

To Study the Effectiveness of Solar Radiation for Advanced Oxidation Process

¹Kavita N. Choksi, ²Jinal R. Jobanputra, ³Sejal K. Bhatt,

^{1,3}Assistant Professor, ²P.G Student

1 Civil Engineering Department,

^{1,3} Shree Swami Atmanand Saraswati Institute of Technology, Surat, Gujarat, India

² S.V.N.I.T, Surat, Gujarat, India

Abstract—The main goal of the present study is to enlarge the existing knowledge in advanced oxidation processes application for water and soil decontamination. Advanced oxidation processes, which involve the in situ generation highly potent chemical oxidants such as hydroxyl radical, have recently emerged as an important class of technologies for accelerating the oxidation and destruction of a wide range of organic contaminants in polluted water and soil. Advanced Oxidation Processes (AOPs) that rely on the efficient generation of reactive radical species increasingly attract greater interest with respect to their application to water remediation from a wide variety of organic micropollutants concerning human health or the environment. Advanced Oxidation Processes for Water Treatment covers the key advanced oxidation processes developed for chemical contaminant destruction in polluted water sources, some of which have been implemented successfully at water treatment plants around the globe. The main focus is to suggest the effectiveness of solar radiation for Advanced Oxidation Process.

Index Terms—Advanced Oxidation Process, Endocrine Disrupting Chemicals, Photocatalyst, Solar Collectors

I. INTRODUCTION

The presence of trace organics including fertilizers, insecticides, pharmaceutically active compounds (PhACs), endocrine disrupting chemicals (EDCs), and various industrial compounds in the aquatic environment is of great concern due to their potential adverse effects on human health and the ecosystem. These compounds, referred as refractory organic compounds (ROCs) prevail in municipal wastewater as well as surface water in the range of up to several $\mu\text{g/L}$ due to the industrial or agricultural discharges. They have been suspected to be associated with altered reproductive function in males and females; increased incidence of breast cancer, abnormal growth patterns as well as changes in immune function. Therefore, it is essential to effectively remove these contaminants to protect the environment and drinking water resources. However, conventional treatment processes like coagulation, filtration or activated sludge process prove inefficient for complete removal of ROCs owing to their low biodegradability. The recent progresses in the decontamination of water concern the treatment of such compounds. These methods rely on the formation of highly reactive chemical species, which degraded the more recalcitrant molecules into biodegradable compounds. These are called the advanced oxidation processes (AOPs).

AOPs are based on the production of free hydroxyl radicals ($\cdot\text{OH}$) that facilitate the conversion of organic pollutants to less harmful and more biodegradable compounds. A chemical agent such as hydrogen peroxide, ozone or metal oxide is required along with an energy source such as ultraviolet-visible radiation, electric current, gamma-radiation or ultrasound for production of hydroxyl radicals. The following are frequently applied AOPs:

Fenton oxidation: It involves reactions of hydrogen peroxide (H_2O_2) in the presence of iron to generate hydroxyl radicals. Ultraviolet light enhances this generation by photo reduction of Fe (III) to Fe (II); referred as photo-fenton oxidation.

Ozonation: Formation of hydroxyl radicals due to ozone decay in the water. H_2O_2 enhances the rate of decomposition; referred as perzonation.

Photolysis: Breakdown of a compound is achieved through photochemical transformation by the absorption of light, the source being natural (sunlight) or artificial (UV mercury lamps). **Photocatalysis:** It is the acceleration of a photochemical transformation by the action of a catalyst. Fenton oxidation and ozonation involve the use of expensive chemical agents like H_2O_2 and O_3 and hence uneconomical. Photochemical transformations are environment friendly and sustainable as solar energy can be used. This study focuses on heterogeneous photocatalysis employing semiconductor catalysts (TiO_2 , ZnO , Fe_2O_3 , CdS , GaP and ZnS) using solar irradiation.

II. MECHANISM OF HETEROGENOUS PHOTOCATALYSIS

The illumination of semiconductors by adsorption of photons of energies greater than or equal to the band gap energy of semiconductor results into photo-excitation of an electron from valence band to conduction band. For TiO_2 the band gap energy is 3.2 eV (anatase) or 3.0 eV (rutile) and the light wavelength for such energy corresponds to lesser than 400 nm. The photonic excitation (Eq. 1) leaves behind a positive hole in valence band (hVB^+) and an electron in conduction band (eCB^-); thus creating the electron-hole pair. If charge separation is maintained, the electron and hole may migrate to the catalyst surface where they participate in redox reactions with adsorbed species. Specially, hole may react with surface-bound H_2O or OH^- to produce the

hydroxyl radical and electron is picked up by oxygen to generate superoxide radical anion ($O_2^{\cdot-}$), as indicated in the equations 2 & 3;

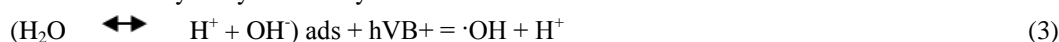
Photonic excitation:



Reduction of adsorbed O_2 by electron:



Generation of hydroxyl radical by hole:



It has been suggested that the hydroxyl radical ($\cdot OH$) are the primary oxidizing species in the photocatalytic oxidation processes. Degradation of organic pollutants is attained through oxidation by $\cdot OH$ radicals or by the hole itself;



Or direct reaction with the hole;



The adsorbed O_2 prevents the recombination of electron-hole pair (Eq. 2) and thus is referred as electron scavenger. In the absence of electron scavengers, the photo excited electron recombines with the valence band hole in nanoseconds with simultaneous dissipation of heat energy. Thus, the presence of electron scavengers is vital for prolonging the recombination and successful functioning of photo catalysis.

