hydrogen Peroxide (6%): 48ml
- Test 9: Sunlight test: 5:1 ratio (Iron: Alum); Aluminium Sulphate: 12g Hydrogen Peroxide (6%): 48ml

The results of the tests 1 to 9 are summarised in Table 1, after 120 minutes. The percentage removal of parameters is depicted in Figure 4, with 10:1 ratio of 6% sunlight and 30% sunlight.

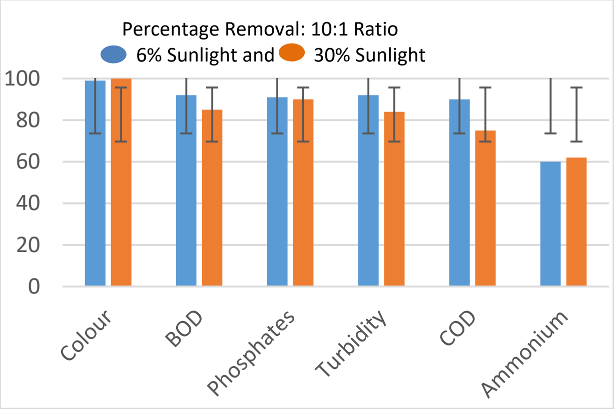

Figure 4. Percentage Removal of Parameters Using 10:1 Ratio of 6% Sunlight and 30% Sunlight

3.4.3 Solar Photocatalytic Semiconductor Experiment

The testing was done using 10 litres of river water sample with varying Titanium Dioxide concentration. Results for Tests 1-4 are depicted in Tables 2-5, respectively.

Table 2. Test 1 Mean Results from Sunlight + 0. 2g/L TiO_2 Test

Minutes	0	60	120	180	240
Colour	500	197	155	45	35
BOD	42.00				1.52
Turbidity	61.35	36.27	28.29	23.95	17.42
PH	7.20	7.40	7.50	7.60	7.70
Phosphates	0.41	0.17	0.12	0.09	0.05
COD	82.41	14.31	5.69	5.51	4.47
Nitrite (NO_3)	0.87	0.12	0.13	0.09	0.07
TDS (ppm)	935.00	881.00	875.00	868.00	860.00

Table 3. Test 2 Mean Results from Sunlight + 0. 5g/L TiO_2 Test

Minutes	0	60	120	180	240
Colour	500	135	32	25	15
BOD	43.00				1.63
Turbidity	61.35	18.27	16.29	14.95	11.22
PH	7.20	7.50	7.80	7.90	7.90
Phosphates	0.41	0.16	0.12	0.09	0.05
COD	82.41	12.31	11.69	9.51	6.47
Nitrite (NO_3)	0.87	0.76	0.62	0.59	0.47
TDS (ppm)	935.00	929.00	910.00	901.00	814.00

Table 1. Average Results for Test 1 to 9 after 120 Minutes

Test #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Colour	5	3	12	16	2	28	26	4	8
BOD	4.81	4.55	5.95	5.15	6.35	8.32	9.32	2.52	3.52
Turbidity	2.64	7.10	3.44	0.42	2.42	8.42	6.42	0.72	8.72
PH	6.90	7.10	7.20	6.80	6.40	6.40	6.40	7.00	7.00
Phosphates	0.08	0.04	0.14	0.05	0.09	0.22	0.15	0.06	0.06
COD	4.74	4.74	5.74	11.77	12.77	19.77	11.77	0.47	0.87
Ammonium	3.64	3.61	3.21	3.41	3.11	5.11	4.11	5.16	5.06

Table 4. Test 3 Mean Results from Sunlight + 1g/L TiO$_2$ Test

Minutes	0	60	120	180	240
Colour	500	85	18	16	7
BOD	43.00				1.68
Turbidity	61.35	16.28	15.25	11.95	7.50
PH	7.20	7.60	7.80	7.90	7.90
Phosphates	0.41	0.36	0.31	0.28	0.26
COD	82.41	16.38	14.69	12.51	10.17
Nitrite (NO$_3$)	0.87	0.72	0.65	0.58	0.36
TDS (ppm)	935.00	852.00	848.00	785.00	630.00

. **Table 5.** Test 4 Mean Results from Sunlight + 2g/L TiO$_2$ Test

Minutes	0	60	120	180	240
Colour	500	16	12	10	8
BOD	43.00				2.23
Turbidity	61.35	13.68	11.25	8.75	6.50
PH	7.20	7.60	7.70	7.90	7.90
Phosphates	0.41	0.38	0.35	0.31	0.29
COD	82.41	16.23	14.29	10.41	9.13
Nitrite (NO$_3$)	0.87	0.52	0.45	0.38	0.25
TDS (ppm)	935.00	710.00	667.00	645.00	607.00

