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Evaluation of wastewater treatment using CNT/TiO_2 coating on a glass slide by a dip-coating method

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ABSTRACT

This study investigated the performance of wastewater treatment using a CNT/TiO_2 coating on a glass slide by a dip-coating method. CNT/TiO_2 nanoparticles were used as catalysts prepared by TiO_2 and CNT with a simple mixing method. CNT/TiO_2 was dip-coated on a glass slide in a PVA polymer solution at room temperature. The catalyst dosage of CNT/TiO_2 was varied at 10, 20, and 30% wt/wt, respectively, after which XRD, TGA, BET, and FE-SEM analyses were carried out to characterize the as-prepared catalysts. As a result, the ratio of 30% wt/wt CNT/TiO_2 coated on a glass slide achieved the greatest methylene blue (1×10^{-5} M) removal at 64% in 3 h. It showed a higher performance than that of other ratios because of the good distribution of the optimized catalyst coated on glass. CNT has a high surface area (confirmed by BET at 218.64 $m^2 g^{-1}$) and is widely used as the support material for improving the photocatalytic activity of TiO_2 under visible light. For the application of wastewater treatment in a reactor, 30% wt/wt CNT/TiO_2 coating on glass slides also showed the highest performance of BOD removal up to 53% in 3 h. The adhesion of CNT/TiO_2 remained on the glass as well, resulting in less loading loss. Therefore, it could be promising as an effective catalyst material in wastewater treatment applications.

Keywords: Titanium dioxide; Carbon nanotube; Dip-coating; Wastewater treatment; Photocatalytic activity

1. Introduction

Photocatalytic activity is well known for its effective performance reaction in environmental treatment. This reaction can produce hydroxyl and superoxide radicals, resulting in the oxidation of pollutants into carbon dioxide, water, and certain intermediate compounds [1,2]. Titanium dioxide (TiO_2) is mostly used as a catalyst in wastewater treatment due to its high photocatalytic activity, low solubility, high thermal activity, and lack of toxicity [3]. Recently, carbon nanotube (CNT) or graphene has been widely used for material support with TiO_2. On general grounds, some properties are almost the same, but some others are different. For instance, graphene is a semi-metal, while carbon nanotube is either a metal or semiconductor depending on chirality. However, CNT is more robust and flexible than graphene sheets. It is very

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cheap and has better mechanical and electrical properties compared to most graphene oxides. Therefore, CNT was selected for use as a nanocomposite of CNT/TiO_2 in this work. CNT/TiO_2 nanocomposite was mostly reported for the various preparation techniques and high efficiency for environment treatment [4,5]. CNT/TiO_2 is very useful as a photocatalyst because of its high photocatalytic activity, super hydrophilicity, chemical stability, and low price [6]. In the past, several studies have investigated the synthesis of TiO_2 nanocomposites with various metal doping by sol-gel method and hydrothermal method for degradation of dyes under UV irradiation [7]. However, UV light in the reaction can directly affect the eyes and skin of the user. Thus, CNT is a material that supports the synthesis of CNT/TiO_2 nanocomposites, which can react under normal light such as fluorescent or visible light. CNT also can absorb a variety of pollutants, increase the surface area, and reduce the recombination of TiO_2 particles, thereby improving the efficiency of pollution treatment [8]. Recently, the photocatalytic activity of CNT/TiO_2 for the degradation of dyes or organic pollutants under visible light was the focus of investigation [2–4]. Another study focused on the improvement of a new method for the preparation of CNT/TiO_2 and evaluated the performance of photocatalytic degradation compared with commercial TiO_2. Many researchers reported that CNT/TiO_2 nanoparticles showed the enhancement of pollutants adsorption and degradation of some organic compounds from wastewater [5,6]. Although CNT/TiO_2 catalyst showed high efficiency of photocatalytic degradation, CNT/TiO_2 nanoparticles had limited work. One drawback of using CNT/TiO_2 for environment applications is its limit for use in particle form for wastewater treatment applications on site. CNT/TiO_2 nanoparticles have difficulty in the recovery process after use.

