OPTIMIZATION OF TITANIUM EXTRACTION FROM DRINKING WATER TREATMENT PLANT RESIDUE AS POTENTIAL PHOTOCATALYST

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To my beloved parents..

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ABSTRACT

Titanium dioxide (TiO_2) is known for its excellent photocatalytic activity and many industries have now shifted their efforts to recover TiO_2 from secondary sources. Hydrometallurgy techniques which comprise of leaching, purification and precipitation have been commonly used to recover TiO_2. However, this technique involves many processes and further work is needed to improve the laboratory process. This study aims to optimize the titanium leaching from drinking water treatment plant (DWTP) residue using response surface methodology (RSM). The parameters studied were acid concentration, temperature and solid to liquid ratio. The purification work was carried out using solvent extraction and the percentage recovery of titanium using Cyanex 272 and Cyanex 301 were investigated. The final product of TiO_2 was obtained via precipitation using magnesium oxide. The performance of TiO_2 as photocatalyst was evaluated using methylene blue and fungi under UV light irradiation. From the characterization study, it was found that the DWTP residue was poorly crystalline and predominantly consists of kaolinite and quartz with minor constituent of hematite, illite and anatase. Experimental results showed that a maximum leaching of titanium was obtained at 66% with optimum condition were found to be at 5.5 M acid concentration, 62˚C heating temperature and 10 g/L solid to liquid ratio. In solvent extraction, the best titanium recovery was achieved at 86% using Cyanex 272 with low extraction of aluminium and iron. In contrast, Cyanex 301 showed 60% titanium recovery with 54% of aluminium was extracted into the organic phase. The X-ray Fluorescence (XRF) analysis indicated that 71% of TiO_2 was produced. In addition, X-ray Diffraction (XRD) confirmed the formation of TiO_2 with the crystalline anatase phase detected at 2θ values of 25.3º, 37.8º, 48.0º. FESEM micrograph of TiO_2 showed that the aggregates were present in the form of uniform spherical shape with considerable variation of particle size. The photocatalytic activity of the final product TiO_2 under UV light irradiation showed maximum degradation (84%) with 0.5 g/L TiO_2 loaded in methylene blue solution. At similar amount of loaded TiO_2, the findings indicated that almost 50% of the fungi growth was inhibited within 14 days. Additionally, zero inhibition of fungi growth was observed without the presence of TiO_2. In summary, the photocatalyst TiO_2 had been successfully recovered from DWTP residue using an optimized leaching process, hence contributes to the improvement of hydrometallurgy technique.

ABSTRAK

Titanium dioksida (TiO_2) dikenali antara pemangkin yang terbaik dan kebanyakan industri kini berusaha untuk mendapatkan TiO_2 daripada sumber sekunder. Teknik hidrometalurgi yang terdiri daripada pelarutan, purifikasi dan pemendakan kebiasaannya digunakan bagi mendapatkan TiO_2. Walau bagaimanapun, teknik ini melibatkan proses yang banyak dan kajian lanjutan diperlukan bagi meningkatkan kualiti kerja makmal. Kajian ini bertujuan untuk mengoptimumkan proses pelarutan titanium daripada bahan baki loji rawatan air minuman (DWTP) dengan menggunakan kaedah gerak balas permukaan (RSM). Parameter yang dikaji ialah kepekatan asid, suhu dan nisbah pepejal kepada cecair. Proses penulenan telah dilakukan dengan menggunakan kaedah pengekstrakan pelarut dan kadar peratusan pengekstrakan titanium telah diselidik menggunakan bahan organik iaitu Cyanex 272 dan Cyanex 301. Hasil akhir TiO_2 telah diperolehi melalui kaedah pemendakan yang menggunakan magnesium oksida. Penilaian produk TiO_2 sebagai bahan pemangkin telah dijalankan dengan menggunakan metilena biru dan kulat di bawah sinaran cahaya UV. Hasil kajian perincian mendapati bahan baki DWTP mempunyai struktur kristal yang lemah dan kebanyakannya terdiri daripada kaolinit dan kuarza dengan sebilangan kecil bijih besi, ilit dan anatase. Hasil eksperimen menunjukkan bahawa pengekstrakan titanium yang maksimum telah diperolehi sebanyak 66% pada keadaan optimum dengan kepekatan asid 5.5 M, suhu pemanasan 62˚C dan nisbah pepejal kepada cecair 10 g/L. Dalam pengekstrakan pelarut, 86% titanium telah diekstrak menggunakan Cyanex 272 dengan peratusan aluminium dan ferum yang rendah. Hasil perbandingan menunjukkan Cyanex 301 telah mengekstrak titanium sebanyak 60% dan aluminium yang turut diekstrak dalam fasa organik adalah 54%. Analisis X-ray Fluorescence (XRF) menunjukkan sebanyak 71% TiO_2 telah dihasilkan. Pembelauan X-ray (XRD) telah membuktikan pembentukan fasa berhablur anatase pada nilai 2θ adalah 25.3º, 37.8º, 48.0º. Mikrograf FESEM menunjukkan gumpalan TiO_2 berbentuk sfera yang tidak sekata dengan pelbagai saiz zarah. Proses pemangkinan di bawah sinaran UV menggunakan produk TiO_2 menunjukkan penguraian maksimum (87%) apabila 0.5 g/L TiO_2 dimasukkan dalam larutan metilena biru. Pada jumlah yang sama, hasil eksperimen menunjukkan bahawa hampir 50% daripada pertumbuhan kulat telah dihalang dalam tempoh 14 hari. Pertumbuhan kulat secara maksimum telah diperhatikan apabila tiada kehadiran TiO_2. Secara ringkas, bahan pemangkin TiO_2 telah berjaya dihasilkan daripada bahan baki DWTP dengan menggunakan kaedah pelarutan yang telah dioptimumkan, dan sekaligus menambah baik kaedah hidrometalurgi.

