This is a PDF file of an unedited manuscript that has been accepted for publication.

Suan Sunandha Science and Technology Journal

Application of Photocatalytic Oxidation Technology in an Air Purifier for Benzene Removal by Using TiO_2/PLA Film

Chaisri Tharasawatpipat[1*], Torpong Kreetachat[2]

[1, 2] School of Energy and Environment, University of Phayao
19 Moo 2 Maeka subdistrict, Muang district, Phayao 56000, Thailand
Corresponding author e-mail: *chaisri.th@gmail.com

Received: *31 October, 2018* / **Revised:** *5 November, 2018* / **Accepted:** *7 November, 2018*

Abstract

The objectives of this research were to synthesize a catalyst from TiO_2 embedded on a bio-composite film through photocatalysis application to benzene removal in 785 litre of air through photocatalyzed oxidation process in Air Purifier. And found out the best of benzene volatile organic compound removal condition with Box-Benkhen design's respond surface method. The scope of the study was tested on three polylactic acid biopolymer films with the volume of TiO_2 at 5.0, 10.0 and 15.0%w/w formed by molding film method. The morphology of the film was examined by scanning electron microscope. The chemical structure of the film was scanned by X-Ray diffraction. Light absorbance was detected by UV/VIS Spectrophotometer. After SEM testing, it was found that TiO_2 on the three films were equally distributed and embedded all over the films. The crystal structure of Titanium dioxide was appeared to be an anatase structure. It was found that the energy gap was from 3.14 to 3.22 eV. The result can be confirmed the decrease of benzene compound after photocatalyzed oxidation process on photoreactor consisted of 785 litre of air. The result was shown that the light intensity at 5.24 mW/cm^2 and TiO_2 at 10.0%w/w can yield the optimum result at 62.28% of benzene compound decrease with initial intensity at 5±0.5 ppm. The most appropriate conditions to remove benzene volatile organic compound with Box-Benkhen design's respond surface method were 5.24 mW/cm^2 of light intensity, 10.0%w/w of TiO_2, and 5±0.5 ppm of benzene initial intensity. With these conditions, the result revealed that the reaction rate was 58.90% at R^2 0.82. Therefore, the concluded that the process of benzene volatile organic compound removal can be further developed in the form of equipment as air purifier with optimum condition.

Keywords: Air purifier, Benzene, Photocatalytic oxidation, Poly lactic acid film, Responsive surface method

1. Introduction

Volatile Organic Chemicals are volatile organic compounds that evaporate into the air at normal temperatures and pressures. Currently found as a compound in many products such as color, cigarette smoke, bleach, solvents in print, scattered in the air. It was found that they have a biological effect and a health hazard (Roschan & Tipayarom, 2014). Office buildings are one area where volatile organic chemicals, benzene, toluene and benzaldehyde are excreted, which, in large doses, pose a risk of disease in people. Photocatalytic oxidation technology is a technology developed to treat both organic and inorganic organic compounds in the water and in the air, called photocatalytic. It is based on ultraviolet wavelength energy combined with semiconductor particle stimulation. However, the process of treating volatile organic chemicals using this technique has several limitations. For example, controlling the factors that affect the effectiveness of treatment requires advanced techniques, catalysts must be developed to be highly efficient and safe for users and the environment, the application of volatile organic chemicals in the work area requires equipment that controls the condition to be proper. Therefore, the purpose of this study is to apply this technology by using TiO_2/PLA film as a titanium dioxide catalyst in the form of blown film. Benzene treatment in the air. The simulated 785-liter simulated room was designed to be close to the operating area where the spread of VOCs was found and the optimum condition of the experiment with the response surface methodology, Box Benkhen method. (Ray, Lalman, & Biswas, 2009) This research will be a

Available online at http://www.ssstj.sci.ssru.ac.th

Suan Sunandha Science and Technology Journal

guideline for further development of the technology for the future design of VOCs removal in air pollution.

2. Research Methodology

2.1 Film synthesis

Film Synthesis: TiO_2/PLA film production by blow film with Titanium dioxide (TiO_2, A220) and PLA, 4042D. Preparation of 5.0, 10.0 and 15.0% w/w TiO_2 powder mixed in a maleic anhydride copolymer in a heat-treated at 100-160 °C was then passed through a mixture of twin screw blown film 30 µm thickness (Suwannahong, Liengcharernsit, Sanongraj, & Kruenate, 2012).

