Research Article

Synthesis of Al-MCM-41@Ag/TiO₂ Nanocomposite and Its Photocatalytic Activity for Degradation of Dibenzothiophene

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Mesoporous Al-MCM-41@Ag/TiO₂ nanocomposites were synthesized successfully by combining the sol-gel method and hydrothermal treatment, using titanium isopropoxide (TTIP), AgNO₃, and Vietnamese bentonite as precursors of Ti, Ag, and Si, respectively. The synthesized materials were well characterized by X-ray powder diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), N₂ adsorption-desorption isotherm measurements, energy dispersive X-ray spectroscopy (EDX), UV-visible diffuse reflectance spectroscopy (UV-Vis/DRS), and X-ray photoelectron spectroscopy (XPS). The photocatalytic activity was evaluated by the photodegradation of dibenzothiophene (DBT) under both UV and visible light irradiation. MCM-41@Ag/TiO₂ catalyst exhibited high catalytic activity for the oxidative desulfurization (ODS) of DBT reaching almost 100% conversions at 50°C after 2 h under UV and visible light irradiations. The significant enhanced degradation of DBT over Al-MCM-41@Ag/TiO₂ might be due to the synergy effects of high surface area of MCM-41, well-distributed TiO₂ anatase, and reduced electron-hole recombination rates due to the dispersion of Ag nanoparticles.

1. Introduction

Dibenzothiophene presenting in diesel is one of the main sulfur-containing organic pollutants in fuel oils and is difficult to be removed [1]. This organic pollutant is difficult to be reduced using the conventional hydrodesulfurization (HDS) due to its steric hindrance [2, 3]. Photocatalytic oxidation is one of the most promising pollution treatments to remove many organic pollutants in water [4] and air steam [5]. Due to more stringent environmental regulations, it is critical to develop effective photocatalysts for the removal of sulfur-containing organic compounds from fuel oils through photocatalytic oxidation processes. Titanium dioxide (TiO₂) has been well known and was the most widely studied semiconductor photocatalyst due to its low cost, nontoxicity, and high chemical stability [6]. However, the

semiconductor TiO₂ has a wide band gap (3.0–3.2 eV) that strongly restricted its application because the material only absorbs a small fraction of the solar photons (the UV light occupies about 5% of the total solar energy). Besides, high recombination between electrons (e⁻) and holes (h⁺) results in reduced photocatalytic efficiency [7, 8].

The incorporation and doping of noble metal nanoparticles (e.g., Ag, Au, and Pt) into the crystal lattice of TiO₂ (metal-TiO₂) to absorb the abundant visible light due to their surface plasmon resonance (SPR) have been investigated to overcome this limitation in the TiO₂ photocatalyst material [9–12]. Silver has an advantage of having a lower cost compared with gold or platinum. However, the use of metal-TiO₂ powders in the treatment of aqueous organic pollutants has some drawbacks such as difficult recovery and poor adsorption capacity due to its low surface area and agglomeration

in suspension [13]. Therefore, noble metal nanoparticles doping on titania with improved crystallinity, surface area, and surface properties to achieve higher adsorption capacity and photocatalytic activity [14] have been studied extensively such as metal-titania nanoparticles coated on the high surface area supports and thermally stable core materials [15, 16]. Nanoporous materials such as ordered mesoporous silica [17–19], activated carbon [20, 21], microporous zeolites [22, 23], and metal organic frameworks [24, 25] have been widely used as TiO_2 carriers due to their versatile structures and high porosity to achieve more active sites per unit area, consequently, a higher photocatalytic reaction rate. Mesoporous aluminosilicate Al-MCM-41 is one of the most widely used support materials due to its remarkable acidic properties, high thermal and mechanical stability, highly ordered hexagonal structure, and high surface area [26–30]. Recent studies have focused on the use of low-cost raw materials, particularly in their natural forms such as bentonite clay to synthesize high value products. The inorganic components consisting of silica and alumina were collected by annealing bentonite with sodium hydroxide at a temperature higher than 500°C to use for the synthesis of Al-MCM-41 [31, 32]. Herein, the Al-MCM-41 mesoporous material was prepared by a hydrothermal method using the Vietnamese bentonite as Si and Al precursors. Then, Ag/ TiO_2 nanoparticles were deposited on the surface of the Al-MCM-41 material to improve the dispersion of TiO_2 , and the synthesized Al-MCM-41@Ag/ TiO_2 nanocomposites were used as a photocatalyst for the oxidative desulfurization of dibenzothiophene under both UV and visible light irradiation.

