

Preparation of ZSM-5/TiO₂ photocatalyst by dip-coating method and evaluation isopropanol removal capacity

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ABSTRACT

The incorporation of TiO₂ with zeolite ZSM-5 has been explored to facilitate photocatalytic activity and establish a continuous volatile organic compound (VOC) treatment system. In this study, composites of ZSM-5 and commercial TiO₂ with various ratios were successfully deposited onto cylindrical glass tubes by the dip-coating method using specialized equipment. To improve suspension stability and mitigate the sedimentation of heavy particles, a carboxymethyl cellulose additive was introduced into the mixture. The morphology properties and component determination were characterized with SEM-EDX, revealing the homogeneous distribution after applying the dip-coating method, showing a minor deviation of only 4% to 12% between actual and theoretical mass loadings. Photocatalytic performance was evaluated through the removal of gaseous isopropanol (IPA) utilizing an air simulation system coupled with gas chromatography (GC-FID) analysis. A wide range of factors, including humidity, concentration of VOC, UV light intensity, and the catalyst's mass, were simulated to investigate their effect on the photocatalyst's performance and make a conclusion in the most optimal working condition. Gas chromatography (GC) analysis of VOC content after treatment asserts the superiority of materials containing ZSM-5 and TiO₂ at appropriate ratios (2:8 and 6:4) over TiO₂ solely, with higher photocatalytic efficiency (47.7% and 42.9%). The higher the humidity and VOC concentrations, the lower the productivity of the photocatalyst. Furthermore, long-term activity testing demonstrated the excellent structural stability and durability of the optimized composite, which maintained a consistent conversion efficiency of approximately 46% over 6 consecutive hours of continuous operation. Interestingly, doubling the deposited catalyst mass from 0.1 g to 0.2 g yielded no significant increase in photocatalytic efficiency, indicating that performance is primarily governed by the component ratios exposed directly to light rather than total coating mass. Quantitatively, increasing the UV intensity from 2 to 4 lamps significantly accelerated hydroxyl radical generation and doubled the maximum treatment efficiency. Therefore, the most optimal condition and catalyst preparation process should be surveyed for the effectiveness of VOC gas treatment.

Key words: Zeolite ZSM-5, TiO₂, Dip-coating method, Isopropanol removal, Photocatalytic activity

INTRODUCTION

Volatile organic compounds (VOCs) are produced and emitted from a diverse range of sources both indoor and outdoor as key ingredients in household products and intermediates in chemical synthesis. Among those, major contributors to VOCs are petrochemical activities and the burning of fossil fuels in industries and vehicles^{1,2}. Being exposed to VOCs through inhalation, ingestion or skin contact can cause symptoms like headaches, nausea, and irritation in the short-term, and cancer growth in case of high content in prolonged periods³. Numerous methods have been developed to enhance VOC removal which can be separated into two categories: recovery technology including absorption, adsorption, condensation, membrane separation, etc., and destruction technology embracing combustion, pho-

tocatalysis, biodegradation, low-temperature plasma, etc⁴.

In this research, the combination of adsorption and photocatalysis methods is studied using two primary materials: zeolite ZSM-5 and Titanium dioxide TiO₂. The high adsorption capacity of zeolite is attributed to their pore topology with microporous channels and/or cages, creating high surface area and pore volumes⁵. Moreover, since hydrophobicity increases with the Si/Al ratio, high silica zeolites are applied to form an inorganic surface with strong adsorption affinity towards the organic compounds⁶. In addition, TiO₂ is the predominant photocatalyst employed in photocatalytic applications since it can be activated by UV light to generate electron and hole pairs⁷⁻⁹. The photo-generated electrons can either directly reduce the organic contaminants or interact with electron acceptors (for example, O₂) to reduce

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it to superoxide radical anion $O_2^{\cdot-}$ then degrade the contaminants. In addition, photo-generated holes can either directly oxidize the organic molecules, or interact with OH^- or H_2O to oxidize them into $\cdot OH$ radicals and then degrade the organic contaminants⁷. With the support of the unique structural properties and chemical composition of zeolite, the composite exhibits an improvement in the photocatalytic overall performance¹⁰.

Extensive research has been conducted to explore and optimize the synthesis of TiO_2 /zeolite composites, aiming to enhance their structural and functional properties for photocatalytic applications. Several methods have been investigated to generate the composition of TiO_2 /zeolite, resulting in various properties for size, shape, specific surface area, hydrophobicity, photocatalytic degradation time, etc. Sol-gel method is one of the most popular method¹¹⁻¹³. T. Kim et al. employed Titanium (IV) isopropoxide as a precursor for titanium dioxide, incorporating zeolite 13X into the synthesis. As the zeolite-to- TiO_2 ratio increased from 0.5 to 1.5, the material's BET surface area rose sharply, exceeding $500\text{ m}^2\text{ g}^{-1}$. The study also revealed that the regeneration efficiency of the composite is higher than that of the bare zeolite filter, proven by over 90% and 80% after the first two cycles for formaldehyde and toluene, respectively¹⁰. In the study conducted by the S. Suárez team, TiO_2 particles were homogeneously distributed on hierarchical ZSM-5 zeolite using the incipient wetness impregnation method. This synthesis approach resulted in a twofold increase in BET surface area, reaching approximately $338\text{ m}^2\text{ g}^{-1}$, and achieved the highest photocatalytic activity toward HCHO with only 8% TiO_2 loading¹⁴. According to Y. Kosuke's research, mechanical mixing enables precise comparisons between photocatalysts by allowing a broad range of TiO_2 and adsorbent compositions, while preserving the TiO_2 particle size and crystallinity. This is attributed to the adsorption of molecules onto the microporous crystal surfaces¹⁵.