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LIST OF ABBREVIATIONS

DWTP	Drinking water treatment plant
TiO_2	Titanium Dioxide
RSM	Response Surface Methology
CCD	Central Composite Design
ANOVA	Analysis of Variance
XRF	X-ray Fluorescence
XRD	X-ray Diffraction
ICP	Inductively Coupled Plasma
FTIR	Fourier Transform Infrared
UV	Ultraviolet
FESEM	Field Emission Scanning Electron Microscopy
g/L	Gram/litre
SX	Solvent Extraction
MB	Methylene Blue
PDA	Potato Dextrose Agar

CHAPTER 1

INTRODUCTION

1.1 Background of study

Titanium dioxide (TiO_2) is an oxide of titanium that occurs naturally and it is proven to be effective for its catalytic properties. Research on photocatalytic degradation of organic pollutants and microorganism has been in a continuous expansion in the recent decades and TiO_2 is still by far the most used photocatalyst (Fresno *et al.*, 2014). The use of semiconductor photocatalyst have shown to be advantageous and useful in the treatment of waste water pollutants such as methylene blue because of its high stability in biological and chemical environment (Mohapatra and Parida, 2006; Arbuj *et al.*, 2010). In addition, the biodeterioration of aesthetic and structural damage of construction materials is prominently caused by the presence of numerous microbial cells, particularly tangles of fungal hyphae, as well as dust. As a consequence, there is a need to develop an antimicrobial coating that employs the application of TiO_2 photocatalytic reactions to protect the external building elements from the bio-deterioration of microorganisms, especially fungi.

Current emphasis on industrialization and rapid growth of technology has led to a high demand of titanium. Due to the increment of titanium consumption, the primary source of titanium (rutile) is reported to become scarce (Zhang *et al.*, 2011a). As a consequence, most of the titanium dioxide (TiO_2) are synthesized using various physical and chemical methods. Some of the commonly used synthetic methods to produce TiO_2 are chemical vapor deposition (CVD) (Karaman *et al.*, 2013), oxidation of titanium tetrachloride (Wang *et al.*, 2012), sol gel technique

(Blanco *et al.,* 2015; Leyva-Porras *et al.,* 2015; Pazokifard *et al.,* 2015) and thermal decomposition of titanium alkoxides (Li *et al.,* 2015). The synthesizing of TiO_2 using the available methods are often involves rigorous reaction, high energy consumption and potentially hazardous.

Alternatively, the recovery of titanium from secondary sources is preferable as this would unlock large tonnage of remaining raw sludge as feed material for production of desired metal oxide. Since decades ago, many studies were conducted on the recovery of titanium from various kind of secondary sources for instance blast furnace slag (Zhang *et al.,* 2007), red mud (Agatzini-Leonardou *et al.,* 2008), sand beach (Begum *et al.,* 2012), titanium slag (Liu *et al.,* 2013) and submerged-arc welding slag (Annoni *et al.,* 2013).

On a global scale, available literature estimates that 10, 000 tons of drinking water treatment plant (DWTP) residue is produced daily in most municipalities worldwide and directly disposed to a landfill (Babatunde and Zhao, 2006). To date, it has been widely used in the buildings and construction materials such as cement (Rodríguez *et al.,* 2010) and ceramics (Teixeira *et al.,* 2011). DWTP residue is mainly consists of clay, fine silt and sediment which are primarily composed of Si, Ti, Al, Fe, Mg, Ca, Na and K (Tour, 1989). Titanium is among one of the most valuable components found in the residue and therefore it can be used as secondary raw material for recovery of titanium.

The previous literatures stated that the method for metal extraction is classified into pyro-metallurgical, hydro-metallurgical and bio-metallurgical. The pyro-metallurgical extraction of titanium normally involved smelting, roasting and refining (Lasheen, 2008). However, this process has been criticised for many years due to high emission of carbon footprint. The bio-metallurgical process involving bacterial leaching has been reported to give poor recovery of titanium (Jonglertjunya and Rubcumintara, 2013). Hydrometallurgical process involves leaching via chemical method and further purifications technique such as solvent extraction is required to concentrate the metals (Borsalani *et al.,* 2011; Swamidoss and Malkhede, 2014).

Acid extraction has been acknowledged as an efficient method in metal recovery as most of the inorganic constituent including titanium are destabilized at low pH range. Direct acid leaching may also offer high solubility of metal complex and high leaching rates. The extraction of various metals including zinc (Oustadakis *et al.*, 2010), chromium (Jiang *et al.*, 2014), aluminium (Shemi *et al.*, 2014; Nayak and Panda, 2010), cobalt (Liu *et al.*, 2015), among others, were successfully performed using sulphuric acid.

It is crucial to determine the most significant variable and interaction between two variables in an experiment which can be achieved using a statistical design analysis (Somasundaram *et al.*, 2014). Nowadays, the uses of Response Surface Methodology (RSM) has been studied extensively mainly on the metal recovery including copper (Somasundaram *et al.*, 2014), aluminium (Shemi *et al.*, 2014), zinc (Zhang *et al.*, 2010), chromium (Sahu *et al.*, 2009), cadmium (Iqbal *et al.*, 2016), vanadium and nickel (Nazari *et al.*, 2014), manganese (Azizi *et al.*, 2012) and gold (Ha *et al.*, 2014). In this study, the application of RSM to design an optimum hydrometallurgical technique is aimed at maximum recovery of titanium from DWTP residue.

1.2 Problem statement

The hydrometallurgical technique is chosen as it provides several substantial advantages including the ability to control the level of impurities, high potentials for metal recovery and suitability for small scale application. However, this technique is divided into many levels of processes which is leaching, purification that involves solvent extraction with stripping and finally precipitation process. This consequently prolonged the experimental work, making it laborious and difficulty to reach the optimal conditions due to the fact that the interaction between variables is ignored. Among the possible approaches, a statistical design method of RSM is found to be practical. This method could reduce a number of experiments to be done in the lab work where this method will be suggesting the best experimental condition based on the design model. In this study, the optimization of hydrometallurgical technique mainly on the leaching part is highlighted.

1.3 Objectives of the study

The optimization of the hydrometallurgy technique to recover TiO_2 from DWTP residue is divided into first and second objective. The third objective refers to the photocatalytic application of the recovered TiO_2. The objectives of the research are simplified as follows:

i) To optimize the parameters affecting leaching of titanium which include acid concentration, temperature and solid to liquid ratio using RSM
ii) To investigate on the types of organic extractants on the recovery of titanium.
iii) To evaluate the photocatalytic activity of recovered TiO_2 against methylene blue and *F. equiseti* under UV light irradiation.

1.4 Scope of the study

This part is discussed according to the objectives; (i) optimization of leaching process, (ii) purification process using solvent extraction and (iii) photocatalytic activity of recovered TiO_2.