III. TYPES OF PHOTOCATALYSTS

A substance which is activated by adsorbing a photon and is capable of accelerating a reaction without being consumed is referred as photo catalysts. These substances are invariably semiconductors. Semiconductor materials are materials whose valence band and conduction band are separated by an energy gap or band-gap characterized by filled valence band and empty conduction band. An ideal photo catalyst should possess the following properties (i) photo activity, (ii) biological and chemical inertness, (iii) stability towards photo corrosion, (iv) suitability towards visible or near UV light, (v) low cost, and (vi) lack of toxicity. Table 1 provides the band gap energies at corresponding wavelength for well known semiconductors.

Among these, Titanium dioxide (TiO_2) stands out as the most effective photo catalyst and has been extensively used in water and wastewater treatment studies due to the stability of its chemical structure, biocompatibility, physical, optical and electrical properties.

Table 1: Types of Photo catalysts

Semiconductor	Band gap energy (eV)	Wavelength
TiO_2 (rutile)	3.0	413
TiO_2 (anatase)	3.2	388
ZnO	3.2	388
ZnS	3.6	335
CdS	2.4	516
Fe_2O_3	2.3	539

(1)

TiO_2 is also known as titania, titanic oxide, titanium white, titanic anhydride, or titanic acid anhydride. It exists in four mineral forms viz: anatase, rutile, brookite and titanium dioxide (B) or TiO_2 (B). Anatase type TiO_2 has a crystalline structure that corresponds to the tetragonal system (with dipyramidal habit) and is used mainly as a photocatalyst under UV irradiation. Rutile type TiO_2 also has a tetragonal crystal structure (with prismatic habit). This type of titania is mainly used as white pigment in paint. Brookite type TiO_2 has an orthorhombic crystalline structure. TiO_2 (B) is a monoclinic mineral and is a relatively newcomer to the titania family. TiO_2 , therefore is a versatile material that has applications in various products such as paint pigments, sunscreen lotions, electrochemical electrodes, capacitors, solar cells and even as a food coloring agent and in toothpastes.

The possible application for this material as a photocatalyst in a commercial scale water treatment facility is due to several factors:

(a) Photocatalytic reaction takes place at room temperature.

(b) Photocatalytic reactions do not suffer the drawbacks of photolysis reactions in terms of the production of intermediate products because organic pollutants are usually completely mineralized to non-toxic substances such as CO_2 , HCl and water.

(c) The photocatalyst is inexpensive and can be supported on various substrates such as, glass, fibers, stainless steel, inorganic materials, sand, activated carbons, and allowing continuous re-use.

(d) Photogenerated holes are extremely oxidizing and photogenerated electrons reduce sufficiently to produce superoxides from dioxygens.

IV. TYPES OF SOLAR COLLECTORS

Contrary to solar thermal processes, which are based on the collection of large quantities of photons of all wavelengths to reach a specific temperature range, solar photochemical processes are based on the collection of only high-energy short-wavelength photons to promote photochemical reactions. Most of the solar photochemical processes use UV or near-UV sunlight (300–400 nm). Nevertheless, the specific hardware needed for solar photochemical applications has much in common with those used for thermal applications. As a result, both photochemical systems and reactors have followed conventional solar thermal collector designs, such as parabolic troughs and non-concentrating collectors. At this point, their designs begin to diverge, since:

- The fluid must be directly exposed to solar radiation and, therefore, the absorber must be transparent to the photons, and
- Temperature usually does not play a significant role in photochemical processes, so no insulation is required.

Concentrating Collectors

Solar photoreactors for photochemical applications were originally designed for use in line-focus parabolic-trough concentrators. This was in part because of the historical emphasis on trough units for solar thermal applications. Furthermore, PTC technology was relatively mature and existing hardware could be easily modified for photochemical processes. There are two types of PTCs: a) One-axis parabolic trough and b) Two-axis parabolic trough.

The first engineering-scale solar photochemical facility to water detoxification was developed in 1989 by Sandia National Labs (USA) using one-axis PTCs and the second by CIEMAT in 1990 (Spain) using two-axis PTCs. Both facilities are considerably large pilot plants (hundreds of square meters of collecting surface) and can be considered the first steps in industrialization of the photochemical processes.

Two-axis PTCs consist of a turret on which there is a platform supporting several parallel parabolic trough collectors with the absorber in the focus. The platform has two motors controlled by a two-axis (azimuth and elevation) tracking system. Thus the collector aperture plane is always perpendicular to the solar rays, which are reflected by the parabola onto the reactor tube at the focus through which the contaminated water to be detoxified circulates.

