Effect of weight percent of tetrapropoyl ammonium hydroxide solution on chemical and photocatalytic properties of titanium dioxide nanoparticles

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Abstract

A sol-gel method was used to prepare four samples of Titanium dioxide TiO\textsubscript{2} by different weight percent of tetrapropoyl ammonium hydroxide solution(TPAOH). The effect of different weight percent of TPAOH on the properties and efficiency of TiO\textsubscript{2} was studied to degradation of methylene blue (MB) dye. The samples were characterized with X-ray diffraction(XRD), ultraviolet and visible spectroscopy (UV–Vis), Photoluminescence (PL) emission spectra, surface area measurements (BET), and transmission electron microscopy (TEM). Furthermore, the photocatalytic performance of TiO\textsubscript{2} was measured in the degradation of methylene blue (MB) dye. The results demonstrate that the best weight percent of TPAOH for the preparation of TiO\textsubscript{2} nanoparticles at high properties and efficiency is 2.88 wt%.

Introduction

For the past ten years, the growth in population, development of technological, industrial and agricultural expansions have affected the environment and the health of human beings in society [1]. In the environment have been searching for suitable techniques of eliminating hazardous dye discharges that are released in the water bodies that result in the increase of dangerous environmental harms that have an effect on the health of human beings and the marine medium [2,3]. There have been many advances that have been incorporated to reduce the rate of toxicity caused by these dyes, methylene blue (MB) from the water [4], pinpoint these methods that include adsorption, especially on high plane area chains precipitation of chemicals, biological membranes, and ion-exchange processes and also through sedimentation [5]. These methods were considered to be effective in the removal of these chemical dyes although the processes were considered to be slow and there was the need to incorporate expensive materials in the removal of these dyes in the photocatalysis process. Also, these methods led to the researches being conducted on the sol-gel method in the synthesis of TiO\textsubscript{2} nanoparticles in the process. Its relevance was also researched in the photocatalytic deprivation of methylene blue through the use of Titanium dioxide [6,7]. The synthesis of TiO\textsubscript{2} nanoparticles by the sol-gel method is among the suggested techniques among the many techniques including the use of Cu\textsubscript{2}O that has been used widely in photocatalysis as a typical photoelectrode in the electrochemical cells especially under irradiation by visible light [8]. The splitting of water produced hydrogen fuel, although the fuel was not enough to be used in the process of combustion. This raised many debates in the research of suitable techniques of degradation of dyes such as methylene blue (MB) that were suggested in the removal of these effluent substances from our ecosystem [9]. However, the advantages attached to the use of TiO\textsubscript{2}, and that which is doped as photo-catalysts triggered the research in this field [10]. Latest studies have paid attention to the use of TiO\textsubscript{2} based photocatalysts for the filtration of dyes in the aqueous solutions. Nanocrystalline TiO\textsubscript{2} is an oxide semiconductor material that had been studied in numerous experiments to develop a photocatalytic water treatment process that is efficient [11,12]. The process where TiO\textsubscript{2} is used is characterized by high reaction rates and short periods of treatment that arise due to the quick oxidation processes caused by the hydroxyl radicals [13]. The study of these uses motivated the research and development of the several techniques employed in the preparation of catalysts that are used for different tasks in the degradation of methylene blue [14]. There is the need for the increase in the catalytic activity so as to enhance the competence of the whole process especially if the process is to be incorporated in the treatment of water in large scales [15]. The resourcefulness of TiO\textsubscript{2} gives it a wide application in different areas of various products such as the manufacturing of pigments, development of electrochemical electrodes, in the production of toothpaste and capacitors [16]. Also, the oxidation process of the photocatalytic process where semiconductors such as TiO\textsubscript{2}, CdS, Cu\textsubscript{2}O, and ZnO has been widely studied in the past has been a point of concern in the degradation process of methylene blue (MB) [17]. This was due to the attention brought about by the hazardous organic substances released into the environment by the textile, technological and agricultural industries strive to produce products that are extensively needed across the globe [18,19]. This paper aims at synthesizing Titanium dioxide (TiO\textsubscript{2}) nanoparticles via the sol-gel method and evaluating the application of TiO\textsubscript{2} to the photocatalytic degradation of the dye direct blue.

Experimental

Photocatalyst preparation

All chemicals in this experiment were analytical grade and used.