In the first objective, three independent variables namely acid concentration, temperature and solid to liquid ratio were optimized using central composite design (CCD) of RSM. The concentration of metals in the leached solution was determined using Inductively Coupled Plasma – Optical Emission Spectrometer (ICP-OES). The chemical composition and properties of DWTP residue and leaching by-product were analyzed using X-ray Fluorescence (XRF) spectroscopy, Fourier Transform Infrared (FTIR) spectroscopy, X-ray Diffraction (XRD) spectroscopy, Scanning Electron Microscope (SEM) and Field Emission Scanning Electron Microscope (FESEM).

For second objective, the purification of sulphate leached solution was conducted using solvent extraction. Two types of selective anionic extractants (Cyanex 272 and Cyanex 301) were evaluated. The stripping of titanium was performed using HCl and final TiO_2 was obtained via precipitation with light magnesium oxide. The produced TiO_2 was calcined at 550ºC and further characterized using XRF, XRD and FESEM analysis.

In the third objective, the photocatalytic activity of TiO_2 was evaluated by the degradation of the organic dye pollutant, methylene blue (MB) in water under UV light irradiation. The amount of TiO_2 loaded into the MB solution was varied and the degradation rate of MB was observed within four hours under UV irradiation. Then, similar amount of TiO_2 loaded obtained from the photocatalytic activity of MB was used against isolated fungi. Fungi sample was collected at C07 UTM exterior building and the fungi sample was identified using polymerase chain reaction (PCR). The efficacy of TiO_2 against fungi was observed at the time intervals of 1, 7, and 14 days by measuring the diameter of fungal colonies.

1.5 Significance of the study

The main aim of this study is to recover TiO_2 from DWTP residue using a hydrometallurgical technique. Optimization of this technique is necessary as it can reduce the laborious work and for more feasible metal recovery in full-scale applications. This study will also contribute as a promising technique for the recovery of titanium from different kind of sources. Apart from that, product of this research which is TiO_2 can be further utilized as a photocatalyst material. Photocatalytic application can provide solutions for many of the environmental challenges as most of the organic pollutants will undergo degradation to produce less harmful or non-harmful substances under UV light irradiation.

REFERENCES

Agatzini-Leonardou, S., Oustadakis, P., Tsakiridis. and P. E., Markopoulos, C. (2008) Titanium Leaching from Red Mud by Diluted Sulfuric Acid at Atmospheric Pressure. *Journal of Hazardous Materials*, 157(2–3), 579-586.

Allal, K. M., Hauchard, D., Stambouli, M., Pareau, D. and Durand, G. (1997). Solvent Extraction of Titanium by Tributylphosphate, Trioctylphosphine Oxide and Decanol from Chloride Media. *Hydrometallurgy*, 45(1–2), 113-128.

Allen, N. S., Edge, M., Verran, J., Stratton, J., Maltby, J. and Bygott, C. (2008). Photocatalytic Titania Based Surfaces: Environmental Benefits. *Polymer Degradation and Stability,* 93(9), 1632-1646.

Amaral, F. A. D., dos Santos, V. S. and Bernardes, A. M. (2014). Metals Recovery from Galvanic Sludge by Sulfate Roasting and Thiosulfate Leaching. *Minerals Engineering*, 60(0), 1-7.

Amézaga-Madrid, P., Nevárez-Moorillón, G. V., Orrantia-Borunda, E. and Miki-Yoshida, M. (2002). Photoinduced Bactericidal Activity Against Pseudomonas Aeruginosa by TiO_2 Based Thin Films. *FEMS Microbiology Letters,* 211(2), 183-188.

Annoni, R., Souza, P. S., Petrániková, M., Miskufova, A., Havlík, T. and Mansur, M. B. (2013). Submerged-Arc Welding Slags: Characterization and Leaching Strategies for the Removal of Aluminum and Titanium. *Journal of Hazardous Materials*, 244–245(0), 335-341.

Aphairaj, D., Wirunmongkol, T., Pavasupree, S. and Limsuwan, P. (2011). Effect of Calcination Temperatures on Structures of TiO_2 Powders Prepared by Hydrothermal Method Using Thai Leucoxene Mineral. *Energy Procedia,* 9(0), 539-544.

Arbuj, S. S., Hawaldar, R. R., Mulik, U. P., Wani, B. N., Amalnerkar, D. P. and Waghmode, S. B. (2010). Preparation, Characterization and Photocatalytic

Activity of TiO_2 Towards Methylene Blue Degradation. *Materials Science and Engineering: B,* 168(1–3), 90-94.

Asahi, R., Morikawa, T., Irie, H. and Ohwaki, T. (2014). Nitrogen-Doped Titanium Dioxide as Visible-Light-Sensitive Photocatalyst: Designs, Developments, and Prospects. *Chemical Reviews,* 114(19), 9824-9852.

Auvinen, J. and Wirtanen, L. (2008). The Influence of Photocatalytic Interior Paints on Indoor Air Quality. *Atmospheric Environment,* 42(18), 4101-4112.

Azizi, D., Shafaei, S. Z., Noaparast, M. and Abdollahi, H. (2012). Modeling and Optimization of Low-Grade Mn Bearing Ore Leaching using Response Surface Methodology and Central Composite Rotatable Design. *Transactions of Nonferrous Metals Society of China,* 22(9), 2295-2305.

Ba-Abbad, M. M., Kadhum, A. A. H., Mohamad, A. B., Takriff, M. S. and Sopian, K. (2012). Synthesis and Catalytic Activity of TiO_2 Nanoparticles for Photochemical Oxidation of Concentrated Chlorophenols under Direct Solar Radiation. *International Journal of Electrochemical Science,* 7(4871-4888.

Babaizadeh, H. and Hassan, M. (2013). Life Cycle Assessment of Nano-Sized Titanium Dioxide Coating on Residential Windows. *Construction and Building Materials,* 40(0), 314-321.

Babatunde, A. O. and Zhao, Y. Q. (2006). Constructive Approaches Toward Water Treatment Works Sludge Management: An International Review of Beneficial Reuses. *Critical Reviews in Environmental Science and Technology,* 37(2), 129-164.

Barik, S. P., Park, K. H., Parhi, P. K., Park, J. T. and Nam, C. W. (2012). Extraction of Metal Values from Waste Spent Petroleum Catalyst using Acidic Solutions. *Separation and Purification Technology,* 101(0), 85-90.