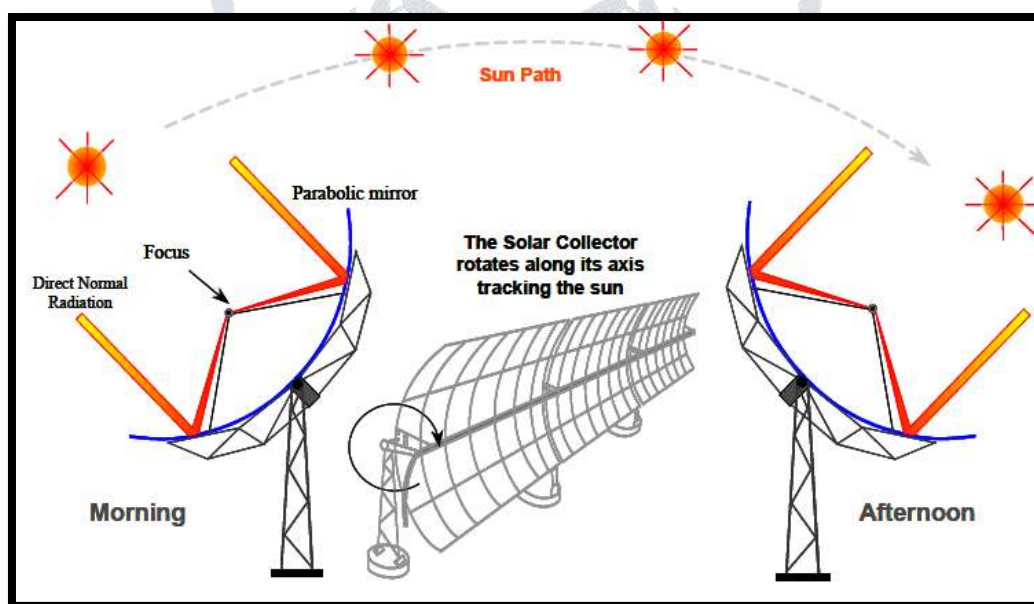


Figure 1: Solar ray reflection on a one-axis parabolic trough collector

One-axis PTCs have only one motor and a one-axis solar-tracking system; the reactor tube (linear focus of the parabola) is then positioned in the same plane containing the normal vector of the collector aperture plane and the solar vector. The angle formed by these two vectors is called the incident angle of solar radiation.

Parabolic-trough collectors make efficient use of direct solar radiation and, as an additional advantage; the thermal energy collected from the concentrated radiation could simultaneously be used for other applications. The reactor is small, while receiving a large amount of energy per unit volume. The flow is turbulent and volatile compounds do not evaporate, so that handling and control of the liquid to be treated is simple and cheap. The main disadvantages are that the collectors (i) use only direct radiation, (ii) are expensive, and (iii) have low optical and quantum efficiencies (at least for TiO_2 applications)

Non-Concentrating Collectors

One-sun (non-concentrating) collectors are, in principle, cheaper than PTCs as they have no moving parts or solar tracking devices. They do not concentrate radiation, so that efficiency is not reduced by factors associated with concentration and solar tracking. Manufacturing costs are cheaper because their components are simpler, which also means an easy and low-cost maintenance. Also,

the non-concentrating collector support structures are easier and cheaper to install and the surface required for their installation is smaller, because, since they are static, they do not project shadows on the others.

Although one-sun collectors are simple, the design of a robust one-sun photoreactor is not trivial, since they must be weather-resistant, chemically inert and UV-transmissive. In addition, flow in non-concentrating systems is usually laminar, which presents mass transfer problems and vaporization of reactants. Consequently, the use of tubular photoreactors has a decisive advantage because of the inherent structural efficiency of tubes, which are also available in a large variety of materials and sizes and are a natural choice for a pressurized fluid system.

Compound Parabolic Concentrator (CPC)

CPCs, extensively employed for evacuated tubes, are an interesting cross between trough concentrators and one-sun systems and are a good option for solar photochemical applications. CPCs are static collectors with an involute reflective surface around a cylindrical reactor tube (Fig. 2). They have been found to provide the best optics for low concentration systems and can be designed with a concentrating ratio close to one, thus having the advantages of both PTCs and one-sun collectors since these static collectors can capture both direct and diffuse UV-sunlight.

The beauty of the solar CPC system is its intrinsic simplicity, while it is also cost-effective, easy to use, and requiring low capital investment. The reflector design enables almost all the UV-radiation arriving at the CPC aperture (not only direct, but also diffuse) to be collected and available to the process in the reactor. The light reflected by the CPC is distributed around the back of the tubular photoreactor so that most of the reactor tube circumference is illuminated. Because of the CPC aperture-to-tube diameter ratio, the incident light on the reactor is very similar to that of a one-sun photoreactor. As in a parabolic trough, water is easier to pipe in and to distribute than in many one-sun designs. All these factors contribute to excellent CPC collector performance in solar photochemical and photocatalytic applications.

