

Application of Photocatalytic Oxidation Technology in an Air Purifier for Benzene removal by using TiO₂/PLA Film

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Abstract

The objectives of this research were to synthesize a catalyst from TiO₂ 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 TiO₂ 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 TiO₂ 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/cm² and TiO₂ 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/cm² of light intensity, 10.0%w/w of TiO₂, and 5±0.5 ppm of benzene initial intensity. With these conditions, the result revealed that the reaction rate was 58.90% at R² 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 and 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 TiO₂/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. (Srimanta, Jerald, and Nihar, 2009) This research

will be a 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: TiO₂/PLA film production by blow film with Titanium dioxide (TiO₂, A220) and PLA, 4042D. Preparation of 5.0, 10.0 and 15.0% w/w TiO₂ 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, et al., 2012)

2.2 Physical characteristics of Catalyst Analysis

The morphology of the TiO₂/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, and Wei, 2009) Examine the structure of TiO₂ embedded crystals distributed in X-Ray film using X-Ray method by the diffraction (TTRAXIII, Rigaku), at a wavelength of 1.5404 Å ($\lambda = 1.5404$ oÅ), at an electrical current of 300 mA and a potential voltage of 50 KV. Ao, Xu, Fu, Shen and 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 TiO₂/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)

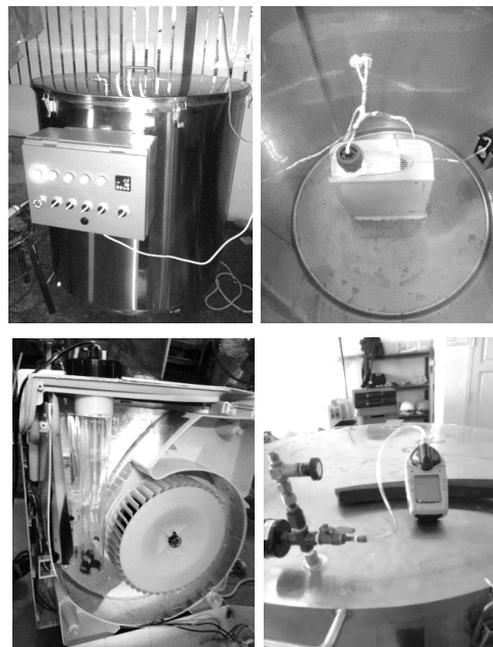


Figure 1. Characteristics of modified air purifier and leak detection

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 (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. Experimental results and criticism

Physical characteristics of TiO₂/PLA film catalysts, bonding and dispersing of catalysts by scanning scanners were found that the surface of the films are smooth. TiO₂ catalysts were deposited on the film surface of Figure (b) - (d) as shown in Figure 2.

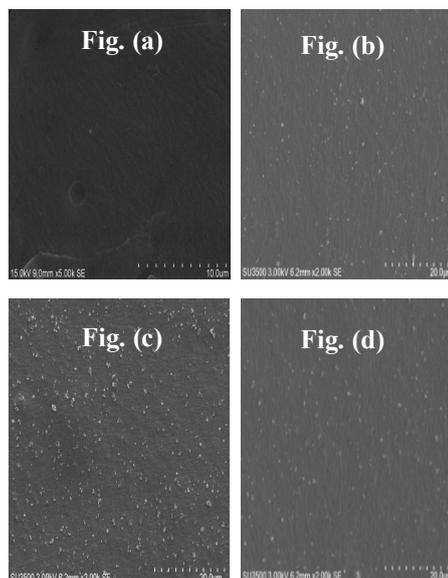


Figure 2. Results of SEM micrographs test (a) PLA film and (b), (c), (d) 5.0, 10.0 and 15.0%w/w of TiO₂/PLA film

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 Fig. 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.

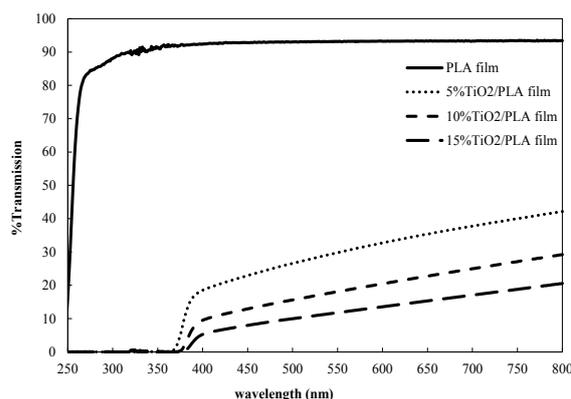
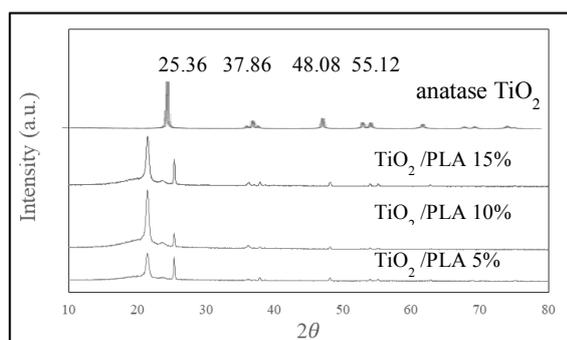


Figure 3. UV absorption test of TiO₂ /PLA film

Table 4. Results of Eg calculation (TiO₂/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 TiO₂ catalyst in the PLA film, which is close to that the crystalline catalysts with anatase structure (Eg 3.20 eV.) (Zhao, and Yang, 2003) The results of the embedded TiO₂ crystalline structure were examined by using X-Ray Diffraction (TTRAXIII, Rigaku) at a wavelength of 1.5404 Å, 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% TiO₂ /PLA Film

From Figure 4, TiO₂ 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 TiO₂/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 R² 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 α = 0.05 were obtained as follows.

$$\%C_6H_6 \text{ Removal} = 53.27 + 4.81A + 5.72C - 4.68(A^2) - 4.94(B^2) - 5.85(C^2) \dots\dots(1)$$

When A = Light Intensity (mW/cm²)
B = Volume TiO₂ (w/w)
C = Initial Concentration (ppm)

The results of this study are consistent with the results of Hugo D. et al. (2012) which found that benzene content suitable for photocatalytic oxidation treatment should be low and consistent with the results of Donya, Fariborz, Chang-S. and Ness (2013) In higher UV intensity, treatment efficiency was higher, consistent with the results of Obee T. N. et al. (2000) The catalytic activity was lowest at 10.0%w/w, consistent with the results of Kreetachat, Krueate, and Suwannahong (2013)

4. Conclusion

The film is made from PLA, which is put on the catalyst by the light, throughout TiO₂ distribution, has the chemical structure of anatase TiO₂ crystals, Eg of 3.14-3.22 eV, close to the Eg power of TiO₂ 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 TiO₂ content was 10.0%w/w and the initial benzene concentration was 5±0.5 ppm, 5.24 mW/cm² of light intensity, 10.0%w/w of TiO₂, initial concentration of benzene 5±0.5 ppm with a 58.90% response at R² of 0.82. The mathematical model of regression equation (1) at significance level α = 0.05 that can be significantly used to test benzene treatment in air purifier kit was found.

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