Begum, N., Maisyarah, A., Bari, F., Ahmad, K. R. and Hidayah, N. (2012). Leaching Behaviour of Langkawi Black Sand for the Recovery of Titanium. *APCBEE Procedia,* 3(0), 1-5.

Behnajady, M. A. and Eskandarloo, H. (2013). Silver and Copper Co-Impregnated Onto TiO_2-P25 Nanoparticles and Its Photocatalytic Activity. *Chemical Engineering Journal,* 228(0), 1207-1213.

Blanco, E., González-Leal, J. M. and Ramírez-del Solar, M. (2015). Photocatalytic TiO_2 Sol–Gel Thin Films: Optical And Morphological Characterization. *Solar Energy,* 122(2), 11-23.

Borsalani, A., Ghahremani, H., Seyfi, S. and Abdi, M. (2011). Solvent Extraction of Tetravalent Titanium from Chloride and Nitrate Solutions by 2-Ethylhexyl Phosphonic Acid Mono-2 Ethylhexyl Ester (EHEHPA) in Kerosene. *Der Chemica Sinica,* 2(6), 204-211.

Bosecker, K. (1997). Bioleaching: Metal Solubilization by Microorganisms. *FEMS Microbiology Reviews,* 20(3-4), 591-604.

Buzatu, T., Popescu, G., Birloaga, I. and Săceanu, S. (2013). Study Concerning the Recovery of Zinc and Manganese from Spent Batteries by Hydrometallurgical Processes. *Waste Management,* 33(3), 699-705.

Byrappa, K. and Adschiri, T. (2007). Hydrothermal Technology for Nanotechnology. *Progress in Crystal Growth and Characterization of Materials,* 53(2), 117-166.

Byrappa, K., Dayananda, A. S., Sajan, C. P., Basavalingu, B., Shayan, M. B., Soga, K. and Yoshimura, M. (2008). Hydrothermal Preparation of ZnO:CNT and TiO_2:CNT Composites and Their Photocatalytic Applications. *Journal of Materials Science,* 43(7), 2348-2355.

Cai, J., Chen, Z., Li, J., Wang, Y., Xiang, D., Zhang, J. and Li, H. (2015). Enhanced Conversion Efficiency Of Dye-Sensitized Solar Cells using a CNT-Incorporated TiO_2 Slurry-Based Photoanode. *AIP Advances,* 5(2), 027118.

Carp, O., Huisman, C. L. and Reller, A. (2004). Photoinduced Reactivity Of Titanium Dioxide. *Progress in Solid State Chemistry,* 32(1–2), 33-177.

Chen, A., Wang, S., Zhang, L. and Peng, J. (2015). Optimization of the Microwave Roasting Extraction of Palladium and Rhodium from Spent Automobile Catalysts Using Response Surface Analysis. *International Journal of Mineral Processing,* 143(18-24.

Chen, F., Yang, X. and Wu, Q. (2009). Antifungal Capability of TiO_2 Coated Film on Moist Wood. *Building and Environment,* 44(5), 1088-1093.

Coelho, L., Viegas, D., Santos, J. L. and de Almeida, J. M. (2016). Optical Sensor Based on Hybrid FBG/Titanium Dioxide Coated LPFG for Monitoring Organic Solvents in Edible Oils. *Talanta,* 148(170-176.

Ctibor, P., Stengl, V. and Pala, Z. (2013). Photocatalytic Activity of Titanium Oxide – Iron Oxide Coatings Prepared by Plasma Spraying. *American Chemical Science Journal,* 3(4), 387-400.

da Silva, G. C., Cunha, J. W., Dweck, J. and Afonso, J. C. (2008). Liquid–Liquid Extraction (LLE) of Iron and Titanium by Bis-(2-Ethyl-Hexyl) Phosphoric Acid (D2EHPA). *Minerals Engineering,* 21(5), 416-419.

Das, G. K., Pranolo, Y., Zhu, Z. and Cheng, C. Y. (2013). Leaching of Ilmenite Ores by Acidic Chloride Solutions. *Hydrometallurgy,* 133(94-99.

De Filpo, G., Palermo, A. M., Rachiele, F. and Nicoletta, F. P. (2013). Preventing Fungal Growth in Wood by Titanium Dioxide Nanoparticles. *International Biodeterioration & Biodegradation,* 85(0), 217-222.

Debadatta, D. and Pramanik, K. (2013). A Study on Chemical Leaching of Iron from Red mud using Sulphuric Acid. *Research Journal of Chemistry and Environment,* 17(7), 50-56.

Deep, A., Malik, P. and Gupta, B. (2001). Extraction and Separation of Ti(IV) using Thiophosphinic Acids and Its Recovery from Ilmenite and Red Mud. *Separation Science and Technology,* 36(4), 671-685.

Di Paola, A., García-López, E., Marcì, G. and Palmisano, L. (2012). A Survey of Photocatalytic Materials for Environmental Remediation. *Journal of Hazardous Materials,* 211–212, 3-29.

Diamanti, M. V., Del Curto, B., Ormellese, M. and Pedeferri, M. P. (2013). Photocatalytic and Self-Cleaning Activity of Colored Mortars Containing TiO_2. *Construction and Building Materials,* 46, 167-174.

Dominguez-Wong, C., Loredo-Becerra, G. M., Quintero-González, C. C., Noriega-Treviño, M. E., Compeán-Jasso, M. E., Niño-Martínez, N., DeAlba-Montero, I. and Ruiz, F. (2014). Evaluation of the Antibacterial Activity of an Indoor Waterborne Architectural Coating Containing Ag/TiO_2 Under Different Relative Humidity Environments. *Materials Letters,* 134, 103-106.

Duyvesteyn, W. P. C., Sabacky, B. J., Verhulst, D. E. V., West-Sells, P. G., Spitler, T. M., Vince, A. and Burkholder, J. R. (2002). US 6375923. Retrieved on 14 February 2016, from http://www.freepatentsonline.com/6375923

El-Didamony, H., Khalil, K. A. and Heikal, M. (2014). Physico-Chemical and Surface Characteristics of Some Granulated Slag–Fired Drinking Water Sludge Composite Cement Pastes. *HBRC Journal,* 10(1), 73-81.