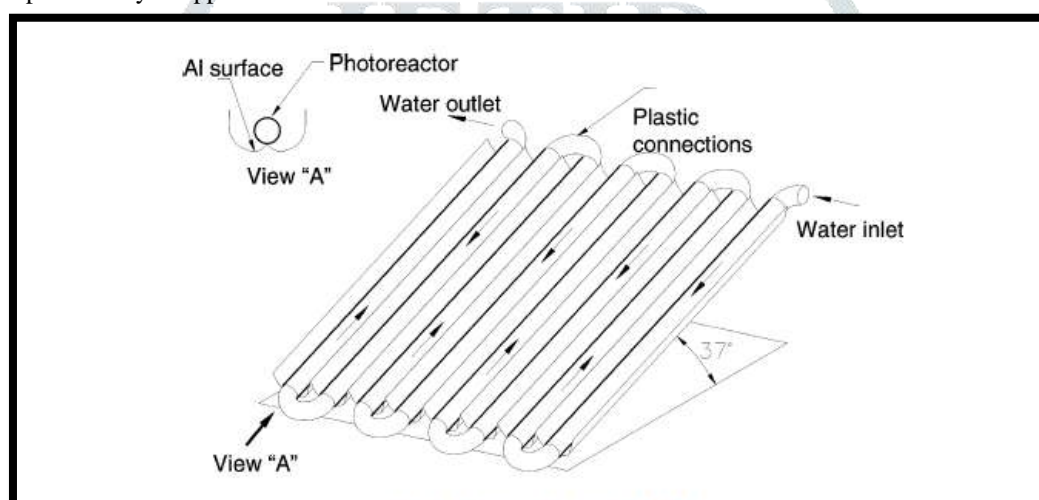


Figure 2: Compound parabolic concentrator

V. SOLAR COLLECTOR CONFIGURATION

Absorber Tube

The photochemical reactor must contain the working fluid, including the catalyst and must transmit solar UV-light efficiently with minimal pressure-drop across the system. It must also provide good mass transfer from the fluid stream to an illuminated photocatalyst or a sensitizer surface. An adequate flow distribution inside the reactor must be assured, since a non-uniform distribution leads to a non-uniform residence time inside the reactor and to a decreased performance compared to that of an ideal flow. The choice of materials that are both transparent to UV-light and resistant to its destructive effects is limited. Temperatures inside solar photochemical reactors can easily reach 40–50 °C. Therefore, photochemical reactors must be able to withstand summer temperatures of 70–80 °C. Furthermore, reactor material must be inert to chemicals and resistant to high or low pH.

Quartz has excellent UV-transmission and resistance to temperature and chemicals, but its high cost makes it completely unrealistic. Fluoropolymers are a good choice because of their good UV-transmittance and chemical inertness. One of their greatest disadvantages is that, in order to achieve a desired minimum pressure rating, the wall thickness of a fluoropolymer tube may have to be increased, which in turn will lower its UV-transmittance. Glass is a natural alternative for photoreactors. Low iron-content borosilicate glass has good transmissive properties in the solar range with a cut-off of about 285 nm and therefore, would seem to be the most adequate.

Reflective Surface

The requirements for the optical quality of reflective surfaces in solar applications are usually related to the solar concentration. With regard to the reflector/concentrator, aluminum is the best option owing to its low cost and high reflectivity. The ideal reflective surface for solar photochemical applications must be highly UV-reflective, acceptably weather-resistant for long lifetime and reasonably priced. Aluminium is the only metal surface that is highly reflective throughout the ultraviolet spectrum. Reflectivities range from 92.3% at 280 nm to 92.5% at 385 nm. Aluminum coated organic films or plastic films can also be used. Because of their lack of rigidity, these films must be bonded over a stiff substrate and about 2% reflectivity is lost in this process.

Catalyst Configuration

In a photochemical process, solar radiation is normally absorbed and transferred to the catalyst that is excited by the solar photons. The catalyst can be kept in suspension (referred as Slurry reactors) or fixed to support (Immobilized reactor).

TiO₂ slurry reactors are most commonly type used in water treatment. These show largest photocatalytic activity compared with the immobilized photocatalyst and provide a high total surface area of photocatalyst per unit volume which is one of the most important factor configuring a photocatalytic reactor. They also have advantages of higher throughput, low pressure-drop through the reactor and excellent fluid-to-catalyst mass transfer. However, these reactors require separation of the sub-micron TiO₂ particles from the treated water which complicates the treatment process. Several techniques were proposed to achieve post-treatment separation such as the use of settling tanks (overnight particle settling) or external cross-flow filtration system.

Photocatalytic reactors with immobilized TiO₂ are those in which catalyst is fixed to support via physical surface forces or chemical bonds. Natural clays, glass, carbon, woven cloth fibres etc can be used as supports. Fixed catalyst configurations eliminate the need for catalyst recovery and allow continuous use of photocatalyst, but reduce system efficiency considerably. Up to now, no efficient supported catalysts have yet been achieved. Moreover, an important question is how long a supported catalyst will last in the fluid stream.

VI. CHALLENGES TOWARDS COMMERCIALISATION

Factors that inhibit the performance of photocatalytic oxidation include slow overall rates, low quantum yields, low-order dependence of rates on light intensity, poisoning and fouling of the catalyst, and scavenging of active oxidizing agents by spectator species. Also, solar energy experiences diurnal and annual cycles and varies with weather patterns. The water being treated can contain chemicals that block the critical wavelengths necessary for photoactivity and may require pre- or post-treatment.