In this study, the MFI-type zeolite ZSM-5 was incorporated with commercial TiO_2 via a mechanical mixing technique, supported by a Carboxymethyl Cellulose (CMC) additive to facilitate the formation of a stable suspension. A simple and suitable dip-coating process was employed to deposit the materials onto a cylindrical glass tube, with the objective of attaining a homogeneous thin film and enhancing the photocatalytic performance of the composite. CMC was introduced to improve mixture uniformity and stability, supporting the dip-coating process by increasing

viscosity. The catalytic efficacy was assessed using isopropanol (IPA) and compared among various samples under a diverse array of experimental conditions.

MATERIALS-METHODS

Materials

Zeolite Na-ZSM-5 was previously synthesized and characterized by CATlab (Department of Physicochemical and Analytical Technologies - Faculty of Chemical Engineering, HCMUT)¹⁶. Titanium Dioxide (TiO_2) P25 is purchased from Degussa (99.9% purity, APS: 25nm). Additives Carboxymethyl cellulose (CMC) is produced by Nippon Paper Co., Ltd, Japan (>90%). Other substances include Sodium Hydroxide (NaOH, >96%) from Xilong, China, and Ethanol (C_2H_5OH , >99.5%) from VN-Chemsol Co., Ltd.

Instrumentation

A dip coating apparatus (Department of Applied Science, HCMUT) consists of 4 main components: the control box, support stand, motor, and lifting clamp, operating at a consistent speed of 30 cm min^{-1} . X-ray diffraction (XRD) pattern of the composite was performed using an X-ray diffractometer (Bruker D2 phaser, Germany). Elemental composition and high-resolution images of surface topography were obtained by Scanning electron microscope-energy dispersive X-ray (SEM-EDX) (FE-SEM Hitachi 4800). VOC removal efficiency was calculated from VOCs output content analyzed by Gas Chromatography - Flame Ionization Detector (GC-FID) (Hewlett-Packard 5890 Series II Plus). To test the VOC gas removal efficiency of the composite, an air simulation system can be employed to establish specific conditions as demonstrated in Figure 1. This system operates on two primary gas sources: pure nitrogen (> 99.99%) and pure oxygen (> 99.99%), combined at a ratio of 4:1, which is similar to the composition of air. Additionally, precise amounts of IPA and water vapor are introduced into these gas streams at varying ratios to achieve the desired concentration and humidity levels for experimental conditions. Additionally, this reaction system includes four Sanko Denki F10T8BLB lamps (UV radiation intensity 1.5W).

Procedure

The initial step involved treating the surface of a glass tube 30cm long with 50 mL of 10 wt.% sodium hydroxide over 1 hour to eliminate contaminants, activate the surface, and etch it for enhanced adhesion in subsequent steps. Subsequently, the tube was rinsed

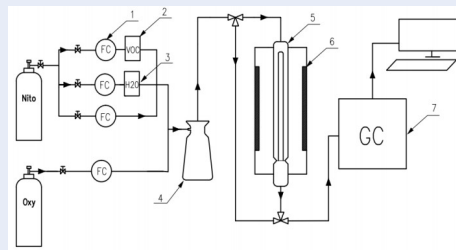


Figure 1: Schematic drawing of VOC gas simulation system [Source: Authors]

1. Flowmeter 2. VOC gas bubbler 3. H₂O container
4. Gas stabilizer 5. Reaction tube 6. UV lights (4 lights)
7. GC-FID equipment

with distilled water and underwent drying in an 80°C oven until no water drop was observed on the surface. Firstly, the solution of CMC additive in 25 mL distilled water was prepared and mixed vigorously by magnetic stirring for 1 hour to form a thick and transparent solution. At the same time, solid powders of Zeolite ZSM-5 and TiO₂ were suspended with various weights as demonstrated in Table 1 in 25 mL of distilled water using ultrasonic mixing. The additive solution was then combined with the solid powder suspension and stirred for 2 hours to create a uniform mixture. The coating was created by dipping the glass tube into the slurry using the dip coater approximately 25 times until a desired amount was obtained, with air drying about 5 minutes between dips. Following the dipping process, the tube was dried at 80°C for 5 minutes and heated to 400°C for 2 hours to eliminate the remaining additives from the surface of the tube.

Table 1: The catalyst data for preparation with variations in ZSM-5 and TiO₂ ratios

Sample	Mass of		
	ZSM-5 (g)	TiO ₂ (g)	CMC (g)
TiO ₂	0	0.50	0.50
Z-T 2:8	0.10	0.40	0.50
Z-T 4:6	0.20	0.30	0.50
Z-T 6:4	0.30	0.20	0.50
Z-T 8:2	0.40	0.10	0.50
ZSM-5	0.50	0	0.50

[Source: Authors]

Two primary categories of experimental analysis exist: investigation into various ratios between two solid

materials, and examination of external factors influencing the performance of photocatalysts. In the former set of tests, six coated tube samples with differing ratios of ZSM-5 and TiO₂ were analyzed and evaluated under consistent conditions to select the most suitable and exemplary sample for subsequent studies. Utilizing an air simulation system, several parameters were adjusted to assess their influence on catalytic efficiency. These parameters included the concentration of isopropanol, humidity of the gas mixture, intensity of UV light, catalyst mass, etc. Table 2 describes all the sets of experiments that were conducted. All samples went through 2 continuous stages: adsorption until saturation point and oxidation by UV light.