2. Experimental

2.1. Chemicals. Dibenzothiophene (DBT), triblock Pluronic F127 ($\text{EO}_{106}\text{PO}_{70}\text{EO}_{106}$, 99 wt%, $M = 12,600$), titanium (IV) isopropoxide (TTIP, 97 wt%), *n*-octane (99 wt%), silver nitrate (99 wt%), cetyltrimethylammonium bromide (CTAB, 98 wt%), ethanol (99.5 wt%), acetic acid (99 wt%), hydrogen peroxide (30%wt), and NaOH (98%wt) were purchased from either Sigma-Aldrich or Merck. Bentonite was obtained from Di Linh, Vietnam, with a chemical composition of $52 \text{ SiO}_2 : 15 \text{ Al}_2\text{O}_3 : 11 \text{ Fe}_2\text{O}_3 : 0.8 \text{ TiO}_2 : 2 \text{ CaO} : 3.5 \text{ MgO} : 2 \text{ Na}_2\text{O}$ in weight percent and the loss on ignition (LOI) of 13.7%.

2.2. Synthesis of Al-MCM-41 from Vietnamese Bentonite. Firstly, Si and Al precursors were obtained following the protocol described by Ali-dahmane et al. [31]. The Vietnamese bentonite was mixed with sodium hydroxide (NaOH) in bentonite:NaOH weight ratio of 1:1.2 and heated at 550°C for 3 h in air. The fused bentonite obtained was cooled, milled, mixed with distilled water with a weight ratio of 1:4, and then stirred at room temperature for 24 h. The supernatant was separated by centrifugation to obtain the Si and Al precursors.

In a typical Al-MCM-41 synthesis, 1.2 g CTAB was added to 20 mL distilled water. Then, 42 mL of the supernatant was added to the above solution and stirred at room temperature for 6 h at pH of about 9–10, which was adjusted

by acetic acid. The crystallization step was carried out at 100°C in a stainless steel autoclave for 24 hours. The white precipitate was then filtered and washed three times with distilled water and ethanol and dried overnight at 100°C . Finally, the template CTAB was removed by calcining at 550°C for 6 h in air.

2.3. Synthesis of Al-MCM-41@nAg/ TiO_2 Nanocomposite. Al-MCM-41@nAg/ TiO_2 nanocomposite microspheres were synthesized by a sol-gel method. 0.1 g of the synthesized Al-MCM-41 was dispersed in 100 mL ethanol via sonication for 1 h. Then, 0.2 g F127 and 2 mL distilled water were added to the above solution. The mixture was stirred at 50°C for 30 minutes.

A TiO_2 precursor (solution A) was prepared by dissolving titanium(IV) isopropoxide (TTIP) in a mixed solvent of ethanol and nitric acid to form a final composition of 1 TTIP : $\text{C}_2\text{H}_5\text{OH}$: 2 H_2O : 0.2 HNO_3 . Solution B was prepared by adding $n\%$ ($n = 5, 10, \text{ and } 15$) moles of AgNO_3 into 15 mL ethanol and stirred for 30 minutes. Then, solution A was mixed with solution B and stirred vigorously for 30 minutes. The Ag/ TiO_2 precursor was added dropwise to the Al-MCM-41 suspension to obtain Al-MCM-41@nAg/ TiO_2 . The temperature was then increased to 80°C under refluxing conditions for 6 h. The solid was collected by centrifugation and washed thoroughly with ethanol and dried at 80°C . Finally, F127 was removed by calcining the obtained solid at 450°C in air for 5 h.

2.4. Oxidative Photodesulfurization of Dibenzothiophene. Dibenzothiophene was dissolved in *n*-octane to create a model fuel with known sulfur content in ppm. Next, 20 mL of DBT/*n*-octane solution was placed in a 500 mL three-neck round-bottom flask containing 0.05 g catalyst. The suspension was stirred for 30 minutes in the dark and then was illuminated with two 15 W UV lamps (UV light) or a 165 W tungsten lamp (visible light) at various temperatures (30°C , 50°C , and 70°C) under refluxing conditions for 5 h. 0.5 mL of H_2O_2 as an oxidative agent was added to the mixture at the reaction temperatures. After certain reaction time, small amounts of the products were taken out, centrifuged, and analyzed by high-performance liquid chromatography (HPLC). Then, peak areas were converted to their corresponding concentrations through the standard curves. The percentage of degradation of DBT (η) was calculated according to the initial, C_0 (ppm), and final, C (ppm), concentrations of DBT in the solution following this equation: $\eta = 100 \times (C_0 - C)/C_0$.