2.2 Physical characteristics of catalyst analysis

The morphology of the TiO_2/PLA films was investigated by scanning electron microscope: SEM (model JXA-840, JEOL), which protected the charge during the test coated with gold, which is used by the metal coating (Shifu, Wei, Sujuan, & Wei, 2009). Examine the structure of TiO_2 embedded crystals distributed in X-Ray film using X-Ray method by the diffraction (TTRAXIII, Rigaku), at a wavelength of 1.5404 °A (λ= 1.5404 oA), at an electrical current of 300 mA and a potential voltage of 50 KV (Ao, Xu, Fu, Shen, & Yuan, 2008)

2.3 Reactor design

Box design, diameter 1.0 m, height 1.0 m, is made from SS 314 corrosion resistant material. Replace the reactor in the Bionaire BAP-625 series air purifier that cleans the pollutants through the annular reactor. Inside is equipped with an air velocity gauge, thermometer, moisture, UV-C and TiO_2/PLA films. Check the leakage of the pollutant when the machine is running with the method of detecting the joint with bubbles and compressed air with pressure gauge installed on the tank as shown in Figure 1 and Table 1. Examine the effectiveness of benzene treatment that knows the exact concentration, then injected through an air sampling system with gas chromatograph (GC-FID)

Figure 1. Characteristics of modified air purifier and leak detection.

Table 1. Experimental conditions for benzene treatment with 785 liters of laboratory.

Laboratory size	Diameter 1.00 m., Height 1.00 m.
Volume of laboratory	785 liters
Average wind speed within the experimental set	0.380 m/h
Average air velocity in the air purifier room	4.106 m/h
Room size within the air purifier	Width 0.2 m., Length 0.2 m, Height 0.35 m.,
The air flow ratio inside the air purifier unit	0.240 m^3/ h (4.7 L/min)
Average laboratory temperature	34.24 °C
Average room humidity	55.79%
Duration	600 mins

2.4 Testing to find the right conditions for benzene removal with respond surface method (RSM)

Testing to find the right conditions for benzene treatment in the test with respond surface method

Suan Sunandha Science and Technology Journal

(RSM), Box-Benkhen Design: BBD model. The results of 3 factors and the level of factors affecting the three levels of experiment were studied with 15 experiments as shown in Table 2 and Table 3.

Table 2. Factors and levels of each factor affecting the experiment.

Factor	Symbol	Level		
		-1	0	1
UV Light intensity (mW/cm^2)	A	1.96	3.59	5.24
TiO_2 Volume (%w/w)	B	5.00	10.00	15.00
Benzene initial concentration (ppm)	C	5.21	10.02	15.50

Table 3. Data for the optimal conditions of three-factor RSM and three-level test.

Experiment	Light Intensity (mW/cm^2)	TiO_2 Volume (w/w)	Initial intensity (ppm)
1	1.96	5.00	10.02
2	1.96	10.00	5.21
3	1.96	15.00	10.20
4	1.96	10.00	15.50
5	3.59	5.00	5.21
6	3.59	5.00	15.50
7	3.59	10.00	10.20
8	3.59	10.00	10.20
9	3.59	10.00	10.20
10	3.59	15.00	15.50
11	3.59	15.00	5.21
12	5.24	10.00	5.21
13	5.24	15.00	10.02
14	5.24	10.00	15.50
15	5.24	5.00	10.20

3. Results and Discussion

Physical characteristics of TiO_2/PLA film catalysts, bonding and dispersing of catalysts by scanning scanners were found that the surface of the films are smooth. TiO_2 catalysts were deposited on the film surface of Figure (b)-(d) as shown in Figure 2.

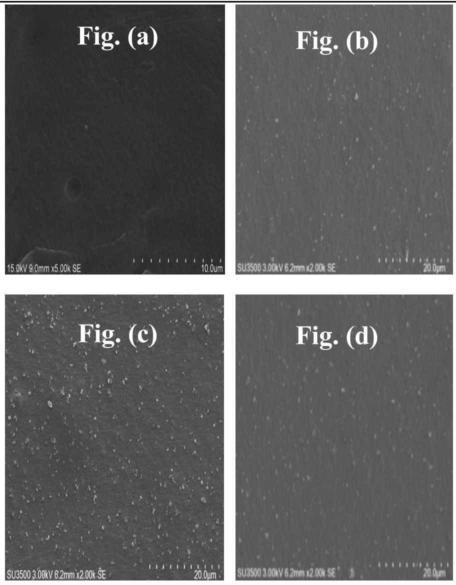

Figure 2. Results of SEM micrographs test (a) PLA film and (b), (c), (d) 5.0, 10.0 and 15.0%w/w of TiO_2/PLA film.