RESULTS AND DISCUSSION

XRD pattern of the composition

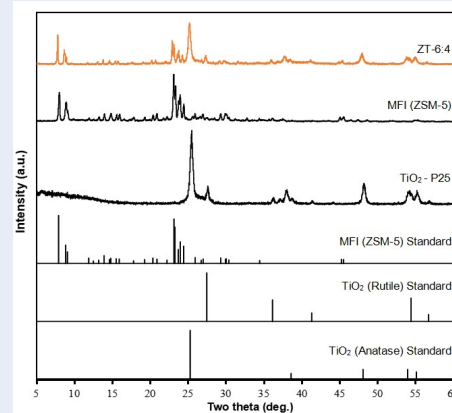


Figure 2: XRD pattern of sample Z-T 6:4 [Source: Authors]

By comparing to the standard Powder Diffraction File data of TiO₂ (Anatase structure and Rutile structure) from JCPDS No. 83-2243 and No. 87-0710 and MFI (ZSM-5) from JCPDS No. 42-0024, the XRD peak of Z-T 6:4 demonstrated in Figure 2 showed a significant compatibility. The 2θ peaks of the sample corresponded to the characteristic diffraction peaks of MFI (ZSM-5) at 7.94°, 8.88°, 23.16°, 23.98°, 24.44° associated with (011), (020), (031), (051), (303) and (313) lattice plane¹⁷. The diffraction pattern of sample Z-T 6:4 exhibited the peaks at 25.29°, 36.15°, 48.10°, 53.98°, and 55.14°, synchronizing to that of the Anatase structure of TiO₂ and at 27.49°, 36.15°, 41.32°, 54.44°, 56.75°, corresponding to the rutile structure. It is noticeable that the intensity of peaks in the synthesized sample is comparable with the standard materials.

Table 2: Investigation of various factors on photocatalytic activity

ZSM-5: TiO ₂ ratio (Humidity: 0% IPA concentration: 1000 ppm Number of UV lights: 4 UV lights Catalyst mass: 0.1g Flowrate: 50ml/min Duration: 1 hour)	TiO ₂	Z-T 2:8	Z-T 8:2	Z-T 8:2	ZSM-5
Humidity (IPA concentration: 1000 ppm Number of UV lights: 4 UV lights Catalyst mass: 0.1g Flowrate: 50ml/min Duration: 1 hour)	0%	20%	50%	50%	60%
IPA concentration (Humidity: 0% Number of UV lights: 4 UV lights Catalyst mass: 0.1g Flowrate: 50ml/min Duration: 1 hour)	250 ppm	500 ppm	1500 ppm	1500 ppm	2000 ppm
Number of UV light (Humidity: 0% IPA concentration: 1000 ppm Catalyst mass: 0.1g Flowrate: 50ml/min Duration: 1 hour)		2 UV lights		4 UV lights	
Catalyst's mass (Humidity: 0% IPA concentration: 1000 ppm Number of UV lights: 4 UV lights Flowrate: 50ml/min Duration: 1 hour)		0.1g			0.2g
Durability (Humidity: 0% IPA concentration: 1000 ppm Number of UV lights: 4 UV lights Flowrate: 50ml/min Catalyst mass: 0.1g)			6h		

[Source: Authors]

SEM and EDX results

Morphology of the coating nanocomposite with 3 representative samples is characterized by SEM as shown in Figure 3. The micrograph of the TiO₂ layer demonstrated the attachment of TiO₂ nanoparticles into clusters with the size varied from 0.5 μm to 4 μm , scattering randomly on the surface. From Figure 3(b) and Figure 3(c), it is noticeable that the incorporation of ZSM-5 and TiO₂ had no effect on the morphology of the initial materials. Small particles deposited on the outer surface of spherical ZSM-5 crystals which can be observed in Figure 3(b) are TiO₂. As depicted in Figure 3(c), ZSM-5 proved its ability to prevent the

conglomeration of TiO₂ by the presence of more dispersed particles compared to Figure 3(a).

EDX analysis results of the element's weight percent and atomic percent are presented in Table 3. Major elements were detected as predicted, as visually shown in Figures 4 and 5, including oxygen, sodium, aluminum, silicon, and titanium without impurities. From Table 4, compared to 80% wt.% of TiO₂ in the suspension mixture, around 71.97% of TiO₂ was deposited on the glass tube surface which was calculated from 43.18% weight of titanium element analyzed by EDX. The result indicated that sample Z-T 6:4 contains 24.96 wt.% of titanium which was equiv-

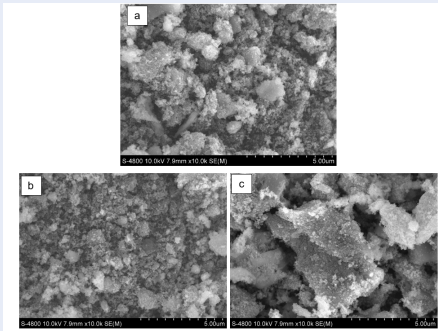


Figure 3: SEM analysis images of coating materials of (a) TiO₂ (b) Z-T 2:8 (c) Z-T6:4 [Source: Authors]

Table 3: Elements’ content of sample ZT-2:8 and ZT-6:4

Element	Z-T 2:8		Z-T 6:4	
	Weight %	Atomic %	Weight %	Atomic %
O	43.82	66.54	57.18	75.19
Na	1.61	1.70	2.68	2.45
Al	0.47	0.43	0.71	0.55
Si	10.92	9.44	14.47	10.84
Ti	43.18	21.90	24.96	10.96

[Source: Authors]

Table 4: Comparison between the actual deposited TiO₂ wt.% and expected TiO₂ wt.%

Sam-ple	TiO ₂ Actual (%)	TiO ₂ Theory (%)	Error (%)
Z-T 2:8	71.97%	80%	10.04%
Z-T 6:4	41.60%	40%	4.00%

[Source: Authors]