To overcome this problem, the immobilization of CNT/TiO_2 thin film must be developed. Consequently, many researchers have studied and developed the preparation of CNT/TiO_2 based photocatalysts for use by various techniques such as dip coating [9], spin coating [10], electrospinning [11], etc. Moreover, several studies have been performed using a combination of CNT/TiO_2 coated substrates, mostly glass slides, for dye removal. The dip-coating technique has many advantages such as simplicity, low cost, easy recovery, and effectiveness to prepare the TiO_2 particle coated on various substrates [12]. The dip-coating method is mostly used for surface coating the various materials onto substrates. In addition, it is simple technology that uses environmentally friendly materials, and is suitable for prerequisite in future applications. Previous research reported that CNT was dispersed in the prepared solution into the substrate and could form a coat as a thin film [13]. The quality of coating depended on several factors such as solution viscosity, immersion time, pull-up speed, and the interaction between the dispersion and substrate. The catalyst nanoparticles can be easily added to the polymer solution and dip to the substrate by a dip coater [14]. Thus, nanoparticles can be embedded directly into various substances with the use of these techniques. In a later study, polyvinyl alcohol (PVA) is widely applied as a copolymer for the synthesis of nanocomposites in a cost-efficient and environmentally friendly, direct-blending method [15]. PVA is best known as a non-toxic polymer with good physical properties, excellent biocompatibility, and cost-effectiveness compared with other polymers [16]. Therefore, PVA was selected as a polymer for forming using dip-coating with CNT/TiO_2 on glass in this work.

Methylene blue (MB) is the most useful standard dye for investigating the photocatalytic degradation of organic pollutants in wastewater [17]. In this work, MB was used for testing the decolorization on photocatalytic activity under visible light because it has very good performance in the degradation of dyes due to post-treatment removal. After obtaining the best ratio of the prepared CNT/TiO_2 coating on a glass slide for the high performance of MB removal, the wastewater treatment in a reactor was evaluated. Besides, a reactor in this work was a new design applied for wastewater treatment. Moreover, it is well known that many researchers have worked on photocatalysis under visible light. As reviewed from literature, however, no paper has reported on the preparation of CNT/TiO_2 coated on a glass slide by dip-coating for wastewater treatment applications in a prototype reactor. Thus, we prepare the simple method of CNT/TiO_2 coated on a glass slide by a dip-coating technique. This is beneficial for applying new photocatalytic methods for increasing wastewater treatment. The prepared CNT/TiO_2 was also investigated for structural properties by XRD, surface compositional properties by TGA and BET, and morphological properties by FE-SEM.

2. Experimental methods

2.1. Chemicals

Titanium dioxide (TiO_2) (Loba Chemie Pvt. Ltd., India) was used as a catalyst of TiO_2. The CNT was from Nano generation Co. Ltd., Thailand. This CNT has an average diameter of 12.9 mm. Nitric acid 69% (HNO_3) (Sigma-Aldrich Chemical Co. Ltd., USA) was used for the CNT acid treatment method. Methylene blue ($C_{16}H_{23}CIN_2S$) was purchased from Sigma-Aldrich Chemical Co. Ltd., USA). Polyvinyl alcohol (PVA) (Sigma-Aldrich Chemical Co. Ltd., USA) was used as a polymer solution for the dip-coating process.

2.2. Preparation of CNT acid treatment

CNT was treated with nitric/sulfuric-mixed acid following the methods reported in previous works [5]. CNT (1.0 g) was stirred for 10 min in HNO_3:H_2SO_4 mixture (1:3 (v/v), 40 mL). The solution was stirred for 24 h to disperse CNT completely in the acid solution. CNT was then washed with deionized water to remove any residual acid until its pH value was adjusted to 7. After that, CNT was dried overnight at 100°C in an oven. Finally, the CNT acid-treated powders were obtained.

2.3. Preparation of CNT/TiO_2 coating on a glass slide by dip-coating method

In the typical dip-coating procedure, the dip-coating solution contained TiO_2, CNT, H_2O, and PVA. The ratio of CNT: TiO_2 was fixed at 1:20 wt/wt. PVA (10%wt/v) 10.0 g was added into 100 mL H_2O for a polymer solution, while CNT 0.048 g and TiO_2 0.952 g were added into 100 mL PVA solution,

respectively. The catalysts in the solution were mixed by a stirrer for 1 h and sonicated for 1 h at room temperature. CNT/TiO_2 nanoparticles were loaded on a glass slide with PVA binders. After that, CNT/TiO_2 coating on a glass slide formed a thin film by dipping using an automatic coating machine and dip-coated with a draw speed of 10 cm min^{-1} for 5 cycles, as illustrated in Fig. 1. After obtaining the CNT/TiO_2 coating on a glass slide, CNT/TiO_2 particles coated on a glass slide were investigated to confirm the chemical and physical properties by X-ray diffraction (XRD, Bruker D8 Discover). Thermogravimetric analysis (TGA, Netzsch TG 209 F3 Tarsus) thermograms, a Brunauer-Emmett-Teller (BET, Autosorb-1 Charantachrome BEL) surface area, and a field emission-scanning electron microscope (FE-SEM, JSM-7610F) were also used.

For the varied CNT/TiO_2 ratios in this work, CNT/TiO_2 coated on a glass slide was studied for evaluation of the highest performance wastewater treatment in the range of 10–30%wt/wt based on the weight of PVA, as described in Table 1. The various catalyst dosages (10–30% wt/wt) were studied from the concept of the particles that must be stabilized against flocculation. Remarkably, the limit of spontaneous gluing of CNT/TiO_2 particles in the PVA solution is caused by the attractive forces between the particles. There is an effect of the dip-coating process coated on a glass slide. After the drying process at 105°C in air, the CNT/TiO_2 coated on a glass slide by the dip-coating method was obtained.