The effect of UV-Vis absorption spectra on all 3 films (5.0, 10.0 and 15.0% w/w) at wavelength range of 200-800 nm showed that the absorption of light spectrum was good at lower 400 nm wavelength. Over 400 nm., as shown in Figure 3. When calculating the power of Eg, it is found that the power in the Eg is at 3.14-3.22 Eg, as shown in Table 4.

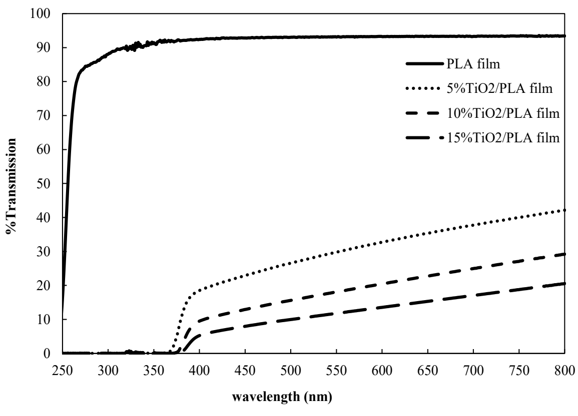

Figure 3. UV absorption test of TiO_2 /PLA film.

Vol.06.No.1 DOI: 10.14456/ssstj.2019.1

Suan Sunandha Science and Technology Journal

Table 4. Results of Eg calculation (TiO_2/PLA film).

Type of film embedded by TiO_2 (%wt)	Eg (eV)
5.0% nano-TiO_2/PLA	3.22
10.0% nano-TiO_2/PLA	3.18
15.0% nano-TiO_2/PLA	3.14

Figure 3 and Table 4 show that the TiO_2 catalyst in the PLA film, which is close to that the crystalline catalysts with anatase structure (Eg 3.20 eV.) (Zhao & Yang, 2003). The results of the embedded TiO_2 crystalline structure were examined by using X-Ray Diffraction (TTRAXIII, Rigaku) at a wavelength of 1.5404 °A, scanning from 20° to 60°. 5°/min, as shown in Figure 4.

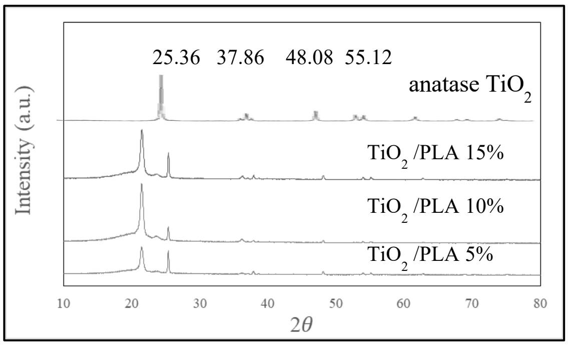

Figure 4. Results of X-Ray on crystal structure in films 5.0, 10.0 and 15.0% TiO_2 /PLA film.

From Figure 4, TiO_2 catalysts were found second signal at 2θ in the range of 25.36, 37.86, 48.08 and 55.12 minutes, corresponding to the crystalline structure of the anatase (JCPDS 65-5714) in all 3 ratio.