The challenge is to reduce the cost (improve performance) of solar photocatalytic processes. Progress in this area will make photocatalytic oxidation using solar or lamp driven, more competitive with other treatment options. Only reductions in the cost of solar-specific hardware (e.g., reactors and collectors) will improve the position of the solar process.

Also, a better understanding of the radical and redox chemistry is sought and the need exists to develop efficient and durable components in conjunction with practical reactor designs that minimize energy dissipation. Elements such as modeling of momentum, mass and thermal energy balances and the determination of radiation field properties and emission models add to the complexity.

VII. OTHER APPLICATIONS OF PHOTOCATALYSIS

Since 1972, when Fujishima and Honda discovered the photocatalytic splitting of water using TiO₂ electrodes; research on the heterogeneous photocatalysis started growing rapidly. The research work focused on energy storage, and in recent years applications have been directed towards environmental clean-up. Later, other applications of this technique have been implemented in many fields such as, drinking water treatment, industrial, and health applications.

a) Removing inorganic compounds

In addition to organic compounds, wide ranges of inorganic compounds are sensitive to photochemical transformation on the catalyst surfaces. Inorganic species such as bromate, or chlorate, azide, halide ions, nitric oxide, palladium and rhodium species, and sulfur species can be decomposed. Metal salts such as AgNO₃, HgCl and organometallic compound can be removed from water, as well as cyanide, thiocyanate, ammonia, nitrates and nitrites.

b) Water disinfections

Photocatalysis can also be used to destroy bacteria and viruses. *Streptococcus mutans*, *Streptococcus natuss*, *Streptococcus cricetus*, *Escherichia coli*, *scaccharomycescerevisisas*, *Lactobacillus acidophilus*, were destructed effectively using heterogeneous photocatalysis. Photodisinfection sensitized by TiO₂ had some effect on the degradation of *Chlorella vulgaris* (Green algae), which has a thick cell wall.

c) Removing trace metals

The environmental applications of heterogeneous photocatalysis include removing heavy metals such as (Hg), chromium (Cr), lead (Pb), Cadmium (Cd), lead (Pb), Arsenic (As), nickel (Ni) copper (Cu). The photoreducing ability of photocatalysis has been used to recover expensive metals from industrial effluent, such as gold, platinum and silver.

d) Degradation of natural organic matter

Humic substances (HS) are ubiquitous and defined as a category of naturally occurring heterogeneous organic substances that can be generally characterised as being yellow-brown and having high molecular weights. They are the main constituents of the dissolved organic carbon (DOC) pool in surface waters (freshwaters and marine waters), and ground waters, commonly imparting a yellowish-brown color to the water system. Advanced oxidation has been applied to decreasing the organic content in water including humic acid. It has the advantage of not leaving any toxic byproducts or sludge. The removal efficiency was reported to be 80% in the first work of this field by Bekbolet in 1996, who studied the effectiveness of photocatalytic treatment on the degradation of humic acid.

VIII. CASE STUDY

Verma et al (2012) reported Photocatalytic degradation of Chlorpyrifos in aqueous phase by using photocatalyst TiO₂ in the presence of artificial UV-light and sunlight. Experiments were performed in both UV and solar light at optimized conditions. The degradation of insecticide was investigated in terms of reduction in COD. The influent COD was obtained as 480 mg/L with 2 ppm of Chlorpyrifos. The effect of catalyst loading, pH, addition of oxidant on the reaction rate was ascertained and optimum conditions for maximum degradation were determined. In this case catalyst concentration was optimized at 4.0 g/L, pH 6.5 and oxidant concentration at 3.0 g/L, where 90% degradation of the insecticide was observed. Treatment under natural solar conditions showed better results as compared with UV treatment.

Methods And Materials

• Chemicals:

Chlorpyrifos is one of the world's most widely used organophosphorus insecticide in agriculture. It is used to control range and forage insect pests as well as soil dwelling grubs, rootworms, borers and subterranean termites. Symptoms of acute poisoning include headache, nausea, muscle twitching and convulsions and in some extreme cases even death. The pesticide having purity >90% was collected from the Dhanuka group of pesticide industries, New Delhi. This pesticide is widely used in the Haryana and Punjab.

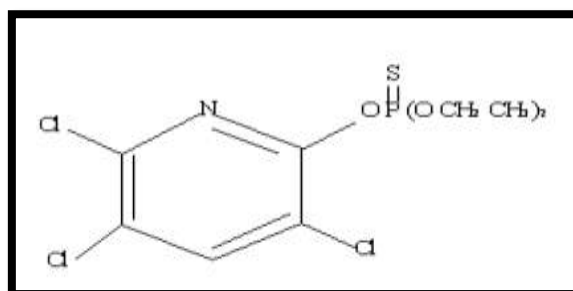


Figure 3: Chemical structure of chlorpyrifos

The photocatalyst TiO_2 P-25 (a mixture of Anatase and Rutile in the ratio of 70:30) received from Evonik Industries India Pvt. Ltd, Mumbai was used. It had a BET surface area of $50 \pm 15 \text{ m}^2\text{g}^{-1}$ and average particle size of 30 nm. All chemicals were used as received.