2.5. Characterization. Powder X-ray diffraction (XRD) patterns were recorded on a D8-Advance Bruker with $\text{Cu-K}\alpha$ radiation ($\lambda = 0.15406 \text{ nm}$) as the X-ray source at a scan rate of $0.3^\circ\text{--}0.6^\circ \text{ min}^{-1}$. Transmission electron microscopy (TEM) images were taken by a TEM TECNAI G 2 20 with an accelerating voltage of 200 kV. Scanning electron microscopy (SEM) images were obtained on an S4800-Hitachi. Pore size distributions were calculated from N_2 isotherms using the

Barrett–Joyner–Halenda (BJH) model. Energy dispersive X-ray (EDX) spectra were measured on a JED-2300 instrument. The surface electronic states identified through X-ray photoelectron spectroscopy (XPS) were taken on an AXIS ULTRA DLD Shimadzu–Kratos spectrometer using monochromatic X-rays Al-K α radiation (1486.6 eV). UV-Vis diffuse reflection spectroscopy (UV-Vis/DRS) was performed on a Shimadzu UV2550 spectrophotometer with a BaSO₄-coated integrating sphere in the wavelength range of 200–800 nm.

3. Results and Discussion

3.1. Characterizations of the Synthesized Materials. Wide-angle XRD patterns of Al-MCM-41, Al-MCM-41@TiO₂, and Al-MCM-41@Ag/TiO₂ with different Ag concentrations are shown in Figure 1. The XRD pattern of Al-MCM-41 (Figure 1(e)) does not have diffraction peaks in the range of 15° to 30°, indicating a characteristic of amorphous silica walls of the pristine material. In contrast, Al-MCM-41@TiO₂ (Figure 1(d)) and Al-MCM-41@Ag/TiO₂ (Figures 1(a)–1(c)) contain diffraction peaks at $2\theta = 25.4^\circ$; 37.9° ; 48.4° ; 54.0° ; 55.2° ; and 62.8° corresponding to (101), (004), (200), (105), (211), and (204) planes of a typical TiO₂ anatase phase, respectively [33]. Al-MCM-41@Ag/TiO₂ composites contain obvious diffraction peaks of TiO₂, but no typical peaks of Ag were observed. This might be due to the low concentration of Ag, or the typical diffraction peaks of Ag were covered by a (004) diffraction peak of the TiO₂ anatase. The presence of Ag in the Al-MCM-41@Ag/TiO₂ composites will be discussed later using EDX and XPS methods.

Figure 1 (inset) is the small angle XRD results of Al-MCM-41, Al-MCM-41@TiO₂, and Al-MCM-41@Ag/TiO₂. Diffraction peaks at $2\theta = 2.3^\circ$; 3.9° ; and 4.5° of the Al-MCM-41 sample were assigned, respectively, to (100), (110), and (200) planes associated with a p6mm hexagonal symmetry of a mesoporous material with highly uniform and ordered structure. However, the peak intensities at $2\theta = 2.3^\circ$ were significantly reduced, and the other peaks at 3.9° and 4.5° were not clear (Figures 1(a)–1(d) (inset)). This could be due to the existence of TiO₂ and Ag/TiO₂ inside the channels of Al-MCM-41@TiO₂ and Al-MCM-41@Ag/TiO₂ materials.

SEM images of Al-MCM-41 and Al-MCM-41@0.1Ag/TiO₂ are shown in Figure 2. The SEM images of Al-MCM-41 revealed irregular spherical particles with a cross-linked network and a particle size of about 120 nm. The average particle size of Al-MCM-41@0.1Ag/TiO₂ (150 nm) was larger than that of Al-MCM-41 nanoparticles, which indicated a possible coverage of TiO₂ nanoparticles having a thickness of about 15 nm on the surface of the Al-MCM-41@0.1Ag/TiO₂ nanocomposite.

Figures 3(a) and 3(b) are the TEM images of Al-MCM-41@0.1Ag/TiO₂ catalyst. The TEM images showed that the nanocomposite possesses ordered mesoporous channels with a slight decrease in the orderly porous structure as compared to the parent Al-MCM-41 material, which is in agreement with the XRD result. The Ag/TiO₂ particles having the size of about 5–15 nm were well-

FIGURE 1: XRD patterns of (a) Al-MCM-41@0.15Ag/TiO₂, (b) Al-MCM-41@0.1Ag/TiO₂, (c) Al-MCM-41@0.05Ag/TiO₂, (d) Al-MCM-41@TiO₂, and (e) Al-MCM-41. Inset is the small angle X-ray diffraction patterns.

dispersed on the surface and mesopore of the Al-MCM-41 support.

