SYNTHESIS OF CARBON MODIFIED TITANIUM DIOXIDE PHOTOCATALYSTS FOR REMOVAL OF PHENOL

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SYNTHESIS OF CARBON MODIFIED TITANIUM DIOXIDE PHOTOCATALYSTS FOR REMOVAL OF PHENOL

MOHD HAYRIE BIN MOHD HATTA

A thesis submitted in fulfillment of the
requirements for the award of the degree of
Master of Science (Chemistry)

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Special dedication to my beloved mom

"SITI MAIMUNAH ABDUL RAHMAN"

ACKNOWLEDGEMENT

The thesis entitled *Synthesis of Carbon Modified Titanium Dioxide Photocatalysts for Removal of Phenol* would have never been completed without the help, expert and patience supervision of Dr. Leny Yuliati. I thank her for all her enthusiasm, encouragement, excellent advice, fruitful discussion and never-tired spirit. I extent my gratitute to Dr. Hendrik Oktendy Lintang and Associate Professor Dr. Nor Aziah Buang for providing idea, knowledge and supervision during my research years in UTM.

I would also like to extent my sincere appreciation and thanks to Lee Shu Chin, Sam Mei Shie, Nur Azmina Roslan, Ahmad Hanami Abd Kadir, Norumisyuhada Mohd Noor, Faisal Hussin and Koh Pei Wen for helping me with experiments. Lee and Koh should be credited for their help in samples characterization and excellent knowledge in chemistry and not forgotten to Sam Mei Shie who sometimes buys me a breakfast. Azmina should also be thanked for her expertise in handling the Gas Chromatography and her excellent in Microsoft Office skills. Ahmad Hanami and Norumisyuhada should be credited for their assistance in some of experimental parts.

Big thanks should also go to Nur Azmina, Nur Fatiha, Juan and Azani for their moral support as well to Faisal Hussin who always “yell” to me. I appreciate the generosity of Malaysian Government for providing the research grant (FRGS Vote No: 4F002). I thank my mother for always being a good listener to me and for her support throughout all my studies in UTM.

ABSTRACT

Titanium dioxide (TiO_2) has been recognized as an excellent photocatalyst, but lack adsorption capability. One of the suitable approaches to solve the problem is to introduce carbon materials to TiO_2, through a simple process and only involve low cost precursors. In this study, carbon modified TiO_2 was synthesized by using modified sol-gel method in the presence of acetyl acetone as the chelating ligand. Two carbon precursors of dichloromethane and carbon nanotubes (CNT) were used and the samples were denoted as DCM-TiO_2 and CNT-TiO_2, respectively. X-ray diffraction patterns showed that the addition of dichloromethane induced the formation of rutile phase in TiO_2, while addition of CNT maintains the anatase phase of TiO_2. Scanning electron microscope and field emission scanning electron microscope revealed the unaffected morphology of TiO_2 after addition of the carbon precursors. The presence of carbon species was confirmed by diffuse reflectance ultraviolet visible spectroscopy and elemental dispersive X-ray analysis especially on samples with high loading of carbon precursors. The photocatalytic removal of phenol was carried out under UV light irradiation at room temperature for 24 hours. It was confirmed that all DCM-TiO_2 and CNT-TiO_2 series showed better adsorption and photocatalytic activity than the TiO_2. The best catalyst for each series, which were 3% DCM-TiO_2 and 5% CNT-TiO_2, gave 72% and 68% phenol removal, respectively, while TiO_2 showed only 17% phenol removal. Adsorption was proposed to be the important factor for the high activity. Since 3% DCM-TiO_2 showed slightly faster rate constant than the 5% CNT-TiO_2, it was proposed that the use of dichloromethane as carbon precursor and modified sol-gel as the simple method would be an alternative good method to prepare highly active carbon modified TiO_2 photocatalysts.

ABSTRAK

Titanium dioksida (TiO_2) dikenali sebagai fotomangkin yang hebat tetapi kebolehan penjerapannya lemah. Salah satu teknik sesuai untuk menyelesaikan masalah tersebut ialah dengan memasukkan bahan karbon ke dalam TiO_2 melalui proses pengubahsuaian yang mudah dan kos pemula yang rendah. Dalam kajian ini, karbon terubahsuai TiO_2 telah disintesis melalui teknik sol gel yang diubahsuai dengan kehadiran asetil aseton sebagai ligan kelat. Dua pemula karbon iaitu diklorometana dan tiubnano karbon (CNT) telah digunakan dan masing-masing dilabelkan sebagai DCM-TiO_2 dan CNT-TiO_2. Corak pembelauan sinar-X menunjukkan bahawa penambahan karbon mendorong pembentukan TiO_2 fasa rutil manakala penambahan CNT masih mengekalkan fasa anatas TiO_2. Mikroskop imbasan elektron dan mikroskop imbasan elektron pancaran medan mengesahkan morfologi TiO_2 tidak berubah selepas penambahan karbon. Kehadiran spesis karbon telah disahkan melalui spektroskopi pantulan serakan ultralembayung-cahaya nampak dan analisis tenaga sebaran sinar-X terutama bagi sampel yang mempunyai kandungan karbon yang tinggi. Penyingkiran fenol melalui teknik pemangkinan foto telah dijalankan di bawah sinaran UV pada suhu bilik selama 24 jam. Hasil eksperimen mengesahkan bahawa kedua-dua siri DCM-TiO_2 dan CNT-TiO_2 menunjukkan penjerapan dan aktiviti pemangkinan foto yang lebih baik daripada TiO_2. Mangkin terbaik bagi setiap siri iaitu 3% DCM-TiO_2 dan 5% CNT-TiO_2 masing-masing memberikan 72% dan 68% penyingkiran fenol sementara TiO_2 hanya menyingkirkan 17%. Penjerapan dicadangkan sebagai faktor penting bagi mendapatkan hasil pemangkinan yang tinggi. Oleh kerana 3% DCM-TiO_2 menunjukkan kadar tindak balas yang lebih cepat daripada 5% CNT-TiO_2, maka dicadangkan bahawa penggunaan diklorometana sebagai pemula karbon dan sol-gel terubah suai sebagai kaedah ringkas adalah kaedah alternatif yang baik dalam menyediakan karbon terubahsuai TiO_2 yang aktif sebagai fotomangkin.