2.4. Photocatalytic activity testing

The experimental method was divided into two parts. For the first part, the dual functions of absorptivity and photocatalytic activities of obtaining CNT/TiO_2 coating on a glass slide were studied from the decolorization of Methylene blue (MB) in an aqueous solution (1×10^{-5} M, 50.0 ml) [5], as illustrated in Fig. 2 (Part 1). To compare with the efficiency of photocatalytic activity, MB was used for testing the decolorization on photocatalytic activity under visible light because it has very good performance in the degradation of dyes due to easy post-treatment removal. The obtained CNT/TiO_2 coating on a glass slide with various ratios (10 to 30%wt/wt) was investigated. CNT/TiO_2 coating on a glass slide with each ratio was immersed in the MB solution and stirred for 1 h at room temperature in a reactor in the dark (closed light) for 3 h to study the performance of adsorption. The reducing concentration of MB under the dark condition was then determined by a UV-vis spectrometer at the maximum wavelength of 664 nm. After completing adsorption, fluorescent lamps (15 W × 4 lamps) with a light intensity of 5,700 lux were used to study the photocatalytic activity of the same catalyst under visible light. Finally, the decrease of MB concentration was recorded at a fixed time interval (every 30 min) using a UV-Vis spectrometer. MB removal was calculated by using Eq. (1) [17].

$$\%\ \text{MB removal} = \frac{(C_0 - C)}{C_0} \times 100 \tag{1}$$

where C_0 and C are the initial concentration and concentration at a measuring time, respectively.

After obtaining the best ratio for the obtained CNT/TiO_2 coating on a glass slide from MB removal testing from Part 1, CNT/TiO_2 coating on a glass slide was evaluated in the wastewater treatment reactor, as illustrated in Fig. 2 (Part 2). The municipal wastewater effluent was collected using the grab sampling method and put in a glass bottle 3 times. It was then injected into a designed reactor following Fig. 2. To study the performance of wastewater treatment, decreased wastewater concentrations were determined by biochemical oxygen demand (BOD). The photocatalytic degradation efficiency of CNT/TiO_2 coating on a

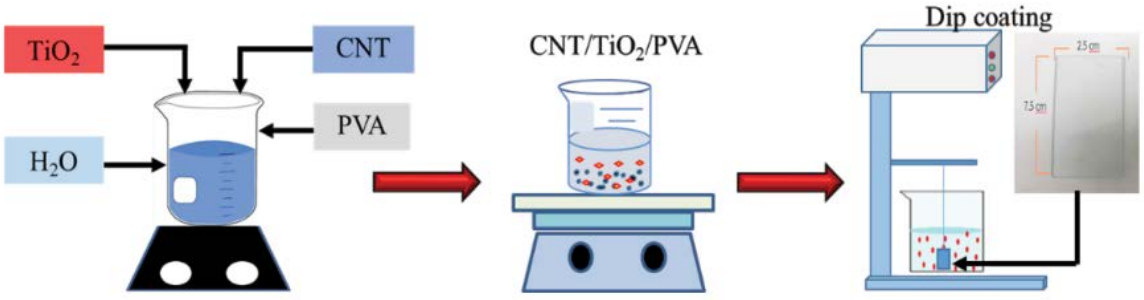

Fig. 1. Dip coating method coated on a glass slide.

Table 1
Composition ratio of preparation

Sample name	PVA (10%wt/v)	CNT/TiO_2	CNT	TiO_2
10%wt CNT/TiO_2	10.0 g	1.0 g	0.048 g	0.952 g
20%wt CNT/TiO_2	10.0 g	2.0 g	0.095 g	1.905 g
30%wt CNT/TiO_2	10.0 g	3.0 g	0.143 g	2.857 g

glass slide was calculated. The obtained from the best ratio CNT/TiO_2 coating on a glass slide was selected and put into the acrylic tube with LED lamps (3,400 lux). Wastewater sample flowed through the reactor model with an axial fan pump at a rate of 25 mL/min. CNT/TiO_2 coating on a glass slide was left to adsorb pollutants from wastewater samples for 3 h. After adsorption equilibrium, the LED lamps were turned on. A wastewater sampling was taken three times from the wastewater treatment model to detect every 30 min for BOD analysis until 3 h at room temperature.