The UV-Vis diffuse reflectance spectra of Al-MCM-41, Al-MCM-41@TiO₂, and Al-MCM-41@nAg/TiO₂ composites in the range of 250–800 nm are shown in Figure 4. The strong UV absorption spectrum of Al-MCM-41@TiO₂ observed at strong absorption band at wavelengths from 250 to 380 nm, with the sharp absorption edge of about 330 nm, is attributed to the intrinsic band gap absorption of anatase TiO₂ [34]. Al-MCM-41@0.1Ag/TiO₂ and Al-MCM-41@0.15Ag/TiO₂ containing a high amount of Ag nanoparticles showed a light absorption band in the visible region with peaks at about 435 nm. This could be related to the localized surface plasmon resonance effect of silver nanoparticles [35], which varies with the Ag content of MCM-41@Ag/TiO₂ nanostructures. The band gaps of the composite samples were calculated from their UV-Vis/DRS spectra based on the method proposed by Kumar et al. [36] using the following equation:

$$\alpha h\nu = (Ah\nu - E_g)^{n/2}, \quad (1)$$

where E_g is the band gap (eV), ν is the light frequency, A is the absorption constant, h is Planck's constant, and α is the absorption coefficient. The band gap E_g values of Al-MCM-41@TiO₂, Al-MCM-41@0.05Ag/TiO₂, Al-MCM-41@0.1Ag/TiO₂, and Al-MCM-41@0.15Ag/TiO₂ were 3.20, 2.9, 2.83, and 2.81 eV, respectively. These results indicated that the dispersion of silver nanoparticles on TiO₂ increases the absorption of light in the visible region and narrows their band gaps. In addition, the Ag nanoparticles acted as electron traps to inhibit recombination [37], which may be beneficial for improving the catalytic activity of the catalysts.

FIGURE 2: SEM images of (a) Al-MCM-41 and (b) Al-MCM-41@0.1Ag/TiO₂.

FIGURE 3: TEM images of Al-MCM-41@0.1Ag/TiO₂.

FIGURE 4: UV-Vis diffuse reflectance spectra of Al-MCM-41@0.15Ag/TiO₂, Al-MCM-41@0.1Ag/TiO₂, Al-MCM-41@0.05Ag/TiO₂, Al-MCM-41@TiO₂, and Al-MCM-41.

The EDX of Al-MCM-41@0.1Ag/TiO₂ (Figure 5) confirmed the presence of the elements of O, Si, Al, Ti, and Ag with no other impurities observed. The weight percentage of Ag loaded into TiO₂ was 6.01% (corresponding to Ag/Ti = 0.095), which is very close to the calculated value of Ag/Ti = 0.1. The EDX analysis of the Al-MCM-41@0.1Ag/TiO₂ sample revealed a Si/Al ratio of about 12. This value confirmed that a fairly high amount of aluminum obtained from the Vietnamese bentonite was incorporated into the structure of silica MCM-41.

The N₂ adsorption-desorption isotherms of Al-MCM-41 and Al-MCM-41@0.1Ag/TiO₂ were typical for type IV, with a hysteresis loop characteristic of mesoporous materials (Figure 6). The calculated specific surface area (S_{BET}) of Al-MCM-41 was 633 m²·g⁻¹ with a pore volume of 0.9 cm³·g⁻¹ and of Al-MCM-41@0.1Ag/TiO₂ was 144 m²·g⁻¹ with a pore volume of 0.3 cm³·g⁻¹. The specific surface area and mesoporous volume of Al-MCM-41 loading Ag/TiO₂ were lower than those of the pristine Al-MCM-41, which is due to the blocking of some pores by the doping of Ag/TiO₂ nanoparticles.