El-Hazek, N., Lasheen, T. A., El-Sheikh, R. and Zaki, S. A. (2007). Hydrometallurgical Criteria for TiO_2 Leaching from Rosetta Ilmenite by Hydrochloric Acid. *Hydrometallurgy,* 87(1–2), 45-50.

Fernandes, A., Afonso, J. C. and Dutra, A. J. B. (2013). Separation of Nickel(II), Cobalt(II) and Lanthanides from Spent Ni-MH Batteries by Hydrochloric Acid Leaching, Solvent Extraction and Precipitation. *Hydrometallurgy,* 133, 37-43.

Fidalgo, A. and Ilharco, L. M. (2001). The Defect Structure of Sol Gel Derived Silica / Polytetrahydrofuran Hybrid Films by FTIR. *Journal of Non-Crystalline Solids,* 283(1–3), 144-154.

Filiz, M. and Sayar, A. A. (2006). Extraction of Titanium(IV) from Aqueous Hydrochloric Acid Solutions into Alamine 336-M-Xylene Mixtures. *Chemical Engineering Communications,* 193(9), 1127-1141.

Flett, D. S. (2005). Solvent Extraction in Hydrometallurgy: The Role of Organophosphorus Extractants. *Journal of Organometallic Chemistry,* 690(10), 2426-2438.

Fresno, F., Portela, R., Suarez, S. and Coronado, J. M. (2014). Photocatalytic Materials: Recent Achievements and Near Future Trends. *Journal of Materials Chemistry A,* 2, 2863-2884.

Ha, V. H., Lee, J.-C., Huynh, T. H., Jeong, J. and Pandey, B. D. (2014). Optimizing the Thiosulfate Leaching of Gold from Printed Circuit Boards of Discarded Mobile Phone. *Hydrometallurgy,* 149, 118-126.

Hadibarata, T., Tachibana, S. and Itoh, K. (2009). Biodegradation of Chrysene, an Aromatic Hydrocarbon by Polyporus Sp. S133 in Liquid Medium. *Journal of Hazardous Materials,* 164(2–3), 911-917.

Hao, X., Lü, L., Liang, B., Li, C., Wu, P. and Wang, J. (2012). Solvent Extraction of Titanium from the Simulated Ilmenite Sulfuric Acid Leachate by Trialkylphosphine Oxide. *Hydrometallurgy,* 113–114, 185-191.

He, L., Liu, Y., Mustapha, A. and Lin, M. (2011). Antifungal Activity of Zinc Oxide Nanoparticles Against Botrytis Cinerea and Penicillium Expansum. *Microbiological Research,* 166(3), 207-215.

Hochmannova, L. and Vytrasova, J. (2010). Photocatalytic and Antimicrobial Effects of Interior Paints. *Progress in Organic Coatings,* 67(1), 1-5.

Innocenzi, P. (2003). Infrared Spectroscopy of Sol Gel Derived Silica-Based Films: A Spectra-Microstructure Overview. *Journal of Non-Crystalline Solids,* 316 (2–3), 309-319.

Iqbal, M., Iqbal, N., Bhatti, I. A., Ahmad, N. and Zahid, M. (2016). Response Surface Methodology Application in Optimization of Cadmium Adsorption by Shoe Waste: A Good Option of Waste Mitigation by Waste. *Ecological Engineering,* 88(265-275.

Jansen, B., Tonneijck, F. H. and Verstraten, J. M. (2011). Selective Extraction Methods for Aluminium, Iron and Organic Carbon from Montane Volcanic Ash Soils. *Pedosphere,* 21(5), 549-565.

Jaworska, M. M. and Guibal, E. (2003). Water Leaching of Titanium From Ore Flotation Residue. *Waste Management,* 23(4), 339-344.

Jayaseelan, C., Rahuman, A. A., Roopan, S. M., Kirthi, A. V., Venkatesan, J., Kim, S.-K., Iyappan, M. and Siva, C. (2013). Biological Approach to Synthesize TiO_2 Nanoparticles using Aeromonas Hydrophila and Its Antibacterial Activity. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy,* 107, 82-89.

Jia, L., Liang, B., Lü, L., Yuan, S., Zheng, L., Wang, X. and Li, C. (2014). Beneficiation of Titania by Sulfuric Acid Pressure Leaching of Panzhihua Ilmenite. *Hydrometallurgy,* 150, 92-98.

Jiang, M., Zhao, Q., Liu, C., Shi, P., Zhang, B., Yang, D., Saxén, H. and Zevenhoven, R. (2014). Sulfuric Acid Leaching of South African Chromite. Part 2: Optimization of Leaching Conditions. *International Journal of Mineral Processing,* 130(102-107.

John, K. S., Rao, T. P., Ramamohan, T. R. and Reddy, M. L. P. (1999a). Solvent Extraction of Tetravalent Titanium from Acidic Chloride Solutions by 2-Ethylhexyl Phosphonic Acid Mono-2-Ethylhexyl Ester. *Hydrometallurgy,* 53(3), 245-253.

John, K. S., Saji, J., Reddy, M. L. P., Ramamohan, T. R. and Rao, T. P. (1999b). Solvent Extraction of Titanium(IV) from Acidic Chloride Solutions by Cyanex 923. *Hydrometallurgy,* 51(1), 9-18.

Jonglertjunya, W. and Rubcumintara, T. (2013). Titanium and Iron Dissolutions from Ilmenite by Acid Leaching and Microbiological Oxidation Techniques. *Asia-Pacific Journal of Chemical Engineering,* 8(3), 323-330.

Joo, J. B., Dahl, M., Li, N., Zaera, F. and Yin, Y. (2013). Tailored Synthesis of Mesoporous TiO_2 Hollow Nanostructures for Catalytic Applications. *Energy & Environmental Science,* 6(7), 2082-2092.

Jurado, M., Vázquez, C., Patiño, B. and Teresa González-Jaén, M. (2005). PCR Detection Assays for the Trichothecene-Producing Species *Fusarium Graminearum, Fusarium Culmorum, Fusarium Poae, Fusarium Equiseti* and *Fusarium Sporotrichioides*. *Systematic and Applied Microbiology,* 28(6), 562-568.

Karaman, M., Sarıipek, F., Köysüren, Ö. and Yıldız, H. B. (2013). Template Assisted Synthesis of Photocatalytic Titanium Dioxide Nanotubes by Hot Filament Chemical Vapor Deposition Method. *Applied Surface Science,* 283, 993-998.