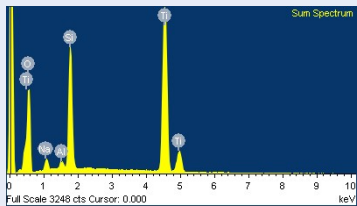


Figure 4: EDX analysis image of sample Z-T 2:8 [Source: Authors]

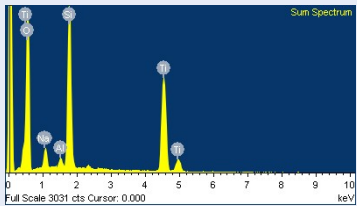


Figure 5: EDX analysis image of sample Z-T 4:6 [Source: Authors]

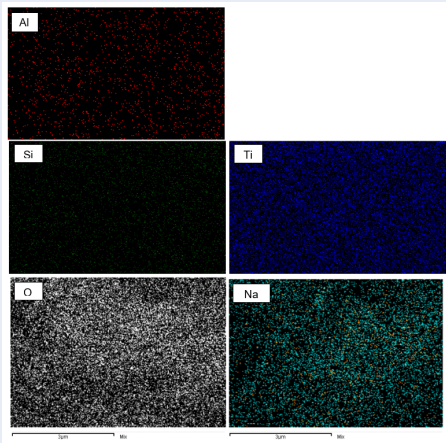


Figure 6: The element distribution of sample Z-T 2:8 analyzed by EDX [Source: Authors]

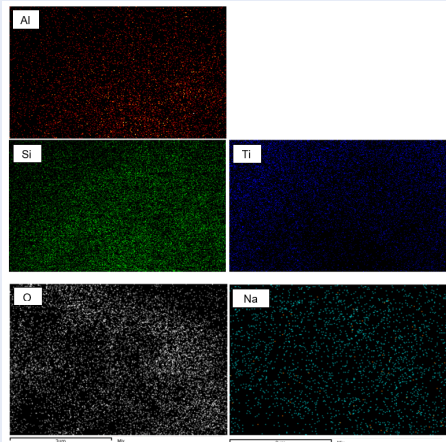


Figure 7: The element distribution of sample Z-T 6:4 was analyzed by EDX mapping [Source: Authors]

alent to 41.60% of TiO_2 on the composite. In general, an insignificant difference between the expected TiO_2 and the actual coating amount was found. With respect to zeolite ZSM-5, the Si/Al molar ratio exhibits negligible alternation subsequent to the incorporation of TiO_2 , persisting at 21-fold. This ratio indicated that ZSM-5 was a hydrophobic material, forming a strong adsorption affinity surface to trap organic compounds.

The distribution of elements aluminum, silicon, and titanium are displayed in Figures 6 and 7. These images show that all of the elements are homogeneously dispersed on the surface of these two analyzed samples. In the case of sample Z-T 2:8, as demonstrated in Figure 6, titanium is confirmed to be densely packed within the sample space while particles in sample Z-T 6:4 cover with a sparser density.

Adsorption and photocatalytic activity of catalysts on isopropanol (IPA)

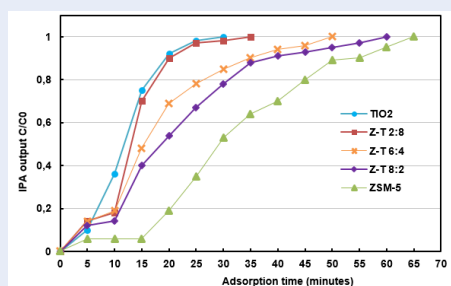


Figure 8: IPA adsorption capacity of samples with various mixing ratios ($C_{IPA} = 1000\text{ppm}$, no humidity, $\text{N}_2:\text{O}_2 = 8:2$, flowrate: 50 mL/min) [Source: Authors]

The adsorption capacity of six composites investigated on isopropanol at the concentration is 1000 ppm, with no humidity, and at room temperature was demonstrated in Figure 8. The TiO_2 samples, Z-T 2:8, Z-T 4:6, Z-T 6:4 all has relatively short saturation times ranging from 30-50 minutes. For the TiO_2 sample, Z-T 2:8, the saturation adsorption time is 30 minutes, while for the Z-T 4:6 and Z-T 6:4 samples, it is 50 minutes. ZSM-5 sample illustrates the highest adsorption capacity compared to others, proved by a stable adsorption during the first 15 mins, the ratio of C/C_0 stands at 0.06, which was marginally lower than other samples (C/C_0 of Z-T 2:8, Z-T 4:6, Z-T 6:4, Z-T 8:2 is 0.18; 0.29; 0.19; 0.14 respectively). Numerous articles have indicated that zeolite ZSM-5 is an effective VOC adsorbent¹⁸⁻²¹. Zeolite has a

large specific surface area with many porous structures capable of capturing gas molecules effectively. Thus, isopropanol still existed in considerable quantities on the surface of the Z-T catalyst following the adsorption stage and needed 60 mins to achieve the adsorption saturation for the Z-T 8:2 sample. Most of these adsorbed isopropanol species were located on the zeolite ZSM5's surface. Physical adsorption probably occurred because the adsorption was carried out at room temperature. The Z-T 2:8 sample demonstrates rapid IPA adsorption capability in just 25 minutes, with the output ratio to the saturated concentration (C/C_0) reaching 0.97, significantly higher than other samples. However, after 30 minutes, it no longer shows adsorption capacity. It can be concluded that the coating layer on the surface of the tube is predominantly TiO_2 , the ratio of ZSM-5 to TiO_2 is low, leading to a low adsorption capacity.