XPS analysis was carried out to analyze the surface composition and chemical states of Al-MCM-41@0.1Ag/TiO₂ (Figure 7(a)). The spectrum confirmed the presence of O, Si, Al, Ti, and Ag elements without any other impurities. Figure 7(b) is the high-resolution XPS spectrum

FIGURE 5: EDX spectrum of Al-MCM-41@0.1Ag/TiO₂. FIGURE 6: N₂ adsorption-desorption isotherms of (a) Al-MCM-41 and (b) Al-MCM-41@0.1Ag/TiO₂.

of Ag 3d of Al-MCM-41@0.1Ag/TiO₂. Two observed energy bands at 367.51 eV and 373.51 eV correspond to Ag 3d_{5/2} and Ag 3d_{3/2} of metallic silver. These bands are slightly lower than the bulk Ag metal at 368 eV and 374 eV indicating a strong interaction between Ag and TiO₂. The splitting energy between Ag 3d_{5/2} and Ag 3d_{3/2} is 6 eV, which further confirmed the existence of metallic Ag nanoparticles in the synthesized Al-MCM-41@0.1Ag/TiO₂ material [35, 38]. It is also clearly observed that the presence of two different peaks for Ag 3d_{5/2} binding energies at 368.1 eV and 367.6 eV were assigned to metallic silver (Ag⁰) and silver ions in Ag₂O (Ag⁺), respectively [39]. Thus, partially oxidized metallic Ag nanoparticles were deposited on the TiO₂ surface during the

synthesis. Figure 7(c) is the high-resolution XPS spectrum of Ti 2p of Al-MCM-41@0.1Ag/TiO₂. Ti 2p consists of two peaks at 458.48 eV and 464.18 eV (splitting energy = 5.7 eV) which are in accordance with Ti 2p_{3/2} and Ti 2p_{1/2} of Ti⁴⁺ in Ag/TiO₂ nanostructures, respectively [35, 40].

3.2. Photocatalytic Activity of Nanocomposite. The photocatalytic performance of Al-MCM-41@Ag/TiO₂ with different Ag loadings was evaluated by the oxidative desulfurization of DBT in the model fuel under the visible light source in 30 minutes at 70°C. The photocatalyst with low Ag loading (0.5wt % Ag/TiO₂) exhibited a weak performance (conversion of DBT~48%) due to the low concentration of active catalytic sites, whereas the highest efficiency was obtained for Al-MCM-41@0.1Ag/TiO₂ (78% DBT conversion). Due to more silver decorated on the surface of TiO₂ for Al-MCM-41@0.15Ag/TiO₂ compared with Al-MCM-41@0.1Ag/TiO₂, although they have almost the same band gaps, the overlapping of the plasmonic field region makes the photocatalytic activity of Al-MCM-41@0.15Ag/TiO₂ mesoporous structure decline (conversion of DBT is 65%). However, overloading of Ag will reduce the amount of available active sites due to the spatial charge repulsion, thereby affecting the photoactivity. Hence, Al-MCM-41@0.1Ag/TiO₂ as a photocatalyst has the best photocatalytic activity due to its suitable plasma resonance band, narrow band gap, and available active sites, which is also consistent with the literature [41–43]. Al-MCM-41@0.1Ag/TiO₂ photocatalyst was then chosen to carry out the next catalytic tests.

For comparison, the degradation of DBT over Al-MCM-41@TiO₂ by the irradiation of UV and visible light was carried out. At 70°C and after 2 hours, the Al-MCM-41@TiO₂ photocatalyst degraded only about 40% of DBT under UV light (Figure 8), and almost negligible degradation was observed under visible light (not shown). Compared with Al-MCM-41@TiO₂ sample, Al-MCM-41@0.1Ag/TiO₂ exhibited remarkably enhanced photocatalytic activities under the same visible light and UV irradiation. The photodegradation efficiencies of DBT increased to almost 100% after 2 h, at 70°C (Figure 8). The improved photocatalytic activity of nanocomposite is due to the strong UV and visible light absorption of Al-MCM-41@0.1Ag/TiO₂ material. The Al-MCM-41 support with a large surface area will increase the ability to disperse the catalytic activity center, which will increase the catalytic activity. The surface plasmon resonance of silver nanoparticles was in the visible light region, leading to efficiently absorbing visible light irradiation. In addition, the excellent conductivity of silver nanoparticles may improve electron mobility to enhance the transfer of surface charge to the boundary and prevent the recombination of electrons and holes. Al-MCM-41 acted as an adsorbent in the reaction. By using the sol-gel method, the TiO₂ silver-modified silver nanoparticles were homogeneously distributed in ethanol, thereby well dispersed on the pristine material through an intermediate polymer layer of F-127. F-127 played a very important role in TiO₂-coated denaturing with Ag because without F-127 TiO₂ nanoparticles are difficult to bond with Al-MCM-41 formed. On

FIGURE 7: XPS spectra of (a) Al-MCM-41@0.1Ag/TiO₂, (b) Ag_{3d}, and (c) Ti_{2p}.