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LIST OF ABBREVIATIONS

arb.u	-	Arbitrary unit
eV	-	Electron volt
h	-	hours
min	-	minutes
nm	-	Nanometers
Wt. %	-	Weight percents
K	-	Kelvin
kV	-	kilovolt
ppm	-	Part per million
DR UV-Vis	-	Diffuse Reflectance Ultra Violet-Visible
FTIR	-	Fourier Transform Infra-red
GC-FID	-	Gas Chromatography Flame Ion Detector
TGA	-	Thermogravimetric Analysis
XRD	-	X-ray Powder Diffraction
TEM	-	Transmission Electron Microscope
SEM	-	Scanning Electron Microscope
λ	-	Wavelength
2θ	-	Bragg angle
CuK_α	-	X-ray diffraction from copper K_α energy levels

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Recently, the applications of heterogeneous photocatalysis in water treatment have attracted global attention due to its effectiveness in degrading and mineralizing the organic pollutant (Grabowska, *et al.*, 2012). By far, TiO_2 is the only photocatalyst applicable for industrial purpose at present and also probably in the future. This is due to the facts that TiO_2 is an efficient photocatalyst with high stability and has low cost. More significantly, it has been used as a white pigment from ancient times, and thus, its safety to humans and the environment is guaranteed by history (Hashimoto, *et al.*, 2007). Photocatalytic degradation of organic pollutants using TiO_2 has been proved to be most efficient method in the point of view of environmentally safe process (Chiou, *et al.,* 2007). However, there are certain disadvantages associated with the conventional TiO_2 powder catalyst, especially its limitation in adsorption of organic compounds sufficiently when in hydrophobic conditions (Cao, *et al.,* 2010). In order to increase the efficiency of TiO_2, many works have been focused to modify TiO_2 with carbon-based material such as activated carbon or carbon nanotubes (CNT) in order to increase the adsorption rate (Tryba, *et al.*, 2003).

Addition of activated carbon to TiO_2 helped increasing its photocatalytic efficiency due to the large surface area of the composite catalyst, in which activated carbon acted as an adsorption trap to the organic pollutant before transferred to TiO_2 surface, where the photocatalytic process occurred (Liu, *et al.*, 2007). However, the high cost of activated carbon in regeneration system make the activated carbon less

economically viable as even though the carbon successfully gave high percentage of phenol removal, the surface area of activated carbon reduced during the preparation process (Tryba, *et al.,* 2003). Incorporation of another type of carbon based material, *i.e.*, CNT into TiO_2 also helped increasing the efficiency of TiO_2 photocatalytic process due to its large surface area and better catalyst dispersion on CNTs (Chen, *et al.,* 2009). The important function of coupling TiO_2 and CNTs was proposed to provide a synergistic effect, which can enhance the overall efficiency of photocatalytic process such as in the treatment of contaminated water (Zhang, e*t al.*, 2009). However, unfortunately, the preparation of CNTs usually involves the use of expensive instruments, resulting in in high cost of production entirely (Danafar, *et al.*, 2009). Therefore, instead of CNT modified TiO_2, different carbon modified TiO_2 should be developed with simple method and low cost production.

Sol-gel method is one of the most widely used methods to prepare carbon modified TiO_2. In the preparation of carbon modified TiO_2 via sol-gel method, the most crucial parameters that need to be considered are the the uses of titania precusors as well as the calcination temperature. According to the previous literature, there are several titania precursors that have been used such as tetrabutyl orthotitanate (Tseng, *et al.*, 2006) and titanium tetrachloride (Konstantinova, *et al,* 2007. It was reported that the different type of alkoxide used gave influence on the contents of produced carbon. There are alkoxides that produce low carbon contents but high surface area and vice versa (Lettmann, *et al.,* 2001). Therefore, the type of alkoxide used must be determined in order to produce TiO_2 with high surface area and high carbon contents that will give high photocatalytic activity. Supporting this information, Treschev, *et al.* (2008) reported that the carbon contents gave influence on the crystallinity of the TiO_2. Lettmann *et al.* (2001) reported the carbonaceous species was produced by pyrolysis of the alcohols during the dissolution of various different alkoxides in responding alcohols. It was proved that carbonaceous species in the photocatalyst exhibited surprisingly a good long-time stability despite of the carbonaceous nature of the sensitising species. However, it must be taken into consideration that different alkoxides used gave different carbonaceous contents and differences surface area. Therefore, in the present study titanium tetraisopropoxide (TTIP) was used with expectation that it could provide high carbon contents as well

as high surface area that would lead to the increase in the photocatalytic activity of carbon modified TiO_2 photocatalysts.

Calcination temperature also is one of the important factors that will determine the nature of the sample contents. It was reported that the carbon modified TiO_2 prepared via different techniques affected the carbon contents in the photocatalyst (Konstantinova *et al.*, 2007). As example, the preparation of C-TiO_2 by hydrolysis of titanium tetrachloride and tetrabutyl ammonium hydroxide with different calcination temperatures and times gave different carbon contents. Calcination at 673.15 K for 1 hour and 623.15 K for 2 hour produces 2.5% and 0.48% carbon contents respectively. It was concluded that the optimum temperature and duration of calcination is required to control obtained TiO_2 with optimum carbon contents that can give high photocatalytic activity. Sakthivel and Kisch (2003) have also prepared the carbon modified TiO_2 by hydrolysis of titanium tetrachloride and tetrabutylammonium hydroxide at different calcination temperatures to investigate the properties of the formed carbon modified TiO_2. It was found that the low carbon content (3% in TiO_2), which was obtained at calcination temperature of 673.15 K for 15 minutes, increased the photocatalytic activity drastically with the rate of the reaction became 30 times higher than that of the unmodified TiO_2. The used calcinations temperature should be controlled as the increase of calcination temperature will increase its crystallization, but the less active rutile phase of TiO_2 could be formed.