3. Results and discussion

3.1. Characterizations of CNT/TiO_2

CNT/TiO_2 coating on a glass slide was fabricated by the dip-coating method. The molar ratio of CNT: TiO_2 was fixed at 1: 20 by weight. It should be noted that in the preparation of the PVA in H_2O (100 mL) for dip coating solution, the weight of PVA (10% wt/v) was used at 10.0 g for all samples. The various ratios of CNT/TiO_2 in PVA solution were prepared in the range of 10 to 30% wt based on PVA, as illustrated in Fig. 3. After dip coating, CNT/TiO_2 coated on glass sides with various ratios were dried in air to remove H_2O. To study and confirm the composition of CNT remaining TiO_2 nanocomposites, 30% wt CNT/TiO_2 nanoparticle-based on PVA was selected to study the chemical and physical properties.

The XRD patterns of 20% wt CNT/TiO_2 are illustrated in Fig. 4. The crystalline TiO_2 anatase peaks could be formed at 25.3°, 37.9°, 48.0°, 54.0°, 55.0°, and 62.5° at diffractions of (101), (004), (200), (105), (211), and (204), respectively, corresponding to the standard diffraction data of JCPDS 071-1166 [18]. The crystal size was calculated through XRD in Fig. 4. It was found that the average size of CNT/TiO_2 was 21.27 nm. The structure of the CNT/TiO_2 composites shows a typical single and clear anatase crystal structure. However, the peak of TiO_2 could be observed, but the impurity peak of PVA was also observed at the peaks of 12°, 32°, and 38° [19]. Besides, CNT peaks could be formed at

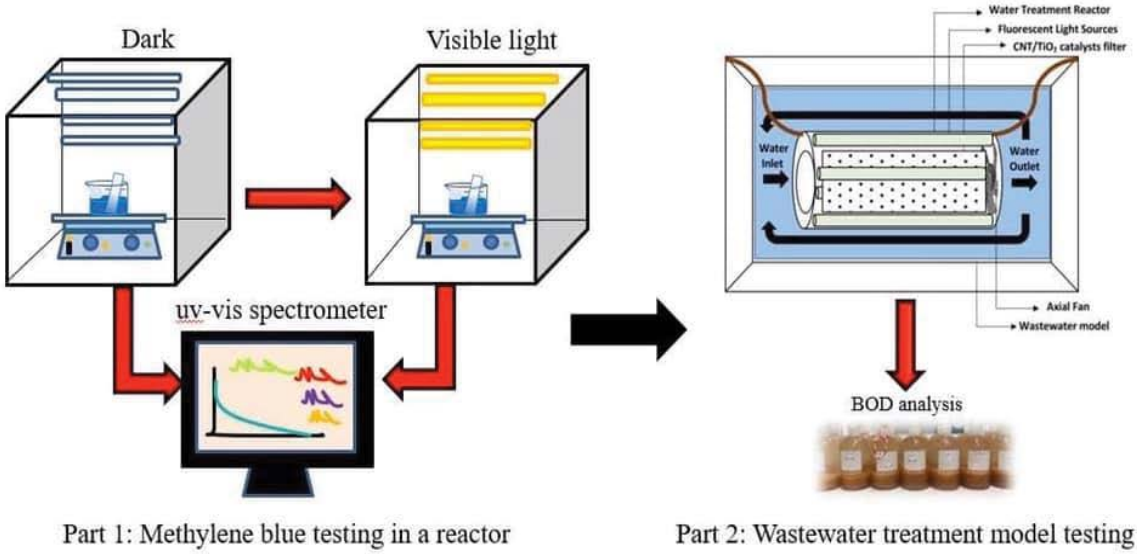

Fig. 2. Photocatalytic activity testing by CNT/TiO_2 coating on a glass slide.

Fig. 3. CNT/TiO_2 with various ratios coating on a glass slide.

26.3°, corresponding to (002) of CNT (JCPDS 008-0415) was detected and almost overlaps with the (101) peak of anatase TiO_2 [20], indicating the CNT/TiO_2 composites had been prepared by simple mixing and dip coating completely.

TGA thermograms of CNT/TiO_2 nanoparticles are shown in Fig. 5. It was found that CNT/TiO_2 exhibited 5 steps loss of its mass. The first step was to cover the temperature range from 30°C to100°C, which corresponds to the loss of moisture (H_2O). The second step covered the temperature range from 120°C to 274°C and 274°C to 442°C, which corresponded to the loss of PVA polymer. This is following a previous report for the thermal decomposition of PVA polymer [21]. The third step covered the temperature range from 442°C to 555°C, which corresponded to the thermal decomposition of the CNT structure. The fourth step covered the temperature range from 555°C to 680°C, which corresponded to the impurities of carbon in a nanocomposite. After increasing temperature to 680°C, the residue weight of TiO_2 was found at 12.63 %wt. This agreed with Rodríguez, et al. [22], which also showed the XRD patterns of CNT/TiO_2. It can be confirmed again that the CNT and TiO_2 powders could be mixed well in a spinning polymer solution during the dip-coating method.