Khezri, S. M., Shariat, S. M. and Tabibian, S. (2011). Reduction of Pollutants in Painting Operation and Suggestion of an Optimal Technique for Extracting Titanium Dioxide from Paint Sludge in Car Manufacturing Industries. *Toxicology and Industrial Health,* 28(5), 463-469.

Khosravi, K., Hoque, M. E., Dimock, B., Hintelmann, H. and Metcalfe, C. D. (2012). A Novel Approach for Determining Total Titanium from Titanium Dioxide Nanoparticles Suspended in Water and Biosolids by Digestion with Ammonium Persulfate. *Analytica Chimica Acta,* 713, 86-91.

Koestler, R. J., Koestler, V. H., Charola, A. E. and Nieto-Fernandez, F. E. (2003). Art, Biology, and Conservation: Biodeterioration of Works of Art. New York, Metropolitan Museum of Art.

Lakshmanan, V. I., Harris, G. B. and Puvvada, G. (2010). US7803336 B2. Retrieved on October 20, 2015, from https://www.google.com/patents/US7803336

Lasheen, T. A. 2008. Soda Ash Roasting of Titania Slag Product from Rosetta Ilmenite. *Hydrometallurgy,* 93(3–4), 124-128.

Le, H. A., Linh, L. T., Chin, S. and Jurng, J. (2012). Photocatalytic Degradation of Methylene Blue by a Combination of TiO_2-Anatase and Coconut Shell Activated Carbon. *Powder Technology,* 225, 167-175.

Leyva-Porras, C., Toxqui-Teran, A., Vega-Becerra, O., Miki-Yoshida, M., Rojas-Villalobos, M., García-Guaderrama, M. and Aguilar-Martínez, J. A. (2015). Low-Temperature Synthesis and Characterization of Anatase TiO_2 Nanoparticles by an Acid Assisted Sol–Gel Method. *Journal of Alloys and Compounds,* 647(627-636.

Li, W., Shang, C. and Li, X. (2015). A One-Step Thermal Decomposition Method to Prepare Anatase TiO_2 Nanosheets with Improved Adsorption Capacities and Enhanced Photocatalytic Activities. *Applied Surface Science,* 357, 2223-2233.

Li, Z., Wang, Z. and Li, G. (2016). Preparation of Nano-Titanium Dioxide from Ilmenite using Sulfuric Acid-Decomposition by Liquid Phase Method. *Powder Technology,* 287, 256-263.

Liu, S. S., Guo, Y.F., Qiu, G. Z., Jiang, T. and Chen, F. (2013a). Preparation of Ti-Rich Material from Titanium Slag by Activation Roasting Followed by Acid Leaching. *Transactions of Nonferrous Metals Society of China,* 23(4), 1174-1178.

Liu, S., Guo, Y., Qiu, G., Jiang, T. and Chen, F. (2013b). Preparation of Ti-Rich Material from Titanium Slag by Activation Roasting Followed by Acid Leaching. *Transactions of Nonferrous Metals Society of China,* 23(4), 1174-1178.

Liu, W., Rao, S., Wang, W., Yang, T., Yang, L., Chen, L. and Zhang, D. (2015). Selective Leaching of Cobalt and Iron From Cobalt White Alloy in Sulfuric Acid Solution with Catalyst. *International Journal of Mineral Processing,* 141, 8-14.

Liu, Y., Wu, W., Liu, L., Liu, M. and Li, Y. Z. (2006). Thermodynamics Behavior of Titanium for BOF Smelting Bearing Steel. *Journal of Iron and Steel Research, International,* 13(6), 74-78.

Lombardi, A. T., Garcia Jr, O. and Waldenir, M. A. N. (2006). The Effects of Bacterial Leaching on Metal Partitioning in Sewage Sludge. *World Journal of Microbiology and Biotechnology,* 22(10), 1013-1019.

Lombardi, A. T., Garcia, O. J. and Menezes, W. A. N. (2002). Biological Leaching of Mn, Al, Zn, Cu and Ti in an Anaerobic Sewage Sludge Effectuated by *Thiobacillus Ferrooxidans* and Its Effect on Metal Partitioning. *Water Research,* 36(13), 3193-3202.

Lucas, S. S., Ferreira, V. M. and de Aguiar, J. L. B. (2013). Incorporation of Titanium Dioxide Nanoparticles in Mortars — Influence of Microstructure in the Hardened State Properties and Photocatalytic Activity. *Cement and Concrete Research,* 43, 112-120.

Meawad, A. S., Bojinova, D. Y. and Pelovski, Y. G. (2010). An Overview of Metals Recovery from Thermal Power Plant Solid Wastes. *Waste Management,* 30(12), 2548-2559.

Middlemas, S., Fang, Z. Z. and Fan, P. (2013). A New Method for Production of Titanium Dioxide Pigment. *Hydrometallurgy,* 131–132, 107-113.

Mishra, D. and Rhee, Y. (2014). Microbial Leaching of Metals from Solid Industrial Wastes. *J Microbiol.,* 52(1), 1-7.

Mohapatra, P. and Parida, K. M. (2006). Photocatalytic Activity of Sulfate Modified Titania 3: Decolorization of Methylene Blue in Aqueous Solution. *Journal of Molecular Catalysis A: Chemical,* 258(1–2), 118-123.

Monteiro, S. N., Alexandre, J., Margem, J. I., Sánchez, R. and Vieira, C. M. F. (2008). Incorporation of Sludge Waste from Water Treatment Plant Into Red Ceramic. *Construction and Building Materials,* 22(6), 1281-1287.

Morizono, H., Oshima, T. and Baba, Y. (2011). Liquid–Liquid Extraction of Transition Metal Ions With An Alkylhistidine Extractant. *Separation and Purification Technology,* 80(2), 390-395.

Nayak, N. and Panda, C. R. (2010). Aluminium Extraction and Leaching Characteristics of Talcher Thermal Power Station Fly Ash with Sulphuric Acid. *Fuel,* 89(1), 53-58.

Nayl, A. A. and Aly, H. F. (2009). Acid Leaching of Ilmenite Decomposed by KOH. *Hydrometallurgy,* 97(1–2), 86-93.

Nazari, E., Rashchi, F., Saba, M. and Mirazimi, S. M. J. (2014). Simultaneous Recovery of Vanadium and Nickel from Power Plant Fly-Ash: Optimization of Parameters Using Response Surface Methodology. *Waste Management,* 34(12), 2687-2696.