In sol-gel process, controlling the hydrolysis and condensation process would be the important factor to get the expected materials. Since titanium oxide precursors such as alkoxides and chlorides are very reactive, some papers reported the use of the chelating agent, *i.e.*, acetyl acetone to decrease the reactivity of the precursors (Yuliati, *et al*, 2006). It was proposed that the addition of the acetyl acetone resulted in a better dispersion of titanium oxide on silica matrix during the preparation of silica-titania photocatalysts by sol-gel method. The same concept should be applicable to prepare the carbon-containing TiO_2 since the hydrolysis of the titanium oxide precursor should be controlled so that there is sufficient time for carbon to be

dispersed in the titania matrix during sol-gel process. To the best of our knowledge, this strategy has never been applied to the preparation of the carbon modified TiO_2 by sol-gel method. Therefore, in this study, we adopted the strategy for the first time to prepare the series of carbon modified TiO_2 photocatalysts. As comparison, the series of CNT modified TiO_2 was also prepared in this research. In addition, previous literature reported the successful production of CNT using dichloromethane as CNT precursor by adopting hydrothermal method in low temperature synthesis. The advantages of using dichloromethane as carbon precursor include the easiness to be reduced into carbon species and also considered as low-cost material. Thus, dichloromethane has been chosen as carbon precursor in this research as it offers low cost production entirely (Manafi, *et al.,* 2008).

Both of the prepared dichloromethane and CNT modified TiO_2 series were applied for photocatalytic removal of phenol under UV light irradiation. Phenol has been recognized as the most common organic pollutants in wastewater. Industrial waste such as those from the oil waste, plastic, pharmaceutical and domestic wastewaters is the main source of introduction of phenol to water. Their presence in water supplies is noticed as a bad taste and odour. Therefore, the wastewaters containing phenolic compounds must be treated before their discharges into the water streams (Lin, *et al.,* 2009). Due to its toxicity even at low concentration and the nature of phenol that leads to formation of substituted compounds during disinfection and oxidation processes (Busca, *et al.,* 2008), many researchers focus on the finding and developing efficient techniques for phenol removal. Photocatalytic oxidation method has been proposed as one of the most efficient and environmentally safe processes to remove the phenol pollutants (Chun, *et al.*, 2000).

1.2 Statement of Problems

TiO_2 has been recognized as the most commonly used photocatalyst in removal of organic pollutants. However, TiO_2 has limitation in its ability to adsorb organic pollutants. Therefore, modification of TiO_2 with material having high

adsorption abilities is required in order to increase the photocatalytic efficiency of TiO_2. On the other hand, various carbon materials have been considered as good adsorbents. Carbon material such as CNT has been proposed to improve the photocatalytic activity of TiO_2 by creating a synergic effect of adsorption and photocatalytic processes. Unfortunately, the high cost in production of CNT has limited its application and development of a low cost process by using low cost carbon material via simple method is remained as a challenge. Moreover, there is still lack of knowledge on designing TiO_2 based photocatalyst with high adsorption capability without reducing its high photocatalytic activity. In this study, a new carbon based material synthesized from dichloromethane (CH_2Cl_2) was proposed to modify TiO_2 by using an improved sol-gel method. In this study, dichloromethane has been chosen as carbon precursor since it is easily to be dispersed in the reaction medium. On the other hand, since dichloromethane is low cost and easily obtained, the uses of dichloromethane in this research contributed in the low cost preparation in production of carbon modified TiO_2.The series of prepared carbon modified TiO_2 was then characterized in detail, tested for photocatalytic reaction, and compared to the prepared CNT modified TiO_2.

Sol-gel method has been recognized as a good method to prepare carbon modified TiO_2. While some studies to prepare silica titania photocatalysts showed the significance of controlling the hydrolysis process of the titanium oxide precursors, there is still no report on this point to prepare carbon modified TiO_2. Therefore, there is no clear understanding on the effect of carbon dispersion on TiO_2 in the properties and the photocatalytic activity.

Phenolic compounds are found to be the most common organic pollutants found in wastewaters and most of them are generated from chemical and petroleum based industries. Uncontrolled phenolic compound introduced to wastewater caused a cumulative hazardous effect on the environment. Even though there are many studies on the development of TiO_2 photocatalysts to degrade the phenolic compounds, the improvement in the photocatalytic activity of TiO_2 is still highly required. In the present study, the prepared carbon and CNT modified TiO_2 materials

were used to remove phenol under UV light irradiation. Some studies on the adsorption process and kinetic parts were also made to clarify the enhanced performance of the prepared materials.

1.3 Objective of the Study

The objectives of this study are:

a) To synthesize dichloromethane modified TiO_2 (DCM-TiO_2) and CNT modified TiO_2 using an improved sol gel method.
b) To study the properties of the prepared DCM modified TiO_2 and CNT modified TiO_2.
c) To investigate the photocatalytic activity of the prepared DCM modified TiO_2 and CNT modified TiO_2 for degradation of phenol under UV light irradiation.

1.4 Scope of the Study

In this study, two series of potocatalysts, which were DCM modified TiO_2 and CNT modified TiO_2 were synthesized by an improved sol-gel method. The first series was prepared using dichloromethane as the precursor of carbon with different amount of loading (1, 3, and 5 wt%), while the second series was prepared using the CNT. The CNT was only prepared by using catalytic chemical vapour deposition. For both series, the TTIP was used as the TiO_2 precursor and hydrolysis process was controlled in the presence of acetyl acetone as the chelating ligand with mol ratio of TTIP to acetylacetone of 1 to 2. The calcination process was fixed at 773.15 K for 8 hours in air.

Both the prepared DCM and CNT modified TiO_2 series were characterized by X-ray Diffraction (XRD) to investigate the structure and degree of crystallinity.