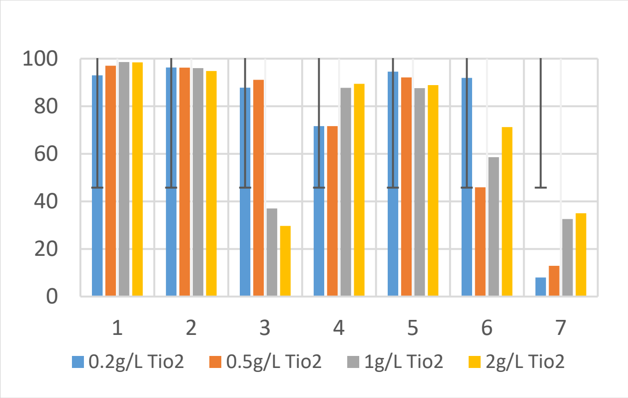

Figure 5. Percentage Removal with Different Concentrations of TiO$_2$

4. Analysis

4.1 Solar Photo Fenton Kinetics

The main presumption is that a 30% concentration of hydrogen peroxide would be sufficient to remove the contaminants in accordance with the literature review. Even in the climate that was present, the sample yielded the expected results. The effectiveness of the reaction, however, was significantly influenced by the light source.As revealed by earlier studies, the 10:1 ratio proved to be the most effective during testing for eliminating the degradants. When used in conditions with sunlight, hydrogen peroxide at a 30% concentration can eliminate the bulk of contaminants. However, when the experiment was repeated with hydrogen peroxide at a 6% concentration, it was less successful and significant amounts of physiochemical parameters were still present in the sample.

The optimum concentration of hydrogen peroxide cost more than twice as much as the 6% concentration when the price differential is taken into consideration. This puts a lot of pressure on the technology's ability to be both economical and useful. Therefore, the goal was to achieve the same effects at 30% concentration utilising only 6% hydrogen peroxide. The elimination of degradants between 30% and 6% with aluminium sulphate is comparable with particular physiochemical characteristics, as indicated in Table 6. When comparing the original 6% and the 6% with aluminum sulfate, the coagulant's impact on the peak findings was highly noticeable. When the concentration of iron sulfate to aluminium sulfate was increased from the 2:1 concentration, it seemed to be less active. Pollutant reduction is significantly hampered by dosage increases of 5:1 and 10:1. The findings of coagulation supplementation demonstrated high elimination activity despite the varying amounts of sun exposure that were seen during testing in external settings. Another element that needs to be taken into account is the experiment's overall settlement term. This happens because iron is a reaction by-product. It is necessary to separate the sample from the iron that has impurities attached.

4.2 Solar Photocatalytic

4.2.1 Effect of Initial Concentration

Concentration photo degradation of the river water was implemented at different concentrations ranging from 0.2, 0.5, 1.0, and 2.0 g/L. The results show that the rate of deterioration increased with increased concentration until it reached the plateau stage.

From the first test, turbidity was very bad even after 240 minutes, and colour was not good either, but this sample, which was collected from the river, contained a high level of colour and turbidity to begin with. Despite the poor turbidity and colour, there was a rapid decrease in COD from 82.41 mg/L to 14.31 mg/L during one hour; hence, an 82.6% reduction in COD was achieved. Although the water was clearly non-toxic after treatment, it was not aesthetically pleasing.

The second test showed turbidity and colour were partially improved but still well below the maximum WHO drinking water guidelines. Generally, this experiment was better than the first test (0.2 mg/L concentration).

The third experiment was very positive and produced the best solar results. The water was cloudy, and the BOD and COD reductions were worse than in the previous concentration of the experiment. Turbidity and colour were partly better, proving the hypothesis that colour and turbidity decrease when permitted to settle over a period of time.

The results for the fourth experiment indicated that the first hour of the test saw a slight degradation rate, and after 3 hours, most of the values obtained were higher than the 0.1 mg/L concentration.

Overall, it can be inferred from the tests that the Titanium Dioxide amount was proportional to the reaction

Table 6. Optimal Results with Mean Water Quality Parameters from Experimental Tests