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as received without further purification. Titanium dioxide TiO$_2$ nanoparticles were prepared via sol-gel method according to the following route: different weight percent of tetrapropoyl ammonium hydroxide solution (TPAOH) (10%) (0.96, 1.44, 2.88, and 3.92%) were added to the mixture of 5.28 ml distilled water, 16.8 ml ethanol (96%) and 0.05 ml nitric acid with constant stirring at room temperature for 1 hr. Then, 5 ml of Titanium(IV) butoxide (TBT) (97%), was added slowly with constant stirring at room temperature for another 1 hr. The produced white precipitate were collected by centrifugation, filtration, washing, and dried in a vacuum oven at 60°C for 24 hrs, crushed to fine powder followed and heated at 550°C for 5 h in muffle furnace.

Characterization techniques

X-ray diffraction (XRD) analysis was performed at room temperature with a Bruker axis D8, using Cu Kα radiation (λ = 1.540 Å). The specific surface area was calculated from measurements Of N$_2$ adsorption with a Nova 2000 series Chromatech apparatus at 77 K. Prior to measurement, all samples were treated for 2 h under a vacuum at 200°C. The band gap of the samples was identified using UV–Vis diffuse reflectance spectra (UV–Vis-DRS) in air at room temperature in the wavelength range of 200–800 nm, with an UV/Vis/NIR spectrophotometer (V-570, JASCO, Japan). Transmission electron microscopy (TEM) was recorded with a JEOL-JEM-1230 microscope, and the samples were prepared by suspending them in ethanol, thereafter ultrasonication for 30 min. placing a small amount of this solution onto a carbon-coated copper grid and dried the solution before loading the sample in the TEM.

Photocatalytic test

The photocatalytic activity test was studied by study degradation of methylene blue (MB) under UV light irradiation. The degradation reactions were carried out in a Pyrex glass beaker. The photocatalytic activity experiment was performed by adding 0.1 g of photocatalyst into the beaker with 300 ml aqueous methylene blue solution (50 ppm). This mixture was placed inside the photocatalytic reactor for 60 minutes and then O$_2$ flow was bubbled through the reactor with constant flow rate to keep the mixture homogeneous. The reaction was initiated irradiation process when the UV-lamp was switched on. The experiment was performed at room temperature and pH about 7. The resulting mixture was taken after irradiation and the catalyst separated from solution by centrifugation process. After that, the content of methylene blue in the solution after irradiation was determined by follow UV/Vis spectrophotometer which was recorded on a Shimadzu UV-2450 with an UV/Vis/NIR spectrophotometer (V-570, JASCO, Japan). Transmission electron microscopy (TEM) was recorded with a JEOL-JEM-1230 microscope, and the samples were prepared by suspending them in ethanol, thereafter ultrasonication for 30 min. placing a small amount of this solution onto a carbon-coated copper grid and dried the solution before loading the sample in the TEM.

Results and discussion

Photocatalysts characterization

Phase analysis: TiO$_2$ nanoparticles which prepared by different weight percent of tetrapropoyl ammonium hydroxide solution (TPAOH) were characterized by X-ray diffraction (XRD) analysis to determine their phase compositions. The X-ray diffraction patterns of TiO$_2$ nanoparticles prepared by different weight percent of (TPAOH) were shown in Figure 1. The results reveal that TiO$_2$ phase is present for all samples as a pure TiO$_2$ phase. As the weight percents of tetrapropoyl ammonium hydroxide solution was increased, the diffraction peaks of the samples gradually became narrow and sharp. This change indicates that the particle size grew as weight percent of TPAOH increased.

Surface area analysis: The Specific surface area (SBET) of TiO$_2$ nanoparticles which were prepared by different weight percent of tetrapropoyl ammonium hydroxide solution (TPAOH) such as 0.96%, 1.44%, 2.88% and 3.92% are tabulated in Table 1. The results reveal that the surface area of the TiO$_2$ obtained at 2.88 wt% is 138 m$^2$/g. As the weight percent increases, the surface area is increases from 80 m$^2$/g at 0.96 wt% to 140 m$^2$/g at 3.92 wt%. There was no significant change when adding 3.92 wt% of tetrapropoyl ammonium hydroxide solution. Thus, the TiO$_2$ prepared by 2.88 wt% of tetrapropoyl ammonium hydroxide solution (TPAOH) is expected to have the highest photocatalytic activity, due to it has highest specific surface area which provide active sites to promote the adsorption capacity leading to higher photocatalytic activity.