Diffuse Reflectance Ultraviolet-Visible Spectroscopy (DR UV-Vis) was used to determine the absorption spectra and band gap energy of the prepared photocatalysts. The band gap energy was only determined by Tauc Plot. Fourier Transform Infra-Red Spectroscopy was used to study the functional surface groups on the prepared photocatalysts. Scanning Electron Microscope (SEM) and Field Emission Scanning Electron Microscope (FESEM) were used to study the surface morphology of the prepared photocatalysts. Elemental analysis was determined from the Energy Dispersive X-ray Spectroscopy (EDX) attached to the FESEM. Thermal analysis was carried out by Thermal Gravimetric Analysis (TGA).

The photocatalytic activity of the prepared photocatalysts was tested for removal of phenol under UV light irradiation. The reactions were carried out at room temperature and closed reactor attached with a cooling water system. The reaction product and photocatalytic activity were analyzed by a gas chromatography equipped with a Flame Ionization Detector (GC-FID).

1.5 Significance of the Study

The aim of this study is to increase the efficiency of the TiO_2 by modify it with carbon materials. A new carbon precursor, which is dichloromethane, was proposed in this study. Furthermore, the slow hydrolysis due to the addition of chelating agent, acetyl acetone in the preparation process give sufficient time for dichloromethane to be dispersed in TiO_2 was a new strategy adopted in this study. Therefore, this study will contribute on the fundamental knowledge on the material science, especially in the synthesis method and preparation of carbon modified TiO_2.

This study also highlighted the comparisons between the dichloromethane modified TiO_2 and CNT modified TiO_2 series in terms of properties and photocatalytic activity. It is expected that this study will catalyse the innovative finding on how to design good photocatalysts for removal of organic pollutants.

This study used photocatalytic removal of phenol as the model reaction. Since phenol is one organic pollutant that can be found in our environment, this research is also important for environmental study. This study will open the possibility to utilize the photocatalytic reaction method to solve the environmental problems relating to the organic pollutants as well as to promote the green technology by using clean and environmentally safe process.

REFERENCES

Addamo, M., Augugliaro, V., Di Paola, A., García-López, E., Loddo, V., Marcì, G. and Schiavello, M. (2004). Preparation, Characterization and Photoactivity of Polycrystalline Nanostructured TiO_2 Catalysts. *The Journal of Physical Chemistry B,* 108**(10)**, 3303-3310.

Ananpattarachai, J., Kajitvichyanukul, P., and Seraphin, S. (2009). Visible Light Absorption Ability and Photocatalytic Oxidation Activity of Various Interstitial N-doped TiO_2 Prepared from Different Nitrogen Dopants. *Journal of Hazardous Materials,* 168**(1)**, 253-261.

Anpo, M., Shima, T., Kodama, S., and Kubokawa, Y. (1987). Photocatalytic Hydrogenation of Propyne with Water on Small-particle Titania: Size Quantization Effects and Reaction Intermediates. *The Journal of Physical Chemistry,* 91**(16)**, 4305-4310.

Ansón-Casaos, A., Tacchini, I., Unzue, A., and Martínez, M. T. (2013). Combined Modification of a TiO_2 Photocatalyst with Two Different Carbon Forms. *Applied Surface Science,* 270, 675-684.

Asiltürk, M., and Şener, Ş. (2012). TiO_2-activated Carbon Photocatalysts: Preparation, Characterization and Photocatalytic Activities. *Chemical Engineering Journal,* 180, 354-363.

Augugliaro, V., Loddo, V., Pagliaro, M., Palmisano, G. and Palmisano, L. (2010). Clean by Light Irradiation: Practical Applications of Supported TiO_2. Cambridge, UK: The Royal Society of Chemistry. 258.

Ba-Abbad, Muneer M., Kadhum, Abdul Amir H., Mohamad, Abu Bakar., Takriff, Mohd S and Sopian, Kamaruzzaman. (2012). Synthesis and Catalytic Activity of TiO_2 Nanoparticles for Photochemical Oxidation of Concentrated Chlorophenols under Direct Solar Radiation. *Int. J. Electrochem. Sci.,* 7, 4871 – 4888.

Babuponnusami, A., and Muthukumar, K. (2011). Degradation of Phenol in Aqueous Solution by Fenton, Sono-Fenton and Sono-photo-Fenton Methods. *CLEAN – Soil, Air, Water,* 39**(2)**, 142-147.

Bansal, V. K., Kumar, R., Prasad, R., Prasad, S., and Niraj. (2008). Catalytic Chemical and Electrochemical Wet Oxidation of Phenol using New Copper(II) Tetraazamacrocycle Complexes under Homogeneous Conditions. *Journal of Molecular Catalysis A: Chemical,* 284**(1-2)**, 69-76.

Batzill, M., Morales, E. H., and Diebold, U. (2006). Influence of Nitrogen Doping on the Defect Formation and Surface Properties of TiO_2 Rutile and Anatase. *Physical Review Letters,* 96**(2)**, 026103.

Bickley, R. I., Bond, G. C. and (1982). Heterogeneous Photocatalysis, *Catalysis: Volume 5,* Cambridge, UK: The Royal Society of Chemistry.309.

Blake, D. M., Maness, P., Huang, Z., Wolfrum, E. J. and Huang, J. (1999). Application of The Photocatalytic Chemistry of Titanium Dioxide To Disinfection and The Killing of Cancer Cells. *Separation and Purification Methods*. 28**(1)**, 1-50.

Bond, G. C., Webb, G. and Bickley, R. I. (1982). Heterogenous Photocatalysis. *Catalysis: Volume 5,* Cambridge, UK: The Royal Society of Chemistry. 309.

Busca, G., Berardinelli, S., Resini, C., and Arrighi, L. (2008). Technologies for The Removal of Phenol from Fluid Streams: A Short Review of Recent Developments. *Journal of Hazardous Materials,* 160**(2-3)**, 265-288.

Cao, X., and Shiraishi, F. (2010). A Mechanism of Photocatalytic and Adsorptive Treatment of 2,4-dinitrophenol on a Porous Thin Film of TiO_2 Covering Granular Activated Carbon Particles, *Chemical Engineering Journal,* 160**(2)**, 651-659.

Caza, N., Bewtra, J. K., Biswas, N., and Taylor, K. E. (1999). Removal of Phenolic Compounds from Synthetic Wastewater using Soybean Peroxidase. *Water Research,* 33**(13)**, 3012-3018.