Oustadakis, P., Tsakiridis, P. E., Katsiapi, A. and Agatzini-Leonardou, S. (2010). Hydrometallurgical Process for Zinc Recovery from Electric Arc Furnace Dust (EAFD): Part I: Characterization and Leaching by Diluted Sulphuric Acid. *Journal of Hazardous Materials,* 179(1–3), 1-7.

Owaid, H. M., Hamid, R. and Taha, M. R. (2014). Influence of Thermally Activated Alum Sludge Ash on the Engineering Properties of Multiple-Blended Binders Concretes. *Construction and Building Materials,* 61(216-229.

Pathak, A., Dastidar, M. G. and Sreekrishnan, T. R. (2009). Bioleaching of Heavy Metals from Sewage Sludge: A Review. *Journal of Environmental Management,* 90(8), 2343-2353.

Pazokifard, S., Farrokhpay, S., Mirabedini, M. and Esfandeh, M. (2015). Surface Treatment of TiO_2 Nanoparticles Via Sol–Gel Method: Effect of Silane Type on Hydrophobicity of The Nanoparticles. *Progress in Organic Coatings,* 87(36-44.

Periasamy, V. S., Athinarayanan, J., Al-Hadi, A. M., Juhaimi, F. A., Mahmoud, M. H. and Alshatwi, A. A. (2015). Identification of Titanium Dioxide Nanoparticles in Food Products: Induce Intracellular Oxidative Stress Mediated by TNF and CYP1A Genes in Human Lung Fibroblast Cells. *Environmental Toxicology and Pharmacology,* 39(1), 176-186.

Polo-López, M. I., García-Fernández, I., Velegraki, T., Katsoni, A., Oller, I., Mantzavinos, D. and Fernández-Ibáñez, P. (2012). Mild Solar Photo-Fenton: An Effective Tool for The Removal of Fusarium from Simulated Municipal Effluents. *Applied Catalysis B: Environmental,* 111–112, 545-554.

Provazi, K., Campos, B. A., Espinosa, D. C. R. and Tenório, J. A. S. (2011). Metal Separation from Mixed Types of Batteries using Selective Precipitation and Liquid–Liquid Extraction Techniques. *Waste Management,* 31(1), 59-64.

Ratova, M. and Mills, A. (2015). Antibacterial Titania-Based Photocatalytic Extruded Plastic Films. *Journal of Photochemistry and Photobiology A: Chemistry,* 299, 159-165.

Razali, M., Zhao, Y. Q. and Bruen, M. (2007). Effectiveness of A Drinking-Water Treatment Sludge in Removing Different Phosphorus Species from Aqueous Solution. *Separation and Purification Technology,* 55(3), 300-306.

Remya, P. N. and Reddy, M. L. (2004). Solvent Extraction Separation of Titanium(IV), Vanadium(V) and Iron(III) from Simulated Waste Chloride Liquors of Titanium Minerals Processing Industry by The Trialkylphosphine Oxide Cyanex 923. *Journal of Chemical Technology & Biotechnology,* 79(7), 734-741.

Reszczyńska, J., Grzyb, T., Sobczak, J. W., Lisowski, W., Gazda, M., Ohtani, B. and Zaleska, A. (2015). Visible Light Activity of Rare Earth Metal Doped (Er^{3+}, Yb^{3+} or Er^{3+}/Yb^{3+}) Titania Photocatalysts. *Applied Catalysis B: Environmental,* 163, 40-49.

Rodríguez, N. H., Ramírez, S. M., Varela, M. T. B., Guillem, M., Puig, J., Larrotcha, E. and Flores, J. (2010). Re-Use of Drinking Water Treatment Plant (DWTP) Sludge: Characterization and Technological Behaviour of Cement Mortars with Atomized Sludge Additions. *Cement and Concrete Research,* 40(5), 778-786.

Sahu, J. N., Acharya, J. and Meikap, B. C. (2009). Response Surface Modeling and Optimization of Chromium(VI) Removal from Aqueous Solution using Tamarind Wood Activated Carbon in Batch Process. *Journal of Hazardous Materials,* 172(2–3), 818-825.

Schmidt, M. and Scharf, K. (2014). US 20140073729 Retrieved on October 17, 2015, from https://www.google.com/patents/US20140073729

Scuderi, V., Buccheri, M. A., Impellizzeri, G., Di Mauro, A., Rappazzo, G., Bergum, K., Svensson, B. G. and Privitera, V. (2016). Photocatalytic and Antibacterial Properties of Titanium Dioxide Flat Film. *Materials Science in Semiconductor Processing,* 42, 32-35.

Seyfi, S. and Abdi, M., (2009). Extraction of Titanium (IV) from Acidic Media by Tri-N-Butyl Phosphate in Kerosene. *Minerals Engineering,* 22(2), 116-118.

Shamaila, S., Sajjad, A. K. L., Chen, F. and Zhang, J. (2010). Synthesis and Characterization of Mesoporous-TiO_2 With Enhanced Photocatalytic Activity for The Degradation of Chloro-Phenol. *Materials Research Bulletin,* 45(10), 1375-1382.

Shawabkeh, R. A. (2010). Hydrometallurgical Extraction of Zinc from Jordanian Electric Arc Furnace Dust. *Hydrometallurgy,* 104(1), 61-65.

Shemi, A., Ndlovu, S., Sibanda, V. and Van Dyk, L. D. (2014). Extraction of Aluminium from Coal Fly Ash: Identification and Optimization of Influential Factors Using Statistical Design of Experiments. *International Journal of Mineral Processing,* 127, 10-15.

Shihong, H., Ting, L., Fengxia, H. and Lin, Z. (2014). Effect of Ilmenite Component and AIR on Element Distribution of Titanium Slag Smelted by DC Arc Furnace. *Rare Metal Materials and Engineering,* 43(12), 2921-2926.

Sichel, C., de Cara, M., Tello, J., Blanco, J. and Fernández-Ibáñez, P. (2007). Solar Photocatalytic Disinfection of Agricultural Pathogenic Fungi: Fusarium Species. *Applied Catalysis B: Environmental,* 74(1–2), 152-160.