Test results for benzene removal in air purifier using TiO_2/PLA film by respond surface method. The optimum condition for benzene treatment in 785 liters experimental set found the best response of benzene removal, the linear correlation coefficient at R^2 was 0.82, at 5.24 mW/cm2 light intensity, 10.0% w/w of TiO2 volume, the initial concentration of benzene volatile 5±0.5 ppm was 58.90%, the mathematical equation for the experimental results and the regression model at the significance level $\alpha = 0.05$ were obtained as follows.

$$\%C_6H_6\ Removal = 53.27 + 4.81A + 5.72C - 4.68(A^2) - 4.94(B^2) - 5.85(C^2) \quad ....(1)$$

When A = Light Intensity (mW/cm^2)
B = Volume TiO_2 (w/w)
C = Initial Concentration (ppm)

The results of this study are consistent with the results of Destaillats et al. (2012) which found that benzene content suitable for photocatalytic oxidation treatment should be low and consistent with the results of Farhanian, Haghighat, Lee, & Lakdawala (2013). In higher UV intensity, treatment efficiency was higher, consistent with the results of Cao et al. (2000) The catalytic activity was lowest at 10.0%w/w, consistent with the results of Kreetachat, Kruenate, & Suwannahong (2013).

4. Conclusion

The film is made from PLA, which is put on the catalyst by the light, throughout TiO_2 distribution, has the chemical structure of anatase TiO_2 crystals, Eg of 3.14-3.22 eV, close to the Eg power of TiO_2 crystals. Therefore, it is suitable for application for the treatment of volatile organic chemicals in the air, and can be applied in benzene treatment with modified air purifier kit at maximum 62.28% and the optimal condition of the experiment by RSM technique with the best response. The TiO_2 content was 10.0%w/w and the initial benzene concentration was 5±0.5 ppm, 5.24 mW/cm^2 of light intensity, 10.0%w/w of TiO_2, initial concentration of benzene 5±0.5 ppm with a 58.90% response at R^2 of 0.82. The mathematical model of regression equation (1) at significance level $\alpha = 0.05$ that can be significantly used to test benzene treatment in air purifier kit was found.

5. Acknowledgements

We would like to thank the School of Energy and Environment, Phayao University for the support of the place. The Suan Sunandha Rajabhat University, with the advanced chemical analysis tools.

6. References

Ao, Y., Xu, J., Fu, D., Shen, X., & Yuan, C. (2008). Low temperature preparation of anatase TiO_2-coated activated carbon. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *312*(2-3), 125-130.

Cao, L., Gao, Z., Suib, S. L., Obee, T. N., Hay, S. O., & Freihaut, J. D. (2000). Photocatalytic oxidation of toluene on nanoscale TiO_2 catalysts: Studies of deactivation and regeneration. *Journal of Catalysis*, *196*(2), 253-261.

Suan Sunandha Science and Technology Journal

Destaillats, H., Sleiman, M., Sullivan, D. P., Jacquiod, C., Sablayrolles, J., & Molins, L. (2012). Key parameters influencing the performance of photocatalytic oxidation (PCO) air purification under realistic indoor conditions. *Applied Catalysis B: Environmental*, *128*, 159-170.

Farhanian, D., Haghighat, F., Lee, C.-S., & Lakdawala, N. (2013). Impact of design parameters on the performance of ultraviolet photocatalytic oxidation air cleaner. *Building and Environment*, *66*, 148-157.

Kreetachat, T., Kruenate, J., & Suwannahong, K. (2013). Preparation of TiO_2/Bio-composite film by sol-gel method in VOCs photocatalytic degradation process. *Applied Mechanics and Materials*, *390*, 552-556.

Ray, S., Lalman, J. A., & Biswas, N. (2009). Using the Box-Benkhen technique to statistically model phenol photocatalytic degradation by titanium dioxide nanoparticles. *Chemical Engineering Journal*, *150*(1), 15-24.

Roschan, S., & Tipayarom, A. (2014). Health risk assessment of exposure to volatile organic compounds emitted from photocopiers. In *The Graduate Research Conferences* (pp. 971-976). Khon Kaen: Khon Kaen University.

Shifu, C., Wei, Z., Sujuan, Z., & Wei, L. (2009). Preparation, characterization and photocatalytic activity of N-containing ZnO powder. *Chemical Engineering Journal*, *148*(2-3), 263-269.

Suwannahong, K., Liengcharernsit, W., Sanongraj, W., & Kruenate, J. (2012). Appliaction of nano-TiO_2/LDPE composite film on photocatalytic oxidation degradation of dichloromethane. *Journal of Environmental Biology*, *33*(5), 955-959.

Zhao, J., & Yang, X. (2003). Photocatalytic oxidation for indoor air purification: a literature review. *Building and Environment*, *38*(5), 645-654.

Vol.06.No.1 DOI: 10.14456/ssstj.2019.1