Chang, H., Hsieh, T., Chen, T., Huang, K. H., Jwo, C.H., and Chien, S. H. (2009). Dye-Sensitized Solar Cells Made with TiO_2-Coated Multi-Wall Carbon Nanotubes and Natural Dyes Extracted from Ipomoea. *Materials Transactions*, 50(12), 2879-2884.

Chen, H. J., Wang, L., and Chiu, W.Y. (2007). Chelation and Solvent Effect on the Preparation of Titania Colloids. *Materials Chemistry and Physics,* **101**(1), 12-19.

Chen, M., Zhang, F., and Oh, W. (2009). Synthesis, Characterization, and Photocatalytic Analysis of CNT/TiO_2 Composites Derived from MWCNTs and Titanium sources. *New Carbon Materials,* 24**(2)**, 159-166.

Chiou, C., and Juang, R. (2007). Photocatalytic Degradation of Phenol in Aqueous Solutions by Pr-doped TiO_2 nanoparticles. *Journal of Hazardous Materials,* 149**(1)**, 1-7.

Chun, H., Yizhong, W., and Hongxiao, T. (2000). Destruction of Phenol Aqueous Solution by Photocatalysis or Direct Photolysis. *Chemosphere,* 41**(8)**, 1205-1209.

Colón, G., Hidalgo, M. C., and Navío, J. A. (2002). A Novel Preparation of High Surface Area TiO_2 Nanoparticles from Alkoxide Precursor and using Activated Carbon as Additive. *Catalysis Today,* 76**(2-4)**, 91-101.

Comninellis, C., and Pulgarin, C. (1993). Electrochemical Oxidation of Phenol for Wastewater Treatment using SnO_2, Anodes. *Journal of Applied Electrochemistry,* 23**(2)**, 108-112.

Dąbrowski, A., Podkościelny, P., Hubicki, Z., and Barczak, M. (2005). Adsorption of Phenolic Compounds by Activated Carbon-A Critical Review. *Chemosphere,* 58**(8)**, 1049-1070.

Danafar, F., Fakhru'l-Razi, A., Salleh, M. A. M., and Biak, D. R. A. (2009). Fluidized Bed Catalytic Chemical Vapor Deposition Synthesis of Carbon Nanotubes-A Review. *Chemical Engineering Journal,* 155**(1–2)**, 37-48.

Davis, K. A. (1982). Titanium Dioxide. *Journal of Chemical Education,* 59**(2)**, 158.

Dekant, W., and Völkel, W. (2008). Human Exposure to Bisphenol A by Biomonitoring: Methods, Results and Assessment of Environmental Exposures. *Toxicology and Applied Pharmacology,* 228**(1)**, 114-134.

Deng, H., Zhang, H., and Lu, Z. (2002). Dye-sensitized Anatase Titanium Dioxide Nanocrystalline with (001) Preferred Orientation Induced by Langmuir–Blodgett Monolayer. *Chemical Physics Letters,* 363**(5-6)**, 509-514.

Duminica, F. D., Maury, F., and Hausbrand, R. (2007). Growth of TiO_2 Thin Films by AP-MOCVD on Stainless Steel Substrates for Photocatalytic Applications. *Surface and Coatings Technology,* 201(22-23), 9304-9308.

El-Naas, M. H., Al-Muhtaseb, S. A., & Makhlouf, S. (2009). Biodegradation of phenol by Pseudomonas putida Immobilized in Polyvinyl Alcohol (PVA) gel. *Journal of Hazardous Materials,* 164(2-3), 720-725.

Fujishima, A., and Honda, K. (1972). Electrochemical Photolysis of Water at a Semiconductor Electrode. *Nature,* 238(5358), 37-38.

Gao, Y., Wang, H., Wu, J., Zhao, R., Lu, Y., and Xin, B. (2014). Controlled Facile Synthesis and Photocatalytic Activity of Ultrafine High Crystallinity TiO_2 Nanocrystals with Tunable Anatase/Rutile ratios. *Applied Surface Science,* 294, 36-41.

González-Muñoz, M. J., Luque, S., Álvarez, J. R., and Coca, J. (2003). Recovery of Phenol from Aqueous Solutions using Hollow Fibre Contactors. *Journal of Membrane Science,* 213**(1-2)**, 181-193.

Gorska., P., Zaleska, A., Suska, A., and Hupka, J. (2009). Photocatalytic Activity and Surface Properties of Carbon Doped Titanium Dioxide. *Physicochemical Problems of Mineral Processing,* 43, 21-30.

Grabowska, E., Reszczyńska, J., and Zaleska, A. (2012). Mechanism of Phenol Photodegradation in the Presence of Pure and Modified-TiO_2: A Review. *Water Research,* 46**(17)**, 5453-5471.

Hasanoğlu, A. (2013). Removal of Phenol from Wastewaters using Membrane Contactors: Comparative Experimental Analysis of Emulsion Pertraction. *Desalination,* 309, 171-180.

Hashimoto, K., Irie, H., and Fujishima, A. (2005). TiO_2 Photocatalysis: A Historical Overview and Future Prospects. *Japan Journal of Applied Physics*, 44 , 8269-8285.

Hoffmann, M. R., Martin, S. T., Choi, W., and Bahnemann, D. W. (1995). Environmental Applications of Semiconductor Photocatalysis. *Chemical Reviews,* 95**(1)**, 69-96.

Hurum, D. C., Agrios, A. G., Gray, K. A., Rajh, T., and Thurnauer, M. C. (2003). Explaining the Enhanced Photocatalytic Activity of Degussa P25 Mixed-Phase TiO_2 Using EPR. *The Journal of Physical Chemistry B,* 107**(19)**, 4545-4549.

Idris, A. and Saed, K. (2002). Degradation of Phenol in Wastewater using Anolyte Produced from Electrochemical Generation of Brine Solution. *The International Journal,* 4**(2-3)**, 139 -144.

Inagaki, M., Kojin, F., Tryba, B., and Toyoda, M. (2005). Carbon-coated Anatase: The Role of The Carbon Layer for Photocatalytic Performance, *Carbon*, 43, 1652-1659.