FIGURE 8: Conversion of DBT over Al-MCM-41@TiO₂ and Al-MCM-41@0.1Ag/TiO₂ under UV/visible light irradiation. Experimental conditions: V (model fuel) = 20 mL, $m_{\text{Al-MCM-41@0.1Ag/TiO}_2}$ = 0.05 g, $V_{\text{H}_2\text{O}_2}$ = 0.5 mL, and T = 70°C.

the other hand, Al-MCM-41 covered with F-127 to help disperse the TiO_2 nanoparticles onto the surface. The F-127 also protected the hexagonal structure of Al-MCM-41 in the core without being broken down during synthesis. Teng et al. [44] showed that SiO_2 not only played a role in the dispersion of TiO_2 but also protected the Fe_3O_4 core and prevented the core from dissolving into the solution in the formation of the sandwich structure of $\text{Fe}_3\text{O}_4@\text{SiO}_2@\text{TiO}_2$.

The effect of temperature on the oxidative desulfurization of DBT during UV and visible irradiations are shown in Figures 9 and 10. It can be seen that as the temperature increased from 30°C to 70°C under both UV and visible light, the conversion of DBT increased and reached 100% at 70°C after 2 hours. The results are in good agreement with literature that increase in the reaction temperature improves the photodegradation efficiency [45].

After 2 h at the reaction temperature slightly above room temperature (30°C), the deep desulfurization could be achieved with 89% and 81% conversions under UV and visible light irradiation, respectively. This was attributed to the formation of conduction band (CB) electrons (e^-) and valence band (VB) holes (h^+) under irradiation. This indicates that the visible light absorption of TiO_2 samples was considerably improved by adding Ag and Al-MCM-41 to TiO_2 .

Al-MCM-41 has a uniform pore structure and high surface area, which facilitates the high adsorption of DBT. The Ag nanoparticles were photoexcited to enable the generation of electron and Ag^+ (h^+) due to the surface plasmon resonance effect, and the photoexcited electrons can be further introduced into the conduction band of TiO_2 (Equation (2)) [34]. The next possible reaction steps could happen as follows:

Species $\bullet\text{OH}$ and $\text{O}_2^{\bullet -}$ obtained in the presence of the photocatalyst and H_2O_2 as the oxidant under irradiation could effectively oxidize DBT to its corresponding sulfone [46]. Ag^+ (h^+) ions were reactive radical species, which were able to oxidize DBT and reduce to metallic silver. Thus, Ag could be rapidly regenerated, and the Al-MCM-41@0.1Ag/ TiO_2 composites remained stable.

4. Conclusions

In summary, the Al-MCM-41@Ag/ TiO_2 nanocomposites have been successfully synthesized using the Vietnamese bentonite as Si and Al sources and well characterized by various analytical techniques. Al-MCM-41@Ag/ TiO_2 composites exhibited much higher photocatalytic activities for

FIGURE 9: Conversion of DBT under UV at various reaction temperatures. Experimental conditions: V (model fuel) = 20 mL, $m_{\text{Al-MCM-41}@0.1\text{Ag}/\text{TiO}_2} = 0.05$ g, and $V_{\text{H}_2\text{O}_2} = 0.5$ mL.

FIGURE 10: Conversion of DBT under visible irradiation at various reaction temperatures. Experimental conditions: V (model fuel) = 20 mL, $m_{\text{Al-MCM-41}@0.1\text{Ag}/\text{TiO}_2} = 0.05$ g, and $V_{\text{H}_2\text{O}_2} = 0.5$ mL.

degrading DBT under visible light irradiation than Al-MCM-41@ TiO_2 , and Al-MCM-41@0.1Ag/ TiO_2 was found to have the best photocatalytic performance. Incorporating Ag and TiO_2 into Al-MCM-41 substrate had positive effects on the photocatalytic activity of the TiO_2 , under both visible light and UV irradiations. At a relatively mild condition of 30°C , DBT degraded 90% under UV light irradiation and 81% under visible light after 2h. At higher temperature (70°C), the DBT photooxidative desulfurization efficiency of 100% could be achieved after 2 hours under visible light. The Ag nanoparticle dispersed on Al-MCM-41@ TiO_2

nanocomposites has shown its superiority and the potential as a promising material for the removal of toxic organic pollutants either in the UV or visible light region.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

The results of the HPLC analysis of the conversion of DBT were investigated over time at various reaction temperatures under UV and visible irradiation conditions using Al-MCM41@0.1Ag/TiO₂ and Al-MCM-41@TiO₂ catalysts. (*Supplementary Materials*)

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