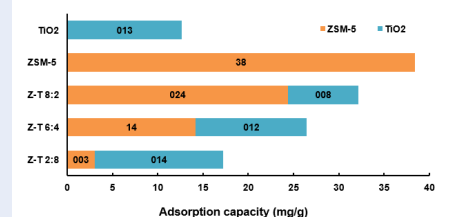


Figure 9: Total adsorption capacity and adsorption capacity of each material ($C_{IPA} = 1000\text{ppm}$, no humidity, $\text{N}_2:\text{O}_2 = 8:2$, flowrate: 50 mL/min) [Source: Authors]

Figure 9 illustrates the total adsorption capacity, which was calculated based on the adsorption curves obtained at conditions of no humidity and an IPA concentration of 1000 ppm. Moreover, the actual deposited amount of ZSM-5 and TiO_2 was estimated depending on the theory that the adsorption capacity of each material is highly proportional to the coated weight. In accordance with previous articles, the highest adsorption capacity belongs to ZSM-5 with 38.4 mg/g. In contrast, the tube coated with purely TiO_2 just adsorbed a third of that. In general, it is noticeable that the adsorption capacity rises with the increase of ZSM-5, as proven by 17.23 mg/g, 26.48 mg/g, and 32.18 mg/g for Z-T 2:8, Z-T 6:4, and Z-T 8:2, respectively.

From the total adsorption capacity of composites and pure materials, the occupancy of each substance on the coated layer was calculated. The mass of each component was calculated based on the assumption that its adsorption in the mixture was proportional

to the adsorption of each material alone. The desired deposited amount of ZSM-5 was higher than the actual amount on three samples: Z-T 2:8, Z-T 6:4, and Z-T 8:2. It can be explained by the fact that zeolite particles are much heavier compared to nano TiO_2 -P25. Therefore, zeolite ZSM-5 had a tendency to sediment in the suspension, despite the support of CMC as a stabilizer agent. Instead of 20%, 60%, and 80% of ZSM-5 as predicted, the layers contain 18%, 54%, and 76%, respectively. The errors varied from 5% to 12% compared to the ZSM-5 in the mixture and in EDS result, which is not too significant.

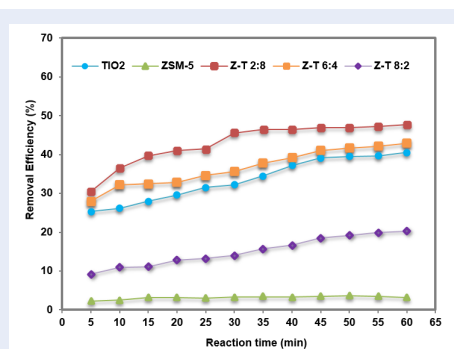


Figure 10: IPA photocatalytic activity of composites with various mixing ratios ($C_{IPA} = 1000\text{ppm}$, no humidity, $\text{N}_2:\text{O}_2 = 8:2$, flowrate: 50 mL/min) [Source: Authors]

IPA conversion efficiency of the samples at different ratios exhibits significant differences in values and increases with the rise of TiO_2 content in this experiment. As predicted, the tube coated with purely ZSM-5 displays nearly no photocatalytic activity with roughly 3.5% IPA being removed since ZSM-5 is not a photocatalytic active material. Regarding the samples containing TiO_2 , the IPA removal ability increased significantly in the first 30 to 40 minutes and then became relatively stable or experienced increased effectiveness. Among those, the Z-T 8:2 sample demonstrates low photocatalytic activity, with the highest conversion reaching only 20.2% within 60 minutes of the reaction. On the other hand, the photocatalytic activity of Z-T 6:4 and TiO_2 samples was higher compared to Z-T 8:2, with maximum conversions of 42.9% and 47.7% respectively. As observed in Figure 10, sample Z-T 2:8 shows the highest photocatalytic efficiency compared to other samples, which is 47.7%.

The zeolite structure consists of framework types that allow for the penetration of light. Consequently, there is easy interaction between the light and the TiO_2 sites

on the $\text{TiO}_2/\text{ZSM-5}$. Zeolite ZSM-5 plays an important role in photocatalytic activity since it serves two crucial functions. Firstly, the effective dispersion of TiO_2 as nanoparticles on zeolite ZSM-5 limits the agglomeration of TiO_2 and enhances the efficiency of UV light utilization during the photo-activation step. Secondly, the porous structure of ZSM-5 captures organic particles, fostering a reaction with unstable hydroxyl radicals and oxygen anion radicals. This is the reason why higher IPA removal was obtained on the Z-T 2:8 and Z-T 6:4 samples as compared to that on the pure commercial TiO_2 -P25. Therefore, synergistic adsorption-photocatalysis resulted in superior performance of the catalyst in the photocatalytic activity for IPA removal. In the first 30 minutes after turning UV light, the reaction efficiency increased gradually to reach a certain stability. This situation can be explained by the saturation of IPA on the surface pores at the beginning, which prevented newly introduced IPA molecules from being captured and oxidized. Based on the results obtained, Z-T 2:8 was selected for further investigation and evaluation of the influence of external factors. This choice is based on the fact that sample Z-T 2:8 demonstrates the best interaction between the two types of materials. This is significant for the application of the material in photocatalytic processes that require prolonged activity, such as VOC treatment.