Jeng, M., Wung, Y., Chang, L., and Chow, L. (2013). Dye-Sensitized Solar Cells with Anatase TiO_2 Nanorods Prepared by Hydrothermal Method. *International Journal of Photoenergy,* 2013, 8.

Fink, J. K. (2005). Phenol/formaldehyde Resins. Reactive Polymers Fundamentals and Applications: A Concise Guide to Industrial Polymers. Leoben, Austria: William Andrew. 241-281.

Kim, S., Lee, E. G., Park, S. D., Jeon, C. J., Cho, Y. H., Rhee, C. K., and Kim, W. W. (2001). Photocatalytic Effects of Rutile Phase TiO_2 Ultrafine Powder with High Specific Surface Area Obtained by a Homogeneous Precipitation Process at Low Temperatures. *Journal of Sol-Gel Science and Technology,* 22**(1-2)**, 63-74.

Kim, T., Lee, M., Shim, W., Lee, J., Kim, T., Lee, D., and Moon, H. (2008). Adsorption and Photocatalytic Decomposition of Organic Molecules on Carbon-coated TiO_2. *Journal of Materials Science,* 43(19), 6486-6494.

Kokot, Z., and Burda, K. (1998). Simultaneous Determination of Salicylic Acid and Acetylsalicylic Acid in Aspirin Delayed-release Tablet Formulations by Second-derivative UV Spectrophotometry. *Journal of Pharmaceutical and Biomedical Analysis,* 18**(4–5)**, 871-875.

Konstantinova, E. A., Kokorin, A. I., Sakthivel, S., Kisch, H., and Lips, K. (2007). Carbon-Doped Titanium Dioxide: Visible Light Photocatalysis and EPR Investigation. *CHIMIA International Journal for Chemistry,* 61**(12)**, 810-814.

L. Tsetseris: Phys. Rev. B, 2011, 84, 165201.

Lancaster, M. (2010). Green Chemistry: An Introduction Text. Cambridge, UK: The Royal Society of Chemistry. 117.

Lettmann, C., Hildenbrand, K., Kisch, H., Macyk, W., and Maier, W. F. (2001). Visible Light Photodegradation of 4-chlorophenol with a Coke-containing Titanium Dioxide Photocatalyst. *Applied Catalysis B: Environmental,* 32**(4)**, 215-227.

Li, Y., Zhang, S., Yu, Q., and Yin, W. (2007). The Effects of Activated Carbon Supports on the Structure and Properties of TiO_2 Nanoparticles Prepared by a Sol-gel Method. *Applied Surface Science,* 253**(23)**, 9254-9258.

Li, Z., Wu, M., Jiao, Z., Bao, B., and Lu, S. (2004). Extraction of Phenol from Wastewater by N-octanoylpyrrolidine. *Journal of Hazardous Materials,* 114**(1-3)**, 111-114.

Lin, H., Huang, C. P., Li, W., Ni, C., Shah, S. I., and Tseng, Y. (2006). Size Dependency of Nanocrystalline TiO_2 on its Optical Property and Photocatalytic Reactivity Exemplified by 2-chlorophenol. *Applied Catalysis B: Environmental,* 68**(1-2)**, 1-11.

Lin, K., Pan, J., Chen, Y., Cheng, R., and Xu, X. (2009). Study the Adsorption of Phenol from Aqueous Solution on Hydroxyapatite Nanopowders. *Journal of Hazardous Materials,* 161**(1)**, 231-240.

Lin, S., and Juang, R. (2009). Adsorption of Phenol and its Derivatives from Water using Synthetic Resins and Low-cost Natural Adsorbents: A Review. *Journal of Environmental Management,* 90**(3)**, 1336-1349.

Liu, S. X., Chen, X. Y., and Chen, X. (2007). A TiO_2/AC Composite Photocatalyst with High Activity and Easy Separation Prepared by a Hydrothermal Method. *Journal of Hazardous Materials,* 143**(1-2)**, 257-263.

Lubis, S., Yuliati, L., Lee, S. L., Sumpono, I., and Nur, H. (2012). Improvement of Catalytic Activity in Styrene Oxidation of Carbon-coated Titania by Formation of Porous Carbon Layer. *Chemical Engineering Journal,* 209, 486-493.

Reddy, K., Manorama, S. V., and Ramachandra Reddy, A. (2003). Band gap Studies on Anatase Titanium Dioxide Nanoparticles. *Materials Chemistry and Physics,* 78**(1)**, 239-245.

Manafi, S., Nadali, H., and Irani, H. R. (2008). Low Temperature Synthesis of Multi-walled Carbon Nanotubes via a Sonochemical/Hydrothermal Matthews, R. W., and McEvoy, S. R. (1992). Photocatalytic Degradation of Phenol in the Presence of near-UV Illuminated Titanium Dioxide. *Journal of Photochemistry and Photobiology A: Chemistry,* 64**(2)**, 231-246.

Meng, H., Hou, W., Xu, X., Xu, J., and Zhang, X. (2013). TiO_2-loaded activated carbon fiber: Hydrothermal synthesis, adsorption properties and photo catalytic activity under visible light irradiation. *Particuology.*(Article in Press-Corrected Proof)

Montoya, I. A., Viveros, T., Domínguez, J. M., Canales, L. A., and Schifter, I. (1992). On the Effects of the Sol-gel Synthesis Parameters on Textural and Structural Characteristics of TiO_2. *Catalysis Letters,* 15**(1-2)**, 207-217.

Musameh, M., Lawrence, N. S., and Wang, J. (2005). Electrochemical Activation of Carbon Nanotubes. *Electrochemistry Communications,* 7**(1)**, 14-18.

Norris, J.D. (1984). Determination of Titanium in Titanium Dioxide Pigments, Paints and Other Materials by Chromium (II) Chloride Reduction and Automatic Potentiometric Titration. *Analyst.* 100**(11)**, 1475-1482.