	Physiochemical Parameters	Time (Minutes)				
		0	**30**	**60**	**90**	**120**
1	Ammonium 6%	8.31	7.95	5.82	4.91	3.11
	pH	6.2	6.2	6.3	6.3	6.4
	COD 6%	50.71	35.32	24.69	17.51	12.77
	Phosphates 6%	0.574	0.213	0.180	0.146	0.089
	Turbidity 6%	27.35	13.27	8.21	4.43	2.42
	Colour	314	32	13	8	2
2	Ammonium 30%	9.21	7.15	5.32	4.11	3.61
	pH	6.1	6.3	6.7	7.1	7.1
	COD 30%	51.31	25.35	18.69	8.51	4.74
	Phosphates 30%	0.474	0.233	0.212	0.176	0.039
	Turbidity 6%	29.25	12.61	6.54	4.43	2.24
	Colour	290	38	12	6	3
3	Ammonium 6% with Al	9.31	8.93	7.25	5.91	5.16
	pH	6.3	6.4	6.7	7.0	7.0
	COD 6% with Al	52.71	16.31	9.69	2.51	0.47
	Phosphates 6% with Al	0.474	0.263	0.118	0.046	0.059
	Turbidity 6% with Al	28.35	12.27	7.29	2.41	0.72
	Colour	343	24	15	7	4
4	Ammonium 6%	8.31	7.95	5.82	4.91	3.11
	pH	6.2	6.2	6.3	6.3	6.4
	COD 6%	50.71	35.32	24.69	17.51	12.77
	Phosphates 6%	0.574	0.213	0.180	0.146	0.089
	Turbidity 6%	27.35	13.27	8.21	4.43	2.42
	Colour	314	32	13	8	2
5	Ammonium 30%	9.21	7.15	5.32	4.11	3.61
	pH	6.1	6.3	6.7	7.1	7.1
	COD 30%	51.31	25.35	18.69	8.51	4.74
	Phosphates 30%	0.474	0.233	0.212	0.176	0.039
	Turbidity 6%	29.25	12.61	6.54	4.43	2.24
	Colour	290	38	12	6	3
6	Ammonium 6% with Al	9.31	8.93	7.25	5.91	5.16
	pH	6.3	6.4	6.7	7.0	7.0
	COD 6% with Al	52.71	16.31	9.69	2.51	0.47
	Phosphates 6% with Al	0.474	0.263	0.118	0.046	0.059
	Turbidity 6% with Al	28.35	12.27	7.29	2.41	0.72
	Colour	343	24	15	7	4

and degradation rate until it got to the point when the latter became constant and then started to significantly decline. The absorption of light (photons) coefficient often falls dramatically as the Titanium Dioxide amount increases up to saturation point (creating a high turbidity scenario). A reactor's surface area exposed to the photo catalyst is decreased when too much Titanium Dioxide is added because excess titanium dioxide particles have a tendency to shade the reactors.

This problem can be resolved by operating the photo reactors below the saturation point of the photo catalyst and combining the Titanium Dioxide with a sample of wastewater that must be processed to make a solution before introducing it to the reactors.

4.2.2 Effect of Light Intensities

Intensity of light has an inverse relationship with rate of deterioration. Although the difference in degradation rates became exceedingly minor after a certain point, greater light intensities did produce increased degradation rates. At increasing light intensity, electron holes are created.

More electron holes were produced as light intensity rose from noticeably lower levels. However, this grew more steady and gradual when the light intensity peaked, with little change in the rate of disintegration. Due to the collisions and recombination of electron holes with the separation of electron holes, the resulting light intensity and rate of deterioration decreased (Chong et al., 2010).

5. Conclusion

According to the solar fenton test results, a 10:1 ratio is the most effective for eliminating the degradants. When used in conditions with sunlight, hydrogen peroxide at a 30% concentration can eliminate the bulk of contaminants. However, when the experiment was repeated with hydrogen peroxide at a 6% concentration, it was less successful and significant amounts of physiochemical parameters were still present in the sample. On particular physiochemical criteria, the elimination of degradants by aluminium sulphate ranges between 30% and 6%. It appeared less active when the ratio of Iron Sulphate to Aluminium Sulphate was increased compared to the 2:1 concentration. The solar photo fenton experiments managed to remove within 80-

100 percent of pollutants measured from the river samples.

It was evident from the findings that the rate of degradation accelerated with rising Titanium Dioxide concentrations until it reached the plateau stage. The absorption of light (photons) coefficient often falls very dramatically as the Titanium Dioxide amount increases up to saturation point (creating a high turbidity scenario). The rate of deterioration is inversely related to light intensity. Increased light intensities caused increased degradation rates, although after a certain point, the difference in degradation rates would become small. On the other hand, solar photocatalytic semiconductors have their disadvantages. However, their positives are greater than their negatives.

Another issue with the climate was the temperature; as previous studies have indicated a higher temperature assists the degradation rate, which was absent when conducting the external tests under solar radiation. Therefore, when implementing this technology in the targeted countries, the outcome will be either improved, or somewhat similar but achieved in less time.

Moreover, compact procedures, very low chemical doses that result in fewer chemical residues and quicker reaction times are some of the benefits. Operational costs, the non-specific reactivity of hydroxyl radicals, and the production of biodegradable dissolved organic carbon (BDOC) are drawbacks. Utilising titanium dioxide for photo catalysis is a successful method of treating wastewater. For this technology to work as intended, intense light must be present constantly.

The study of solar photo fenton and photocatalytic semiconductors has proved to be effective by achieving the targets that were originally set. The reaction has been improved and made more affordable, which is crucial in restoring river water in developing countries to remove the threat that more than 500 million people suffer in these countries.

Graphene-based photo catalysts have gained significant attention in the wastewater treatment process due to their exceptional physical, chemical, and mechanical capabilities. This is a topic for further study. Since graphene exhibits exceptional electron conductivity, there are a wide range of light absorption, a large surface area, and a high adsorption capacity in the graphene-based photo catalyst. It would significantly increase the photocatalytic activity toward the photo degradation of pollutants when integrated into metals, metal-containing nanocomposites, semiconductor nanocomposites, polymers, MXene, and other compounds.

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