According to the surface area studied, the values of BET of CNT/TiO_2 composites are shown in Table 2. BET surface areas of pristine CNT were 218.64 $m^2\ g^{-1}$, while the BET surface areas of TiO_2 and CNT/TiO_2 were 56.09 and 157.71 $m^2\ g^{-1}$, respectively. The surface areas of CNT/TiO_2 were a considerable decrease than that of pristine CNT, which suggests that some porosity decreased during the preparation process. The BET surface area decreased due to the curing of the PVA polymer, which blocked the microspores [23]. The polymer might have coated some CNT particles to form some larger composite particles during the mixing process.

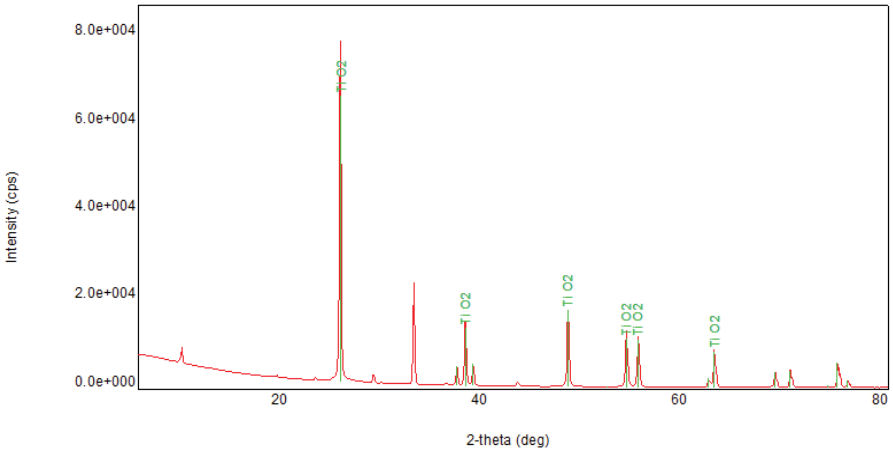

Fig. 4. Crystalline structures of CNT/TiO_2 by XRD.

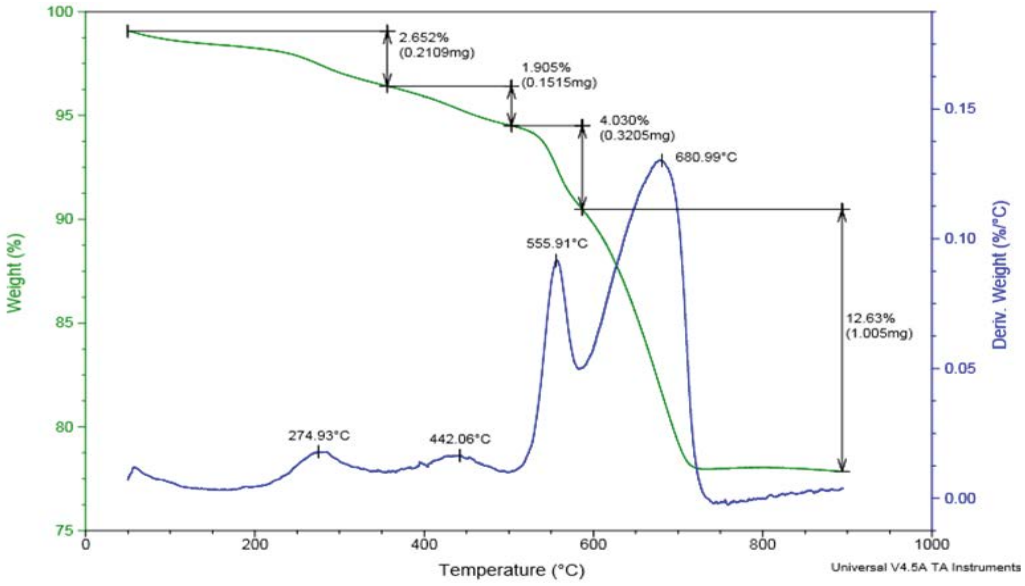

Fig. 5. Thermal degradation of CNT/TiO_2 by TGA.