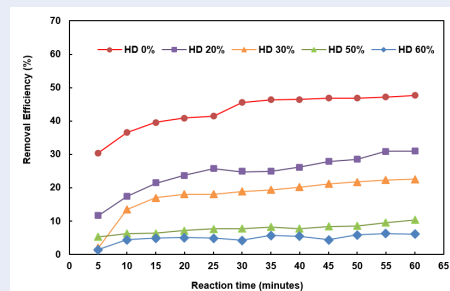


Figure 11: IPA photocatalytic activity of sample Z-T 2:8 at a different relative humidity ($C_{IPA} = 1000\text{ppm}$, $\text{N}_2:\text{O}_2 = 8:2$, flow rate: 50 mL/min) [Source: Authors]

Figure 11 shows Z-T 2:8 samples analyzed under five conditions: no humidity, 20%, 30%, 50%, and 60% humidity. It illustrates stable photocatalytic activity within 60 minutes of the reaction. Under no humidity conditions, the highest IPA photocatalytic conversion reaches 47.7%, indicating the potential for prolonged photocatalysis. Under the test condition of this study, the IPA decreased when relative humidity decreased

from 47.7% to 6.1%. At 20% humidity, there is a significant decrease in photocatalytic efficiency, with the highest conversion reaching 31% within 60 minutes. Finally, at 60% humidity, the overall conversion decreases compared to 30% humidity, with a conversion rate of 4.9% at minute 25, stabilizing under 5% until the end of the period.

Studies on the impact of humidity on VOC decomposition suggest that increased humidity limits the conversion of VOCs. In photocatalytic reactions, water molecules often participate, promoting the formation of $\cdot\text{OH}$ radicals. However, in photocatalytic reactions, water vapor competes with adsorption centers on the catalyst surface, reducing VOC adsorption. When water vapor reaches a certain concentration, the formation of $\cdot\text{OH}$ radicals does not increase with further humidity. Therefore, it can be seen that IPA photocatalytic efficiency decreases with increasing humidity in these experiments. Additionally, it can be concluded that this catalyst doesn't prove its stability with respect to rising humidity.

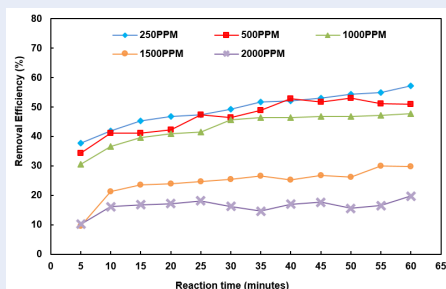


Figure 12: IPA removal rate of sample Z-T 2:8 at different IPA concentrations (no humidity, $\text{N}_2:\text{O}_2 = 8:2$, flow rate: 50 mL/min)
[Source: Authors]

It can be observed from Figure 12 that the influence of the initial IPA concentration on the catalyst's treatment capability. Generally, the efficiency of IPA removal decreases with increasing initial concentration. The IPA removal was reduced by approximately 40% when the initial IPA concentration increased nearly doubled from 1000 ppm to 2000 ppm. At an initial concentration of 1000 ppm, the catalyst's VOC removal capability reaches approximately 47.7% within 1 hour of observation. Additionally, samples observed at an initial concentration of 250 ppm and 500 ppm show the highest catalyst capability, with the maximum conversion rate at these concentrations reaching 57.2% and 53.1% respectively. However, there was no significant difference when the initial

concentration decreased from 1000 ppm to 249 ppm. When the concentration approached 1500 ppm and 2000 ppm, the photocatalytic efficiency remained stable at the lowest level of approximately 26% and 17%, respectively.

The test results above indicated that lower VOC concentrations were advantageous for photocatalytic degradation. When increasing the IPA concentration to a certain level, the removal efficiency does not change considerably. However, when the concentration exceeds the permissible level, the performance of capacity also significantly decreases. This phenomenon occurs since the high concentration of VOC cover partially or completely catalyst active point, hindering the exposure to UV light which can activate the generation of electron and hole pairs. In case of low concentration as 250 ppm and 500 ppm, the photocatalytic activity showed no significant difference compared to 1000 ppm. This situation can be explained by the fact that the lower the concentration, the less IPA particles adsorbed on the ZSM-5 surface. These molecules are located further away from TiO_2 active sites, thus, highly oxidative species cannot interact with.

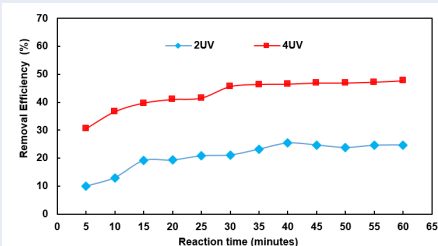


Figure 13: IPA photocatalytic activity of sample Z-T 2:8 under 2 UV light modes ($C_{IPA} = 1000\text{ppm}$, $\text{N}_2:\text{O}_2 = 8:2$, flow rate: 50 mL/min)
[Source: Authors]

The influence of UV intensity on the efficiency of photocatalytic treatment was studied by keeping all reaction conditions constant and varying the UV intensity. Based on Figure 13, we can see that under both conditions of 2 UV lamps and 4 UV lamps, the material exhibits stable photocatalytic oxidation capability. However, increasing the lamp intensity from 2 lamps to 4 lamps significantly increases the treatment efficiency. At the 20th minute, the conversion rates for 2 lamps and 4 lamps are 22.19% and 38.90%, respectively. Meanwhile, the maximum photocatalytic efficiency at 2 lamps is 24.70% at minute 60th, and the maximum photocatalytic efficiency at 4 lamps is

47.70%. Therefore, this survey has shown that under the condition of 4 UV lamps, higher efficiency is achieved. Generally, as the light intensity increases, the generation of hydroxyl free radicals in the VOC processing becomes easier, providing more energy for higher efficiency of photocatalytic oxidation.

