Coating of TiO$_2$ nanoparticles in the surface of transparent plastic grains and its application for photocatalyst under solar irradiation

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Abstract. A cylinder milling has been modified by adding a heating controller for coating TiO$_2$ photocatalyst on the surface of polymer at constant temperature. By testing the polystyrene, polypropylene, and linear-low-density polyethylene polymer density before and after coating, it is obtained that polypropylene polymer is suitable for polymer-coated TiO$_2$ because the surface is transparent and can remain floating on the surface of water although it has been coated with TiO$_2$ catalyst. Coating process of TiO$_2$ nanoparticles on the surface of the polypropylene is performed through three stages, that is stirring while heating in the cylinder milling, washing, and drying. The coating temperature is 110°C for 90 minutes. Photocatalytic activity was observed by testing the photodegradation of methylene blue dissolved in water using a container with a surface area 750 cm$^2$ and illuminated by sunlight for 12 days. The experiment was done at 6 containers with similar volume and area and variable amount of catalyst, which is without catalyst (0 g) to 5 layer of catalyst (550 g). From the colour, turbidity, and UV-Vis characterization, the methylene blue decomposition effectively occurred with amount of 220 g catalyst (2 layer of catalyst).

1. Introduction

Water pollution by organic compounds from the industry is the main reason for the development of water purification techniques. Several waste processing techniques continue to be developed, including biodegradation [1], coagulation flocculation [2], and photocatalytic [3] methods. Photocatalytic technology is a combination of photochemical processes and integrated catalysts to be able to carry out a chemical transformation reaction. The transformation reaction takes place on the surface of the light-induced semiconductor catalyst [4]. Titanium dioxide is one of the semiconductor materials that is widely used as a photocatalyst in the process of decomposing waste of organic compounds in water. TiO$_2$ has high photocatalytic activity, chemically stable, and non-toxic [5].

Various studies have been conducted so TiO$_2$ material can play an effective role in the process of water purification. The research is by coating TiO$_2$ powder on transparent fibers using vibration methods [6] and on HDPE (High Density Polyethylene) polymers by heating method in a simple stirring tube [7].
Research on coating TiO$_2$ photocatalyst material on HDPE polymers shows that the heaters used cannot be controlled at certain temperatures. In addition, coating polymers have a density greater than the density of water, which is between 0.958 - 1.162 g/cm$^3$, which causes the coated HDPE to sink into water [7]. This becomes a problem because sinking HDPE reduces effectiveness of sunlight in the process of purifying water, due to the limitation of sunlight in penetrating the depth of the water.

2. Method

In this research, we used methylene blue as a wastewater model under solar irradiation, and also technical phase titanium dioxide powder. This research was conducted in three stages. The process was initiated by coating polypropylene (PP) polymers with TiO$_2$ powder; then, use the coated polymers in the process of purifying wastewater. Last, is the characterization of wastewater that has been cleared through a photocatalytic process.

The coating process is carried out in cylinder milling that has been connected to the heater. The heating temperature is set around the melting point of the polymer, which is at 110$^\circ$C. The aim of this particular setting temperature is to make polymer surface become softer. If the surface is soft, its make the TiO$_2$ nanoparticles can easily stick around the surface. In order for the TiO$_2$ nanoparticles to stick more evenly, two magnetic stainless steel cylinders are placed in the milling. Coating in this milling is carried out for 90 minutes, then gradually the heater temperature is lowered to cool the milling.

The polymer that has been coated with TiO$_2$ is then washed by adding water and stirring using a mixer. The washing process is done repeatedly until the water that looks no longer cloudy. This shows that there are no more TiO$_2$ nanoparticles that fade from the polymer surface. The last process of this coating is the drying of coated polymers in a microwave oven. Fig.1 shows differences in polymer surface before and after coating.

![Figure 1. Polypropylene polymer before coating (left) and after coating (right) by TiO$_2$ nanoparticles.](image)

The dried coating results are then tested to purify waste water. The wastewater used consists of 15 ml of methylene blue dissolved in 15 liters of water. Tests were carried out by varying the number of polymer layers in each wastewater container with a surface area of 750 cm$^2$, ie 0g, 110g, 220g, 330g, 440g, and 550g coated polymer formed respectively 0-5 layers. Each container is then exposed to sunlight for 12 days.

To find out the results of the wastewater purification process, the color, turbidity, and solution concentration were tested using Macherey Nagel Photometer Nano Color 25 Filter, UV visible spectrophotometer Variant Cary 100 type, and UV-Vis spectrometer.

3. Result and discussion

Coated polypropylene has a density of 0.872 g/cm$^3$. Thus, the polymer can float on the surface of the water when tested to purify water. Table 1 shows the color changes and turbidity that occurs after the addition of polymers that have been coated with TiO$_2$ in wastewater. The initial color and turbidity of wastewater is 0.15 PtCo and 15.92 NTU.
Table 1. Color and turbidity.

| Sample                  | Color (PtCo) | Turbidity (NTU) |
|-------------------------|--------------|-----------------|
| Without Catalyst        | 0.09         | 14.16           |
| 1 Layer of catalyst     | 0.07         | 10.53           |
| 2 Layers of catalyst    | 0.06         | 8.53            |
| 3 Layers of catalyst    | 0.07         | 9.97            |
| 4 Layers of catalyst    | 0.06         | 9.14            |
| 5 Layers of catalyst    | 0.06         | 8.30            |

Based on the data in Table 1, it can be seen that all wastewater in the container changes color and turbidity after being exposed to sunlight for 12 days. The sample box filled with 2 layers, 4 layers, and 5 photocatalyst layers had the lowest color and turbidity compared to the other sample boxes. Besides being tested by color and turbidity test, the purified wastewater was also tested for the concentration of the solution. To determine the concentration of the solution before and after the administration of photocatalyst material in waste water, the absorption of photocatalyst material against methylene blue solution was measured.

Waste water containers that were given 2 layers and 5 layers of photocatalyst material resulted in the lowest decrease in the concentration of methylene blue. Assuming the layers of TiO$_2$ formed on the surface of the polymer are not evenly distributed, it is possible that some sunlight does not hit the layer of TiO$_2$ on the surface of the polymer, but directly on the surface of the polymer. When sunlight comes and penetrates the surface of the polymer, the sunlight can hit the TiO$_2$ layer found on other surface parts. Thus, the possibility of sunlight coming in and regarding the layers of TiO$_2$ nanoparticles will increase so that it will increase photocatalytic activity in decomposing organic pollutants.

4. Conclusion

TiO$_2$-coated polyprophelene polymer were used to degrade wastewater methylene blue solution. Based on the results of testing the color, turbidity, and concentration of the solution, it was concluded that wastewater given 2 layers photocatalyst materials produced the best decomposition of methylene blue pollutants.

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