Table 2
The values BET surface areas of TiO_2, CNT, and CNT/TiO_2

Sample	S_{BET} (m^2 g^{-1})	Pore volume (cm^3 g^{-1})	Pore diameter (nm)
TiO_2	56.09	0.21	3.72
CNT	218.64	0.34	7.62
CNT/TiO_2	157.71	0.28	2.76

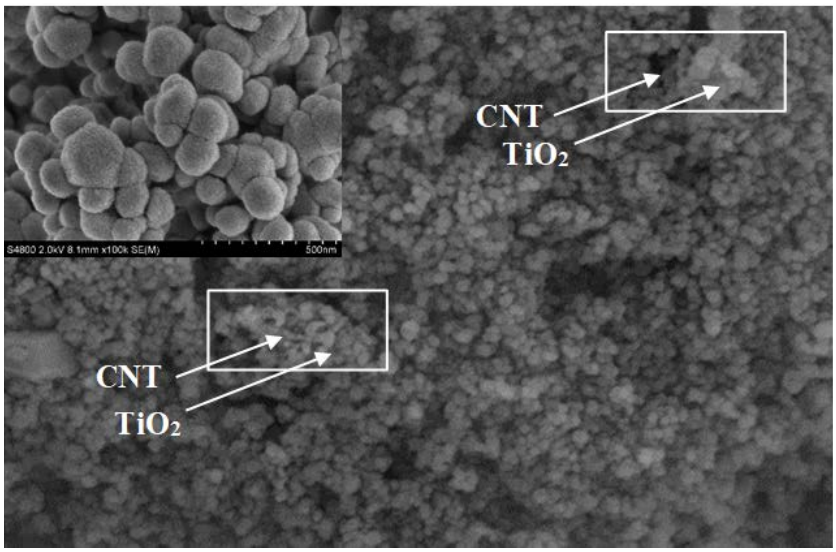

Fig. 6. Morphological appearances of CNT/TiO_2 by FE-SEM.

To confirm the CNT remained on the CNT/TiO_2 nanocomposite, FE-SEM was also used to study. FE-SEM images illustrating the morphological appearance of CNT/TiO_2 are presented in Fig. 6. It could be observed that the particles of TiO_2 were well distributed. According to the close-up scale view of CNT/TiO_2 nanocomposites, it was found that TiO_2 nanoparticles had no smooth surface, uniform agglomeration, and a few observed for CNT in the nanocomposite. However, the dispersion of the CNT in TiO_2 particles was not good in the nanocomposite. This is because CNT/TiO_2 could be mixed well in a PVA solution from the preparation of the spinning solution method, but could not be mixed well for a coating using a glass slide method. The PVA polymer might have coated well for some CNT particles to form some CNT/TiO_2 composite particles during the mixing process. Basically, CNT/TiO_2 particles were revealed from the fact that the cohesion force among CNT/TiO_2 particles was greater than the adhesion force between CNT/TiO_2 and the surface of a glass slide. Moreover, it can occur in the dip-coating process. The catalyst particles cannot stabilize against flocculation and aggregation later before coating on the surface of a glass slide. The morphology of CNT cannot be observed further because the CNT in the ratio of CNT:TiO_2 (1:20%wt/wt) was too low. This could occur due to the blocking of morphological appearance by the formation of TiO_2 and the CNT surface by the PVA binder between a prepared mixing solution process. The diameter of TiO_2 ranged from 18–23 nm, while the diameter of CNT ranged from 30–50 nm. This is following a previous report that showed the average diameters of the TiO_2 nanoparticle and the CNT were in a range of 10–20 nm [24] and 20–40 nm [25], respectively.

3.2. Methylene blue testing in a reactor

The photocatalytic removal of CNT/TiO_2 coating on a glass slide was performed by methylene blue (MB) testing in a reactor under visible light. A reactor consists of four fluorescence lamps (15W × 4 lamps) with a light intensity of 5,700 lux. CNT/TiO_2 coating on a glass slide was injected into the MB solution with concentration 1×10^{-5} M and put into a reactor. MB concentration was studied for 3 h to assess adsorption ability in the dark before photocatalytic degradation. The decreasing MB concentration was investigated by a UV-vis spectrometer. After adsorption was completed, a fluorescence light was turned on and the performance of MB removal was measured. To compare the photocatalytic activities, the performance of CNT/TiO_2 coating on a glass slide with various ratios was investigated, as illustrated in Fig. 7. The photocatalytic activity of MB removal under visible light was carried out for 3 h and the decreasing of MB concentration was investigated using a UV-Vis spectrometer. The results showed that the performance of MB removal by CNT/TiO_2 coating on a glass slide with 30% wt/wt CNT/TiO_2 based on the weight of PVA (64%) was higher than that of 20% wt/wt CNT/TiO_2 (54%) and 10% wt/wt CNT/TiO_2 (47%), respectively.