• Photoreaction Apparatus and Procedure:

The UV Chamber used was rectangular in shape having dimensions of length 4.5 ft, width 3.0 ft and height 3.5 ft (Fig. 4) and made up of GI sheet. It was equipped with seven 36 W UV tubes (Philips) having wavelength of 365 nm; fitted in parallel on the top of the chamber. Small holes were drilled on the sidewall of the chamber to maintain a constant temperature and for proper circulation of air. The reactor (17 cm in diameter and 5.3 cm in height made up of borosilicate glass) was placed on a lab jack so that required intensity could be attained by adjusting the distance of the reactor from the UV tubes. The UV intensity in the reactor can be varied from 10 to 35 W/m^2 corresponding to the average intensity of UV radiation in sunlight. Temperature inside the reactor was maintained by an exhaust fan.

A volume of 200 ml of stock solution (2 ppm of insecticide) was taken in the reactor and the optimum amount of catalyst was added. The suspension was first stirred in dark for at-least one hour to reach complete adsorption equilibrium. This solution was then irradiated under UV lamp with continuous stirring using a magnetic stirrer in the UV chamber for the required period. An aliquot of 5 ml was taken from the reactor at regular interval of time with the help of a syringe. Before analysis, the aqueous samples were filtered through $0.45 \mu\text{m}$ membrane filter to remove TiO_2 agglomerates in suspension.

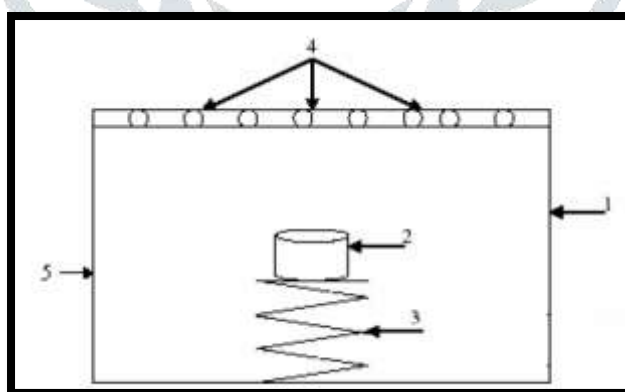


Figure 4: Schematic diagram of lab scale set up: (1) UV chamber (2) Reactor (3) Lab jack (4) UV lamps (5) Holes

All the experiments were carried in Patiala in the month of January between 11 am and 4 pm. Solar light intensity was approximately 700 W/m^2 , determined using a Pyranometer. UV light intensity was approximately 30 W/m^2 measured using Global UV Radiometer. And hence reactor was subjected to UV intensity of 30 W/m^2

Results And Discussion

• Preliminary studies

Dark adsorption and photolysis studies were carried out and correlated with photocatalysis. In dark adsorption study, the stock solution was stirred for 8 hours with the addition of the catalyst in the dark conditions without pH adjustments yielding 17% COD

reduction (Fig. 5). Direct photolysis of the effluent yielded only 8% reduction in COD after 8 hours of irradiation. Degradation of the insecticide using TiO_2 with UV light showed 55% reduction in COD, thus assuming that adsorption-desorption of substrate and reaction intermediate is relatively slow as compared to the formation of electron/hole pairs.

- **Effect of catalyst concentration**

TiO_2 was varied from 1.0 g/L to 10 g/L. It was observed that degradation rate of insecticide increases with increased catalyst concentration and becomes constant above a certain level as shown in Fig.6 and then decreased after one particular optimum dose. This may be due to clustering of catalyst particles.