Ohno, T., Tokieda, K., Higashida, S. and Matsumura, M. (2003). Synergism between Rutile and Anatase TiO_2 Particles in Photocatalytic Oxidation of Naphthalene. *Applied Catalysis A: General*. 244**(2)**, 383–391.

Olurode, K., Neelgund, G. M., Oki, A., and Luo, Z. (2012). A Facile Hydrothermal Approach for Construction of Carbon Coating on TiO_2 Nanoparticles. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy,* 89, 333-336.

Phonthammachai, N., Chairassameewong, T., Gulari, E., Jamieson, A. M., and Wongkasemjit, S. (2003). Structural and Rheological Aspect of Mesoporous Nanocrystalline TiO_2 Synthesized via Sol-Gel Process. *Microporous and Mesoporous Materials,* 66**(2–3)**, 261-271.

Piszcz, M., Tryba, B., Grzmil, B., and Morawski, A. W. (2009). Photocatalytic Removal of Phenol under UV Irradiation on WOx –TiO_2 Prepared by Sol-Gel Method. *Catalysis Letters,* 128**(1-2)**, 190-196.

Komp. R. J. (1995).Practical Photovoltaics: Electricity from Solar Cells. 3rd ed.MI: *Aatec Publications.*

Rao, C., N. and Govindraj, A. (2005). Nanotubes and Nanowires, Cambridge: UK. The Royal Society of Chemistry. 24.

Ravelli, D., Dondi, D., Fagnoni, M., and Albini, A. (2009). Photocatalysis. A Multi-faceted Concept for Green Chemistry. *Chemical Society Reviews,* 38**(7)**, 1999-2011.

Sakthivel, S., and Kisch, H. (2003). Daylight Photocatalysis by Carbon-Modified Titanium Dioxide. *Angewandte Chemie International Edition,* 42**(40)**, 4908-4911.

Sayilkan, F., Asilturk, M., Sayilkan., Onal., Y., Akarsu, M., and Arpac, E. (2005). Characterization of TiO_2 Synthesized in Alcohol by a Sol-Gel Process: The Effects of Annealing Temperature and Acid Catalyst. *Turk J Chem*, 29, 697-706.

Shamaila, S., Sajjad, A. K. L., Chen, F., & Zhang, J. (2010). Synthesis and characterization of mesoporous-TiO2 with enhanced photocatalytic activity for the degradation of chloro-phenol. *Materials Research Bulletin, 45*(10), 1375-1382.

Shaohua, W., and Shaoqi, Z. (2011). Photodegradation of Methyl Orange by Photocatalyst of CNTs/P-TiO_2 under UV and Visible Light Irradiation. *Journal of Hazardous Materials*, 185**(1)**, 77-85.

Shashidhar, R & Murthy L, C, S. (2013). Influence of Various Alcoholic Solvents on Structural, Morphological and Compositional Properties of Sprayed TiO_2 Films. *International Journal of Physics and Research (IJPR)*. 3**(2)**, 27-32.

Shourian, M., Noghabi, K. A., Zahiri, H. S., Bagheri, T., Karballaei, G., Mollaei, M., Abbasi, H. (2009). Efficient Phenol Degradation by A Newly Characterized *Pseudomonas* sp. SA01 Isolated from Pharmaceutical Wastewaters. *Desalination,* 246**(1-3)**, 577-594.

Sinha, N. and Yeow, J. T. (2005). Carbon Nanotubes for Biomedical Applications. *IEEE Transactions on Nanobioscience*, 4**(2)**. 180-195.

Su, C., Hong, B. Y., & Tseng, C. M. (2004). Sol-gel Preparation and Photocatalysis of Titanium Dioxide. *Catalysis Today,* 96**(3)**, 119-126.

Subramani, A. K., Byrappa, K., Ananda, S., Lokanatha Rai, K. M., Ranganathaiah, C., & Yoshimura, M. (2007). Photocatalytic Degradation of Indigo Carmine Dye using TiO_2 Impregnated Activated Carbon. *Bulletin of Materials Science,* 30**(1)**, 37-41.

Sun, Y., Wang, G. and Yan, K. (2011). TiO_2 Nanotubes for Hydrogen Generation by Photocatalytic Water Splitting in a Two-compartment Photoelectrochemical Cell. *International Journal of Hydrogen Energy*. 36**(24)**, 15502-15508.

Taavitsainen, V. and Jalava, U. (1995). Soft and Harder Multivariate Modelling in Developing the Properties of Titanium Dioxide Pigments. *Chemometrics and Intelligent Laboratory Systems*. 29**(2)**, 307-319.

Tauc, J. (1968). Optical Properties and Electronic Structure of Amorphous *Ge and Si. Materials Research Bulletin, 3(1), 37-46.*

Tayade, R.J., Kulkarni, R.G. and Jasra, R.V (2006). Transition Metal Ion *Impregnated Mesoporous TiO_2 for Photocatalytic Degradation of Organic Contaminants in Water. Industrial & Engineering Chemistry Research, 45, 5231-5238.*

Thomas, J. M., and Raja, R. (2005). Design of A "green" One-step Catalytic Production of ε-caprolactam (Precursor of Nylon-6). *Proceedings of the National Academy of Sciences of the United States of America,* 102**(39)**, 13732-13736.

Tian, L., Ye, L., Deng, K., & Zan, L. (2011). TiO_2/Carbon Nanotube Hybrid Nanostructures: Solvothermal Synthesis and Their Visible Light Photocatalytic Activity. *Journal of Solid State Chemistry,* 184**(6)**, 1465-1471.

Treschev, S. Y., Chou, P., Tseng, Y., Wang, J., Perevedentseva, E. V., and Cheng, C. (2008). Photoactivities of the Visible-light Activated Mixed-phase Carbon-containing Titanium Dioxide: the Effect of Carbon Incorporation. *Applied Catalysis B: Environmental,* 79**(1)**, 8-16.

Tryba, B., Morawski, A. W., and Inagaki, M. (2003). Application of TiO_2-mounted Activated Carbon to the Removal of Phenol from Water. *Applied Catalysis B: Environmental,* 41**(4)**, 427-433.