Siswoyo, E., Mihara, Y. and Tanaka, S. (2014). Determination of Key Components and Adsorption Capacity of A Low Cost Adsorbent Based on Sludge of Drinking Water Treatment Plant to Adsorb Cadmium Ion in Water. *Applied Clay Science,* 97–98, 146-152.

Somasundaram, M., Saravanathamizhan, R., Ahmed Basha, C., Nandakumar, V., Nathira Begum, S. and Kannadasan, T. (2014). Recovery of Copper from Scrap Printed Circuit Board: Modelling and Optimization using Response Surface Methodology. *Powder Technology,* 266(0), 1-6.

Swamidoss, C. M. A. and Malkhede, D. D. (2014). Liquid-Liquid Extraction and Spectrophotometric Determination of Titanium (IV) With Hexaacetato Calix (6) Arene. *International Journal of Applied Chemistry,* 10(1), 59-65.

Tang, W., Chen, X., Zhou, T., Duan, H., Chen, Y. and Wang, J. (2014). Recovery of Ti and Li from Spent Lithium Titanate Cathodes by A Hydrometallurgical Process. *Hydrometallurgy,* 147–148, 210-216.

Teixeira, S. R., Santos, G. T. A., Souza, A. E., Alessio, P., Souza, S. A. and Souza, N. R. (2011). The Effect of Incorporation of A Brazilian Water Treatment Plant Sludge on The Properties of Ceramic Materials. *Applied Clay Science,* 53(4), 561-565.

Tour, T. E. L. (1989). Analysis of Rocks using X-ray Fluorescence Spectrometry. *The Rigaku Journal,* 6(1), 3-9.

Tsakiridis, P. E., Oustadakis, P., Katsiapi, A., Perraki, M. and Agatzini-Leonardou, S. (2011). Synthesis of TiO_2 Nano-Powders Prepared from Purified Sulphate Leach Liquor of Red Mud. *Journal of Hazardous Materials,* 194, 42-47.

Tuncuk, A., Stazi, V., Akcil, A., Yazici, E. Y. and Deveci, H. (2012). Aqueous Metal Recovery Techniques from E-Scrap: Hydrometallurgy in Recycling. *Minerals Engineering,* 25(1), 28-37.

Vacher, S., Hernandez, C., Bärtschi, C. and Poussereau, N. (2010). Impact of Paint and Wall-Paper on Mould Growth on Plasterboards and Aluminum. *Building and Environment,* 45(4), 916-921.

Valighazvini, F., Rashchi, F. and Khayyam Nekouei, R. (2013). Recovery of Titanium from Blast Furnace Slag. *Industrial & Engineering Chemistry Research,* 52(4), 1723-1730.

Wang, C., Bai, L., Pei, Y. and Wendling, L. (2014). Comparison of Metals Extractability from Al/Fe-Based Drinking Water Treatment Residuals. *Environ Sci Pollut Res,* 21(23), 13528-13538.

Wang, J., Li, C., Zhuang, H. and Zhang, J. (2013). Photocatalytic Degradation of Methylene Blue and Inactivation of Gram-Negative Bacteria by TiO_2 Nanoparticles in Aqueous Suspension. *Food Control,* 34(2), 372-377.

Wang, L., Yuan, Z. and Egerton, T. A. (2012). Comparison of Nano-Particulate TiO_2 Prepared from Titanium Tetrachloride and Titanium Tetraisopropoxide. *Materials Chemistry and Physics,* 133(1), 304-310.

Wang, X., Hu, Z., Chen, Y., Zhao, G., Liu, Y. and Wen, Z. (2009). A Novel Approach Towards High-Performance Composite Photocatalyst of TiO_2 Deposited on Activated Carbon. *Applied Surface Science,* 255(7), 3953-3958.

Wetchakun, N., Chainet, S., Phanichphant, S. and Wetchakun, K. (2015). Efficient Photocatalytic Degradation of Methylene Blue Over Bivo4/Tio2 Nanocomposites. *Ceramics International,* 41(4), 5999-6004.

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

Yahui, L., Fancheng, M., Fuqiang, F., Weijing, W., Jinglong, C. and Tao, Q. (2016). Preparation of Rutile Titanium Dioxide Pigment from Low-Grade Titanium Slag Pretreated by The Naoh Molten Salt Method. *Dyes and Pigments,* 125, 384-391.

Zhang, L., Li, G. Q. and Zhang, W. (2011a). Synthesis of Rutile from High Titania Slag by Pyrometallurgical Route. *Transactions of Nonferrous Metals Society of China,* 21(10), 2317-2322.

Zhang, L., Zhang, L. N., Wang, M. Y., Li, G. Q. and Sui, Z. T. (2007). Recovery of Titanium Compounds from Molten Ti-Bearing Blast Furnace Slag Under The Dynamic Oxidation Condition. *Minerals Engineering,* 20(7), 684-693.

Zhang, W., Zhu, Z. and Cheng, C. Y. (2011b). A Literature Review of Titanium Metallurgical Processes. *Hydrometallurgy,* 108(3–4), 177-188.

Zhang, Z., Peng, J., Srinivasakannan, C., Zhang, Z., Zhang, L., Fernández, Y. and Menéndez, J. A. (2010). Leaching Zinc from Spent Catalyst: Process Optimization Using Response Surface Methodology. *Journal of Hazardous Materials,* 176(1–3), 1113-1117.

Zhao, F., Dong, B., Gao, R., Su, G., Liu, W., Shi, L., Xia, C. and Cao, L. (2015). A Three-Dimensional Graphene-TiO_2 Nanotube Nanocomposite With Exceptional Photocatalytic Activity for Dye Degradation. *Applied Surface Science,* 351, 303-308.

Zhu, L., Meng, Z. D., Cho, K. Y. and Oh, W. C. (2012). Synthesis of CdS/CNT-TiO_2 with A High Photocatalytic Activity in Photodegradation of Methylene Blue. *New Carbon Materials,* 27(3), 166-174.

Zhu, Z., Zhang, W. and Cheng, C. Y. (2011). A Literature Review of Titanium Solvent Extraction in Chloride Media. *Hydrometallurgy,* 105(3–4), 304-313.

Zielińska-Jurek, A., Wei, Z., Wysocka, I., Szweda, P. and Kowalska, E. (2015). The Effect of Nanoparticles Size on Photocatalytic and Antimicrobial Properties of Ag-Pt/Tio2 Photocatalysts. *Applied Surface Science,* 353(317-325.