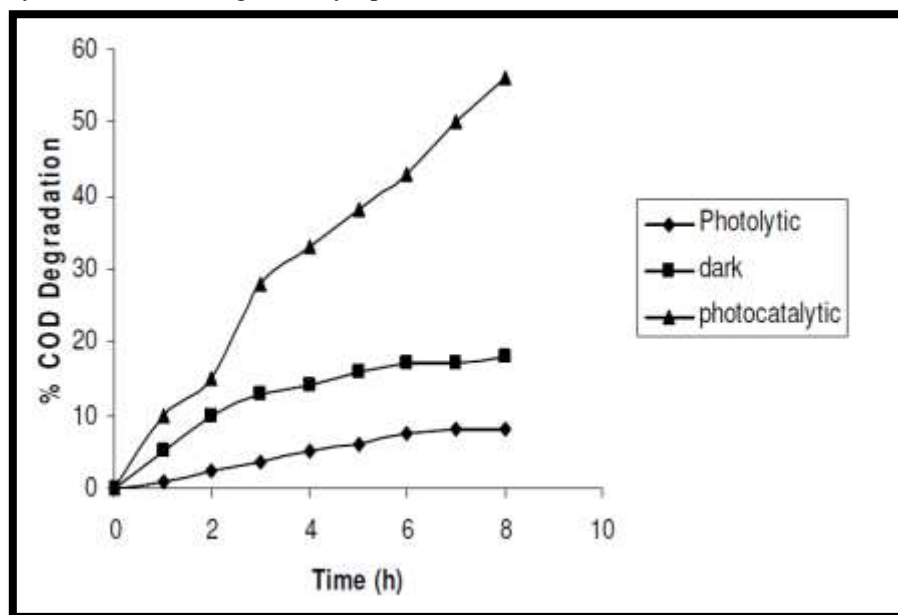


Figure 5: Comparison between photolysis, dark adsorption and photocatalysis

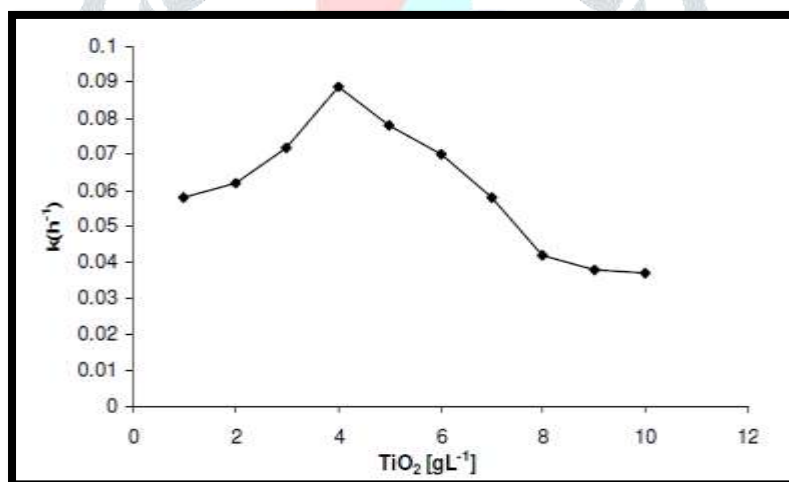
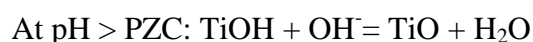


Figure 6: Effect of catalyst concentration on the photodegradation of wastewater

- **Effect of operating pH**

Experiments were carried out at different pH values i.e. 3.5 to 8.5 to study the photodegradation as shown in Fig. 7. Rate of photodegradation of the insecticide under study increases reaches up to 80% with optimum catalyst dose, when the initial pH value increases from 3.5 to 6.5 and then decreases. This is attributed to the fact that TiO_2 shows an amphoteric character so that either a positive or a negative charge can be developed on its surface. The point of zero charge (PZC) of the used TiO_2 (Degussa P-25) is widely reported at pH 6.5. The TiO_2 surface is positively charged in acidic solution and negatively charged in basic solution according to the following equations:



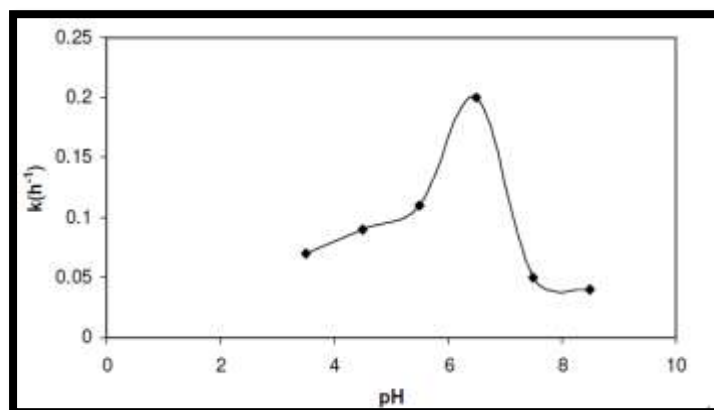


Figure 7: Effect of pH on rate constant k (TiO₂=4.0 g/L, UV intensity 30 W/m²)

- **Effect Of UV Intensity**

For field applications of AOP, the variation in sunlight intensity is always an important factor. The height of the reactor was varied from the UV tubes with the help of lab jack to get the required intensity. Actually the number of photons increases as the intensity is increased, leading to formation of more number of hydroxyl radicals, thus more degradation.

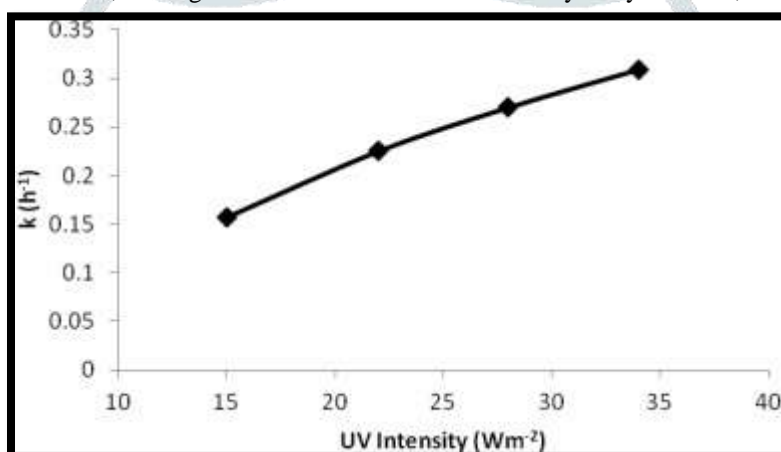


Figure 8: Effect of UV intensity on the first order degradation rate constant for Chlorpyriphos

- **Comparison With Solar Radiation**

Fig. 9 shows the comparison between sample degradation by solar light and artificial UV light with all optimized parameters i.e. 4 gL⁻¹ TiO₂, 6.5 pH, 3.0 gL⁻¹ H₂O₂ addition. Results obtained confirmed more degradation i.e. 83 %, under natural solar radiation as compared UV- light i.e. 70 % after 5 h of treatment with same intensity.