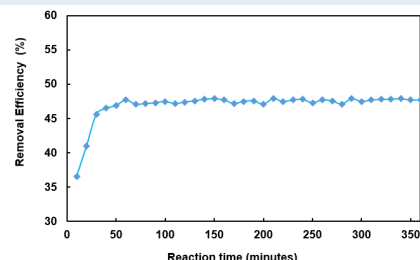


Figure 14: The photocatalytic capacity of sample Z-T 2:8 for 6 hours ($C_{IPA} = 1000\text{ppm}$, $N_2:O_2 = 8:2$, flow rate: 50 mL/min) [Source: Authors]

Long-term activity investigation helps assess the durability of the catalyst in use. Figure 14 illustrates the VOC processing capabilities of material sample Z-T 2:8, which contains significant TiO_2 in the mixture. The graph shows that under this reaction condition, sample Z-T 2:8 still demonstrates stability and photocatalytic efficiency, approximately 46% after 6 hours of testing. It starts to reach stable efficiency at 50 minutes, stands at 44.1%, and continues to maintain the efficiency capacity of the catalyst till the end of the period. There is a slight change in photocatalytic efficiency compared to the previous experiment conducted in 1 hour. Additionally, this result can demonstrate that the catalyst proves the high capacity and its effectiveness to remove VOC during long-lasting experiments. The stability of catalytic material is generally improved at the cost of photocatalytic efficiency. The mass ratio of ZSM-5/ TiO_2 during the loading process affects the ratio of ZSM-5 and TiO_2 in the resulting composite adsorbent. A too-low TiO_2 loading ratio does not achieve the synergistic effect of ZSM-5 and TiO_2 in adsorption, while an excessively high ratio leads to increased cost due to the high price of TiO_2 and ineffective utilization of ZSM-5. Therefore, the experiment was designed with a TiO_2 /ZSM-5 ratio 6:4 mass of 0.1g and 0.2g. From Figure 14, it can be observed that as the ZSM-5/ TiO_2 mass ratio increases from 0.1g to 0.2g, the adsorption capacity significantly improves for the Z-T 6:4 composite adsorbent. The higher the mass of the sample is, the longer the time the sample takes to reach the saturation point. The saturation adsorption time of 0.2g

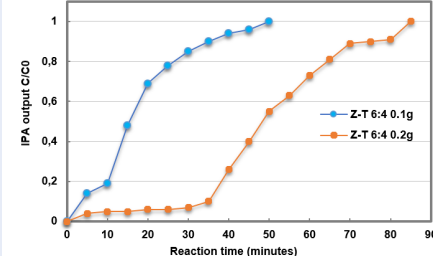


Figure 15: Varying adsorption capacity with respect to the varying mass of Z-T 6:4 sample ($C_{IPA} = 1000\text{ppm}$, $N_2:O_2 = 8:2$, flow rate: 50 mL/min) [Source: Authors]

Z-T 6:4 takes nearly 85 minutes compared to half of the period with respect to 0.1g Z-T 6:4. The results in Figure 15 clearly show that when the adsorbent mass was increased, this resulted in an increase in the adsorption of IPA. The main reason for this is that as the adsorbent mass increases, more adsorption sites are available per mass of the adsorbent surface, and thus the total amount of IPA that is removed increases²².

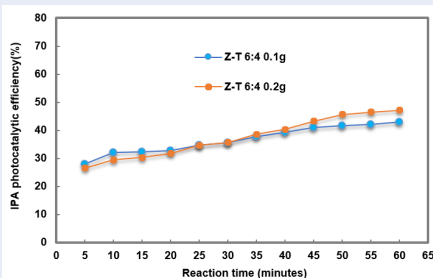


Figure 16: Photocatalytic activity with respect to the varying mass of the Z-T 6:4 sample ($C_{IPA} = 1000\text{ppm}$, $N_2:O_2 = 8:2$, flow rate: 50 mL/min) [Source: Authors]

The photocatalytic activity of sample Z-T 6:4 is depicted in Figure 16 during 60 minutes in constant condition. It is noticeable that there was no considerable difference in photocatalytic efficiency in spite of doubling the catalyst mass, proven by 47.2% and 42.9% removal capacity at the end of the period for the mass of 0.1g and 0.2g, correspondingly. This result indicates that the efficiency of the ZSM-5/ TiO_2 composite exhibits a high degree of dependency on ratios between two components and shows no direct proportion to deposited mass. This phenomenon can be explained by the fact that merely TiO_2 particles located on the outer surface of the tube are exposed to UV light and

activated. Therefore, an appropriate amount of catalyst should be surveyed and selected to ensure that the photocatalytic activity is optimized while consuming materials economically.

CONCLUSIONS

In this study, the nanocomposite of Zeolite ZSM-5/TiO₂ has been successfully prepared by the dip-coating method with the support of a CMC additive to obtain an ideal suspension and uniform coating surface. By using an air simulation system and GC-FID analysis equipment, it has been proved that the photocatalytic activity of TiO₂ is enhanced significantly with the addition of ZSM-5. With the same coating amount, the ratio of ZSM-5 to TiO₂ equal to 2:8 displays the highest IPA removal percentage with 47.7% compared to 42.9% and 41.2% of ratio 6:4 and TiO₂, respectively. The catalyst has shown its durability via the ability to maintain consistent photocatalytic efficiency within 6 consecutive hours. In humid conditions and lighting intensity, the oxidative reaction of the composite decreases with increased humidity and is proportional to the number of UV lights.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

N. T. D. Ngoc conceived the methodology, conducted the experimental investigations, curated the data, and wrote the original draft. P. L. G. Han contributed to the experimental investigations, validated the results, performed the formal analysis, and wrote the original draft. N. Q. Long provided conceptualization, acted as the project supervisor, and was responsible for writing – review.