Optical characterization

The study of UV–Vis radiation absorption constitutes an important agent for the evaluation of the changes produced in prepared nanoparticles by different treatments. The band gap of pure TiO$_2$ phase is usually reported 3.2 eV. The UV-Vis diffuse reflectance spectra of TiO$_2$ nanoparticles which prepared by different weight percent of tetrapropoyl ammonium hydroxide solution are show in Figure 2. The results reveal that the absorbance edges of the TiO$_2$ samples regularly varied. As the weight percents of tetrapropoyl ammonium hydroxide solution (TPAOH) increased, the absorbance edges of the samples moved gradually to higher wavelength (shift on band gap to lower value). In UV-Vis/DR spectrum of samples the threshold edge of absorption band is observed in the range shorter than 400 nm in the area of the spectrum ultraviolet. The UV-Vis reflectance spectra, were used to calculate The band gap values of TiO$_2$ samples by direct extrapolation the absorption edge by linear fit method with the onset corresponding wavelengths, using the following equation:

$$%\text{Photodegradation efficiency} = \frac{C_C - C}{C_0} \times 100$$

Where $C_C$ is the original content of methylene blue and C is the residual methylene blue in solution.

![Figure 1. XRD patterns of as-synthesized TiO$_2$ nanoparticles prepared at different weight percent of TPAOH.](image-url)
The band gap value calculated for the prepared samples are demonstrated in Table 2. The results show that the band gap for TiO₂ nanoparticles prepared by 0.96 wt%, 1.4 wt%, 2.88 wt% and 3.92 wt% of tetrapropyl ammonium hydroxide (TPAOH) are 3.54, 3.38, 3.20 and 3.12 eV, respectively. It is clear that the band gap decreased with increase wt% of tetrapropyl ammonium hydroxide (TPAOH). So, the weight percent plays an important role in determining the band gap of the samples TiO₂.

The photoluminescence (PL) emission spectra were measured for samples excited at 265 nm at room temperature. PL spectra were used to study the transfer of photogenerated electrons and holes and understand the separation and recombination of photogenerated charge carriers in the samples. PL emission spectra is shown in Figure 3. The results reveal that PL intensity decreased by increasing the weight percent of TPAOH. Also, we noticed that the position of emission spectra of TiO₂ was shifted to longer wavelength as weight percent of TPAOH was increased, which are agree with UV-Vis results. The band gap estimated from PL emission spectra are very close to that estimated from UV-Vis spectra, indicating a decrease in the band gap energy and an increase in the amount of photogenerated electrons and holes available to contribute in photocatalytic reactions.

Table 1. BET surface area of TiO₂ nanoparticles prepared at different weight percent of TPAOH.

| Samples              | Surface area (m²/g) |
|----------------------|---------------------|
| 0.96 wt% TPAOH- TiO₂| 80                  |
| 1.44 wt% TPAOH- TiO₂| 100                 |
| 2.88 wt% TPAOH- TiO₂| 138                 |
| 3.92 wt% TPAOH- TiO₂| 140                 |

Table 2. Band gap of TiO₂ nanoparticles prepared by different weight percent of TPAOH.

| Samples              | Band gap, eV |
|----------------------|--------------|
| 0.96 wt% TPAOH- TiO₂| 3.54         |
| 1.44 wt% TPAOH- TiO₂| 3.38         |
| 2.88 wt% TPAOH- TiO₂| 3.20         |
| 3.92 wt% TPAOH- TiO₂| 3.12         |

$E(\text{eV}) = \frac{1239.8}{\lambda(\text{nm})}$

Figure 4 shows TEM images of TiO₂ nanoparticles, prepared by different weight percent of TPAOH. The results demonstrated that the shape of TiO₂ samples is a spherical shape. On increasing the weight percent of tetrapropyl ammonium hydroxide from 0.96% to 1.44% increase the overall particle size of the produced nanoparticles. After increase in weight percent to 2.88%, there was decrease in particle size. Again, When weight percent is increase to 3.92% there was increase in particle size.

Photocatalytic oxidation of MB-dye using TiO₂ nanoparticles under UV irradiation light

The photocatalytic activity of TiO₂ nanoparticles prepared by different weight percent of tetrapropyl ammonium were tested using solution of methylene blue (MB) under UV light irradiation after 60 minutes are shown in Figure 5. The results reveal that as increase

Figure 5. UV-Vis absorption spectra of TiO₂ nanoparticles prepared at different weight percent of TPAOH.
wt% of TPAOH from 0.96 to 3.92%, increase photocatalytic activity from 69 to 100%, respectively. However, increase wt% of TPAOH above 2.88%, i.e., 3.92%, has no significant effect on photocatalytic activity. Therefore, the optimum wt% of TPAOH is 2.88 wt% at which photocatalytic activity is 99%.