Tsai, S., and Juang, R. (2006). Biodegradation of Phenol and Sodium Salicylate Mixtures by Suspended *Pseudomonas putida* CCRC 14365. *Journal of Hazardous Materials,* 138**(1)**, 125-132.

Tseng, Y., Kuo, C., Huang, C., Li. Y., Chou, Cheng, C., and Wong, M. (2006).Visible-light-responsive nano-TiO_2 with Mixed Crystal Lattice and its Photocatalytic Activity. *Nanotechnology*, 17, 2490-2497.

Tsumura, T., Kojitani, N., Izumi, I., Iwashita, N., Toyoda, M., and Inagaki, M. (2002). Carbon coating of Anatase-type TiO_2 and Photoactivity. *Journal of Materials Chemistry,* 12**(5)**, 1391-1396.

Varma, R. J., and Gaikwad, B. G. (2009). Biodegradation and Phenol Tolerance by Recycled Cells of *Candida tropicalis* NCIM 3556. *International Biodeterioration & Biodegradation,* 63**(4)**, 539-542.

Vione, D., Minero, C., Maurino, V., Carlotti, M. E., Picatonotto, T., and Pelizzetti, E. (2005). Degradation of Phenol and Benzoic Acid in the Presence of a TiO_2-based Heterogeneous Photocatalyst. *Applied Catalysis B: Environmental,* 58**(1-2)**, 79-88.

Walling, C., and Goosen, A. (1973). Mechanism of the Ferric Ion Catalyzed Decomposition of Hydrogen Peroxide: Effect of Organic Substrates. *Journal of the American Chemical Society,* 95**(9)**, 2987-2991.

Wang, X., Liu, Y., Hu, Z., Chen, Y., Liu, W., & Zhao, G. (2009). Degradation of Methyl Orange by Composite Photocatalysts nano-TiO_2 Immobilized on Activated Carbons of Different Porosities. *Journal of Hazardous Materials,* 169**(1-3)**, 1061-1067.

Woan, K., Pyrgiotakis, G. and Sigmund, W. (2009). Photocatalytic Carbon-Nanotube-TiO_2 Composites. *Adv. Mater.* 21**(21)**, 2233-2239.

Wojtoniszak, M., Dolat, D., Morawski, A., and Mijowska, E. (2012). Carbon-modified TiO_2 for Photocatalysis. *Nanoscale Research Letters,* 7**(1)**, 1-6.

Wu, Y., and Tai, Y. (2013). Effects of Alcohol Solvents on Anatase TiO_2 Nanocrystals Prepared by Microwave-assisted Solvothermal Method. *Journal of Nanoparticle Research,* 15**(6)**, 1-11.

Xie, W., Huang, X., & Li, H. (2007). Soybean Oil Methyl Esters Preparation using NaX Zeolites loaded with KOH as a Heterogeneous Catalyst. *Bioresource Technology,* 98**(4)**, 936-939.

Xu, Y., Zhuang, Y., and Fu, X. (2010). New Insight for Enhanced Photocatalytic Activity of TiO_2 by Doping Carbon Nanotubes: A Case Study on Degradation of Benzene and Methyl Orange. *The Journal of Physical Chemistry C,* 114**(6)**. 2669-2676.

Yao, M., Liu, B., Zou, Y., Wang, L., Li, D., Cui, T., Zou, G. and Sundqvist, B. (2005). Synthesis of Single-wall Carbon Nanotubes and Long Nanotube Ribbons with Ho/Ni as Catalyst by Arc Discharge. *Carbon,* 43(14), 2894-2901.

Yudianti, R., Onggo., H, Sudirman., Saito., Y, Iwata., T. and Azum., J. (2011). Analysis of Functional Group Sited on Multi-wall Carbon Nanotube Surface. *The Open Materials Science Journal,* 5, 242-247.

Yuliati, L., Itoh, H., and Yoshida, H. (2006). Preparation of Isolated Highly Dispersed Titanium Oxides on Silica by Sol-gel method for Photocatalytic non-oxidative Direct Methane Coupling. *Studies in Surface Science and Catalysis,* 162, 961-968.

Zarezade, M., Ghasemi, S., and Gholami, M. R. (2011). The Effect of Multiwalled Carbon Nanotubes and Activated Carbon on the Morphology and Photocatalytic Activity of TiO_2/C Hybrid Materials. *Catalysis Science & Technology,* 1**(2)**, 279-284.

Zhang, K., Zhang, F. J., Chen, M. L., and Oh, W. C. (2011). Comparison of Catalytic Activities for Photocatalytic and Sonocatalytic Degradation of Methylene Blue in Present of Anatase TiO_2-CNT catalysts. *Ultrasonics Sonochemistry,* 18**(3)**, 765-772.

Zhang, L., Liu, J., Tang, C., Lv, J., Zhong, H., and Zhou, Y. (2011). Palygorskite and SnO_2-TiO_2 for the Photodegradation of phenol. *Applied Clay Science*, 51, 68-73.

Zhang, L., Tse, M. S., Tan, O. K., Wang, Y. X., and Han, M. (2013). Facile Fabrication and Characterization of Multi-type Carbon-doped TiO_2 for Visible Light-activated Photocatalytic Mineralization of Gaseous Toluene. *Journal of Materials Chemistry A,* 1**(14)**, 4497-4507.

Zhang, W., Zou, L., and Wang, L. (2009). Photocatalytic TiO_2/adsorbent Nanocomposites Prepared via Wet Chemical Impregnation for Wastewater Treatment: A Review. *Applied Catalysis A: General,* 371**(1-2)**, 1-9.

Zheng, M., Jin, Y., Jin, G., and Gu, M. (2000). Characterization of TiO_2-PVP Nanocomposites Prepared by the Sol-gel Method. *Journal of Materials Science Letters,* 19**(5)**, 433-436.

Zhu, Shuyun, Niu, Wenxin, Li, Haijuan, Han, Shuang, and Xu, Guobao. (2009). Single-walled Carbon Nanohorn as New Solid-phase Extraction Adsorbent for Determination of 4-nitrophenol in Water Sample. *Talanta,* 79**(5)**, 1441-1445.