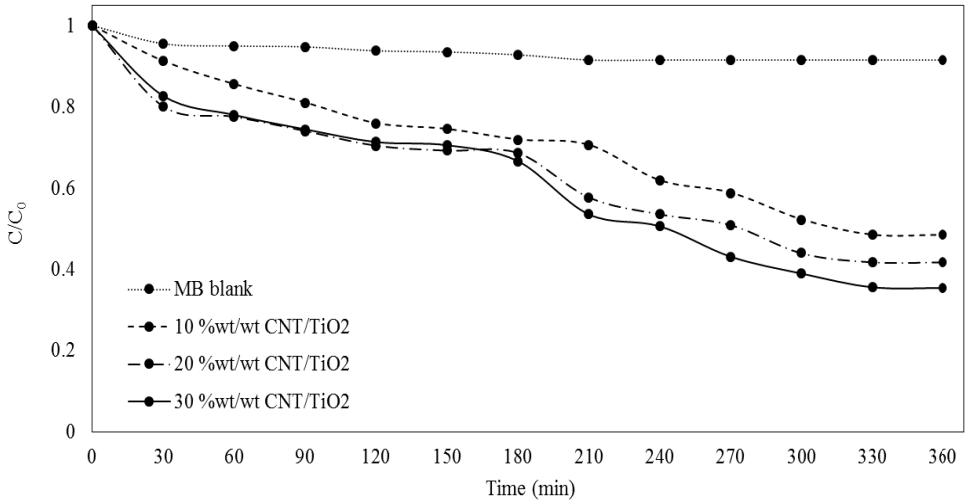

Fig. 7. MB removal of CNT/TiO_2 coating on a glass slide with various ratios.

According to the results, the concentration of MB removal decreased a little in all samples under dark conditions. After the adsorption was completed, the lamps in the reactor were turned on. The results showed a different trend with the dark condition. The efficiency of MB removal using the CNT/TiO_2 coating on a glass slide with 30% wt/wt was the highest. It is evident that a higher weight of catalyst CNT/TiO_2 coated on a glass slide has an important effect on the photocatalytic activity than a lower weight ratio. This is because the total weight of catalyst by CNT/TiO_2 could enhance the photocatalytic activity under visible light irradiation. The roles of the CNT in improving the photocatalytic reactivity of TiO_2 under visible light could be explained by the fact that CNT/TiO_2 has a larger specific surface area (157.71 m^2 g^{-1}) compared with TiO_2 (56.09 m^2 g^{-1}). CNT is material support like activated carbon, which can adsorb more MB. CNT is material support like activated carbon. CNT enhances the adsorption ability that can be used in terms of adsorption, corresponding to previous reports [26,27]. The results could be identified that the adsorption abilities are the performance of CNT/TiO_2 coating on a glass slide to adsorb the MB in the dark. Photocatalytic degradation is the performance of CNT/TiO_2 coating on a glass slide to degrade the MB under visible light. Therefore, adsorption abilities and photocatalytic degradation are the performance of CNT/TiO_2 coating on a glass slide, together with absorbing the MB in the dark and degrading the MB under visible light. However, if the weight of the ratio was increased up to 40% wt/wt CNT/TiO_2, it was observed that CNT/TiO_2 was agglomerated and could not coat on a glass slide. This is because of the limit of the weight ratio that cannot be saluted in the solution for the dip-coating method. Therefore, 30% wt/wt was selected to study for the evaluation of wastewater treatment in a model for the next part.

3.3. Wastewater treatment in reactor testing

The photocatalytic degradation of 30% wt/wt CNT/TiO_2 coating on the ten of glass slides was investigated in a wastewater treatment model under visible light. The wastewater model consists of four LED light lamps (3,400 lux). A reactor was constructed in an acrylic box with a volume of 2.0 L (20.0 cm × 10.0 cm × 10.0 cm). A wastewater sample was collected from municipal drainage and injected into the reactor. The selected 30% wt/wt CNT/TiO_2 coating on the ten of glass slides was put inside and studied for adsorption in the dark for 3 h. The adsorption ability of catalysts was investigated by BOD analysis. After adsorption was completed, the LED lights were turned on, and the performance of wastewater treatment was measured by BOD analysis for 3 h. To compare the performance of the photocatalytic activity, the pristine 30% wt/wt TiO_2 coating on the ten of glass slides was used as a reference. Moreover, the performances of photocatalytic treatment of wastewater were investigated using the glass slides without the catalyst coating. The results for the adsorption abilities and photocatalytic activity of 30%wt/wt CNT/TiO_2 coating on ten glass slides for MB degradation under visible light are shown in Fig. 8.

The photo-degradation efficiency evaluated by BOD analysis showed that 30% wt/wt CNT/TiO_2 was 53% higher than that of pristine 30% wt/wt TiO_2 (24%) and the glass slides without catalyst (19%). These results confirm that the CNT had a significant effect (as confirmed by BET). Additionally, CNT is material support like activated carbon. It is used as a nanocomposite material for the preparation of CNT/TiO_2 on photocatalytic activity under visible light. CNT/TiO_2 has a larger specific surface area (157.71 m^2 g^{-1}) compared with TiO_2 (56.09 m^2 g^{-1}) which can adsorb more organic compound pollutants in wastewater. The CNT was a transporting channel of an electron to TiO_2 for photocatalytic activity and could enhance the photodegradation activity of the photocatalysts. Additionally, CNT/TiO_2 has a larger specific surface area compared with TiO_2, which can absorb more pollutants. Furthermore, CNT can prevent the recombination effect, thus, improving photocatalytic activity. This agreed with previous research [28,29], which also showed high performance for the photocatalytic activity of CNT/TiO_2 nanocomposite. Even though CNT/TiO_2