Conclusions

A sol-gel method was used to prepare four samples of titanium dioxide TiO₂ by different concentrations of tetrapropoyl ammonium hydroxide solution. In UV-Vis/DR spectrum of samples the threshold edge of absorption band is observed in the range shorter than 400 nm in the area of the spectrum ultraviolet. The highest wavelength of the TiO₂ prepared by 2.88 wt% of TPAOH is 386.85 nm (shift on band gap to lower value), and It has lowest PL intensity, which means it has low rate of recombination of photogenerated electron- hole pairs. Therefore, the weight percent of TPAOH is 2.88 wt% which photocatalytic activity is 99%.

References

1. Hernández-Ramírez A, Medina-Ramírez I (2014) Photocatalytic semiconductors: Synthesis, characterization, and environmental applications. Springer.
2. Alcázar ACS, Kalia S (2015) Organic-inorganic hybrid nanomaterials. Berlin: Springer.
3. Hussein AK (2015) Applications of nanotechnology in renewable energies—A comprehensive overview and understanding. Renewable and Sustainable Energy Reviews 42: 460-476.
4. Morales-Torres S, Pastrana-Martín LM (2014) Nanostructured carbon-TiO₂ photocatalysts for water purification: an overview.
5. Zhao Z, Sun ZC, Zhao HF, Zheng M, Du P, et al. (2012) Phase control of hierarchically structured mesoporous anatase TiO₂ microspheres covered with facets. J Mater Chem 22: 21965–21971.
6. Ding X, Zhou S, Jiang L, Yang H (2011) Preparation, photocatalyticactivity and mechanism of nano-Titania/Nafion hybrid membrane. J Sol-Gel Sci Technol 58: 345-354.
7. Chen X, Mao SS (2007) Titanium dioxide nanomaterials: synthesis, properties, modifications, and applications. Chem Rev 107: 2891-2959. [Crossref]
8. Lu X, Song C, Jia S, Tong Z, Tang X, Teng Y (2015) Low-temperature selective catalytic reduction of NOxwith NH3 over cerium and manganese oxides supported on TiO₂-graphene. Chem Eng J 260: 776-784.
9. Liu Y, Yang Q, Wei J, Xiong R, Pan C X, Shi J (2011) Synthesis and photocatalytic activity of hydroxyapatite modified nitrogen-doped TiO₂. Mater Chem Phys 129: 654-659.
10. Lonnen I, Kilvington S, Kehue SC, Al-Touati F, McGuigan KG (2005) Solar and photocatalytic disinfection of protozoan, fungal and bacterial microbes in drinking water. Water Res 39: 877-883. [Crossref]
11. Li D, Haneda H (2003) Synthesis of nitrogen-containing ZnO powders by spray pyrolysis and their visible-light photocatalysis in gasphase acetaldehyde decomposition. J Photochem Photobiol A 155: 171-178.
12. Kamat PV, Meisel D (2002) Nanoparticles in advanced oxidation processes. Curr Opin Colloid Interface Sci 7: 282-27.
13. Daghiri R, Drogui P, Robert D (2012) Photoelectrocatalytic technologies for environmental applications. A Journal of Photochemistry and Photobiology. Chemistry 238: 41-52.
14. Han H, Ba R (2009) Buoyant photocatalyst with greatly enhanced visible-light activity prepared through a low temperature hydrothermal method. Ind EngChem Res 48: 2891-2898.
15. Hernández-Ramírez A, Medina-Ramírez I (2014) Photocatalytic semiconductors: Synthesis, characterization, and environmental applications. Springer.
16. Diallo MST, Fromer NA, Jhon MS (2014) Nanotechnology for sustainable development.
17. Govindaraj R, Pandian MS, Ramasamy P, Mukhopadhyay S (2015) Sol–gel synthesized mesoporous anatase titanium dioxide nanoparticles for dye sensitized solar cell (DSSC) applications. bulletin of Materials Science 58: 291-296.
18. Dawson G, Chen W, Zhang T, et al. (2010) A study on the effect of startingmaterial phase on the production of titanitate nanotubes. Solid State Sci 12: 2170-2176
19. Aparicio M, Jitiana A, Klein LC (2012)Sol-Gel processing for conventional and alternative energy. New York: Springer.