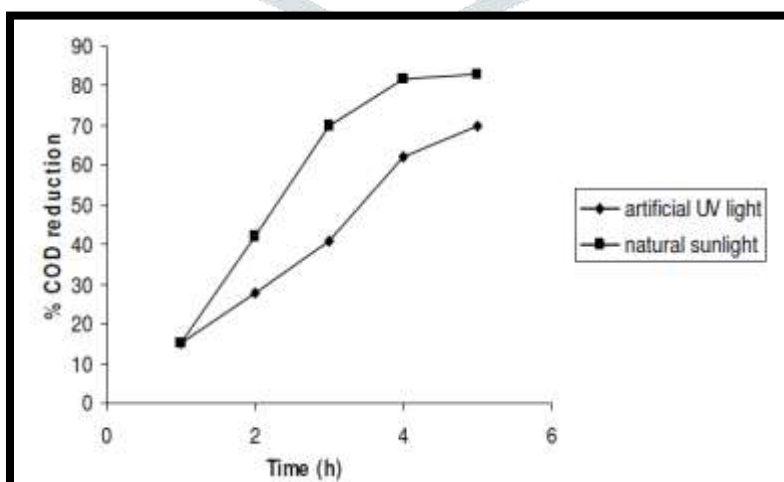


Figure 9: Comparison between UV and Solar radiation

- **Catalyst Recycling**

The catalyst lifetime is an important parameter for industrial application of photo catalyst and also to reduce the cost of the catalyst significantly. After every experiment, catalyst was filtered out using wattmann paper no. 22, activated at 105°C and reused.

As seen from Fig. 10, degradation efficiency decreases as catalyst is recycled. There are two major causes behind the reduction in the efficiency i.e. catalyst fouling and loss of catalyst through filtration.

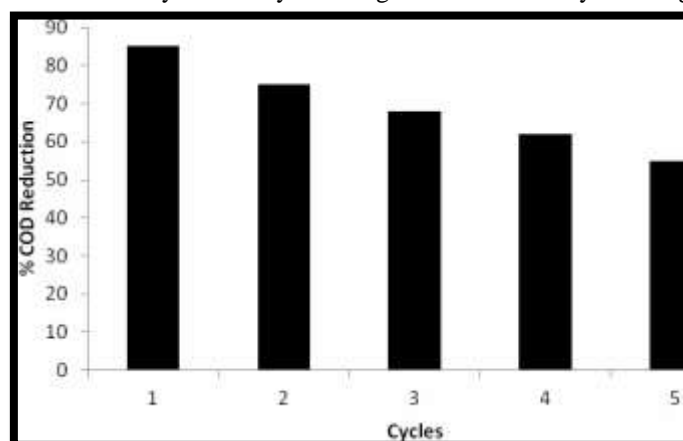


Figure 10: Percentage degradation vs. catalyst (TiO₂) recycling

CONCLUSION

Large shallow pond reactors can be made and implemented in conventional treatment to treat water containing pesticides. But, prior to developing a full scale pond reactor test or experiments should be conducted with a prototype system to calculate the typical values of the rate constant. Solar radiation is more efficient than artificial light and hence solar collectors can be used. Also catalyst recycling can be opted to reduce the material cost. In overcoming one of the major challenges i.e. treatment cost there is a need of the future research that must lead to the reduction of the treatment cost. Future research must also investigate the effectiveness of these technologies in the combination with other cost effective treatments such as biological treatment of bio-recalcitrant compounds.

REFERENCES

- [1] A.M. Deegan; B. Shaik and K. Nolan, Treatment options for wastewater effluents from pharmaceutical companies, *Int. J. Environ. Sci. Tech.*, 8 (3), 649-666, summer 2011.
- [2] Chong M. N. and Christopher W.K., Recent developments in photocatalytic water treatment technology: A review, *Water Research* 44 (2010) 2997-3027.
- [3] Malato S., Blanco J., Vidal A., Photocatalysis with solar energy at a pilot-plant scale: an overview, *Applied Catalysis B: Environmental* 37 (2002) 1-15.
- [4] Photocatalytic Degradation of Organic Pollutants in Water < <http://cdn.intechopen.com/pdfs-wm/42060>>
- [5] Shanmuga .S, Premalatha.M and Anantharaman.N, Solar Photocatalytic Treatment of Phenolic Wastewater- Potential, Challenges and Opportunities, *ARNP Journal of Engineering and Applied Sciences*, Vol. 3, no. 6, December 2008.
- [6] Verma A., Poonam and Dixit D., Photocatalytic degradability of insecticide Chlorpyrifos over UV irradiated Titanium dioxide in aqueous phase, *International Journal of Environmental Sciences*, Volume 3, No 2, 2012