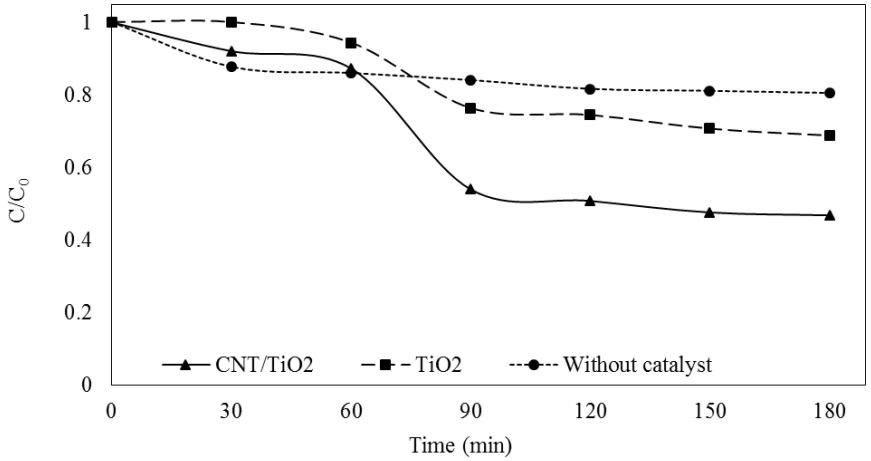

Fig. 8. Performance of BOD treatment using CNT/TiO_2 coating on the glass slides.

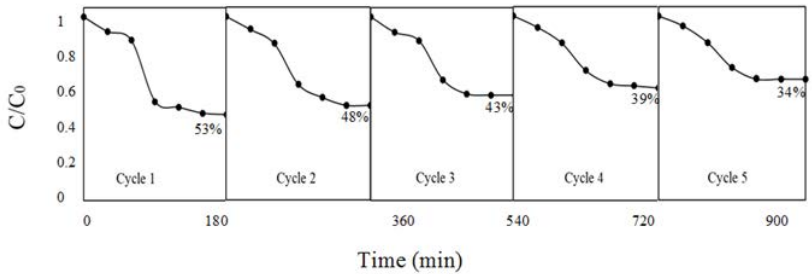

Fig. 9. Cycle of photocatalytic ability of CNT/TiO_2 coating on the glass slides.

coated on the glass slides in this work exhibited a higher wastewater treatment than pristine TiO_2 under visible light irradiation, the effective support for adsorption ability is low, because the thin film form has a small CNT loading on glass surface area, which must be improved as a drawback of the preparation process.

CNT/TiO_2 coating on the glass slides was conducted to evaluate performance and recyclability. The 30%wt/wt CNT/TiO_2 coating on the ten glass slides was investigated repeatedly for the performance of wastewater treatment by BOD analysis up to five times, as illustrated in Fig. 9. The five-cycle repeated photocatalytic degradation efficiency of the catalyst was 53%, 48%, 43%, 39%, and 34%, respectively. This showed the degradation efficiency of CNT/TiO_2 coating on the glass slides was 19% less after being used for five cycles. The surface of the CNT/TiO_2 catalyst was covered with the pollutants contaminated for the recycling, which corresponds with Yuan et al. [23]. The photocatalytic activity of catalysts was stable for at least five cycles. Therefore, CNT/TiO_2 coating on glass slides could be promoted for utilization in wastewater treatment applications.

4. Conclusion

The photocatalytic application of CNT/TiO_2 coating on a glass slide prepared by the dip-coating method for wastewater treatment was investigated in a reactor under visible light. The CNT/TiO_2 catalyst coated on glass slides with various ratios were compared, and 30% wt/wt CNT/TiO_2 showed the highest performance for MB removal. For evaluation of wastewater treatment, CNT/TiO_2 showed a much better photocatalytic performance of BOD loading than that on both pristine TiO_2 and the glass slides without a catalyst. This is because of the high surface area of the CNT, which could support the photocatalytic reactivity of TiO_2. Even though CNT/TiO_2 coating on a glass slide has high photocatalytic efficiency, the recovery process after use and the aggregation of suspended particles are difficult for environmental applications. Moreover, thin-film coating on a glass slide forms a very sticky adhesive between CNT and TiO_2 nanocomposite, more than the particles form, which causes CNT leaching during the run process. Therefore, CNT/TiO_2 coating on glass slides as photocatalysts is effective support for photocatalytic degradation ability, which is beneficial for wastewater efficient photocatalysts.

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