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REFERENCES

1. Bolden AL, Kwiatkowski CF, Colborn T. New look at BTEX: are ambient levels a problem? *Environmental Science & Technology*. 2015;49(9):5261–76. Available from: <https://doi.org/10.1021/es505316f>.
2. Evuti AM. A Synopsis on Biogenic and Anthropogenic Volatile Organic Compounds Emissions: hazards and Control. *International Journal of Engineering Science*. 2013;2(5).
3. Volatile Organic Compounds in Your Home - MN Dept. of Health [Internet]. Available from: <https://www.health.state.mn.us/communities/environment/air/toxins/voc.htm>.
4. Gao M, Mao M, Shi J, Liu Y, Chen Q, Li J. A review of the treatment techniques of VOC. *Applied Mathematics and Non-linear Sciences* [Internet]. 2022;8(1):2063–74. Available from: <https://doi.org/10.2478/amns.2021.2.00131>.
5. Pérez-Botella E, Valencia S, Rey F. Zeolites in Adsorption Processes: state of the art and future Prospects. *Chemical Reviews*. 2022;122(24):17647–95. Available from: <https://doi.org/10.1021/acs.chemrev.2c00140>.
6. Wang C, Guo H, Leng S, Yu J, Feng K, Cao L, et al. Regulation of hydrophilicity/hydrophobicity of aluminosilicate zeolites: a review. *Critical Reviews in Solid State and Materials Sciences/CRC Critical Reviews in Solid State and Materials Sciences* [Internet]. 2020; Available from: <https://doi.org/10.1080/10408436.2020.1819198>.
7. Linsebigler AL, Lu G, Yates JT. Photocatalysis on TiO₂ surfaces: principles, mechanisms, and selected results. *Chemical Reviews*. 1995;95(3):735–58. Available from: <https://doi.org/10.1021/cr00035a013>.
8. Nakata K, Fujishima A. TiO₂ photocatalysis: design and applications. *Journal of Photochemistry and Photobiology C, Photochemistry Reviews*. 2012;13(3):169–89. Available from: <https://doi.org/10.1016/j.jphotochemrev.2012.06.001>.
9. Carp O. Photoinduced reactivity of titanium dioxide. *Progress in Solid State Chemistry/Progress in Solid State Chemistry* [Internet]. 2004;32(1-2):33–177. Available from: <https://doi.org/10.1016/j.progsolidstchem.2004.08.001>.
10. Kim T, Yoo K, Kim MG, Kim YH. Photo-Regeneration of Zeolite-Based volatile organic compound filters enabled by TiO₂ Photocatalyst. *Nanomaterials (Basel, Switzerland)*. 2022;12(17):2959. Available from: <https://doi.org/10.3390/nano12172959>.
11. Rao BG, Mukherjee D, Reddy BM. Novel approaches for preparation of nanoparticles. 2017;p. 1–36. Available from: <https://doi.org/10.1016/B978-0-323-46142-9.00001-3>.
12. Gupta SM, Tripathi M. A review on the synthesis of TiO₂ nanoparticles by solution route. *Open Chemistry*. 2012;10(2):279–94. Available from: <https://doi.org/10.2478/s11532-011-0155-y>.
13. Parashar M, Shukla VK, Singh R. Metal oxides nanoparticles via sol–gel method: a review on synthesis, characterization and applications. *Journal of Materials Science Materials in Electronics*. 2020;31(5):3729–49. Available from: <https://doi.org/10.1007/s10854-020-02994-8>.
14. Suárez S, Jansson I, Ohtani B, Sánchez B. From titania nanoparticles to decahedral anatase particles: photocatalytic activity of TiO₂/zeolite hybrids for VOCs oxidation. *Catalysis Today*. 2019;326:2–7. Available from: <https://doi.org/10.1016/j.cattod.2018.09.004>.
15. Yamaguchi K, Inumaru K, Oumi Y, Sano T, Yamanaka S. Photocatalytic decomposition of 2-propanol in air by mechanical mixtures of TiO₂ crystalline particles and silicalite adsorbent: the complete conversion of organic molecules strongly adsorbed within zeolitic channels. *Microporous and Mesoporous Materials*. 2009;117(1-2):350–5. Available from: <https://doi.org/10.1016/j.micromeso.2008.07.009>.
16. Bui TL. Synthesis, study, and application of Mesoporous Zeolite ZSM-5 materials; 2022.
17. Sabarish R, Unnikrishnan G. A novel anionic surfactant as template for the development of hierarchical ZSM-5 zeolite and its catalytic performance. *Journal of Porous Materials*. 2020;27(3):691–700. Available from: <https://doi.org/10.1007/s10934-019-00852-5>.
18. Corma A, García H. Zeolite-based photocatalysts. *Chemical Communications (Cambridge)*. 2004;(13):1443–59. Available from: <https://doi.org/10.1039/b400147h>.
19. Song W, Justice RE, Jones CA, Grassian VH, Larsen SC. Synthesis, characterization, and adsorption properties of nanocrystalline ZSM-5. *Langmuir : The ACS Journal of Surfaces and Colloids*. 2004;20(19):8301–6. Available from: <https://doi.org/10.1021/la049516c>.

20. Pasti L, Rodeghero E, Sarti E, Bosi V, Cavazzini A, Bagatin R, et al. Competitive adsorption of VOCs from binary aqueous mixtures on zeolite ZSM-5. *RSC Advances*. 2016;6(59):54544–52. Available from: <https://doi.org/10.1039/c6ra08872d>.
21. Kim KJ, Ahn HG. The effect of pore structure of zeolite on the adsorption of VOCs and their desorption properties by microwave heating. *Microporous and Mesoporous Materials*. 2012;152:78–83. Available from: <https://doi.org/10.1016/j.micromeso.2011.11.051>.
22. Kim KJ, Ahn HG. The effect of pore structure of zeolite on the adsorption of VOCs and their desorption properties by microwave heating. *Microporous and Mesoporous Materials*. 2012;152:78–83. Available from: <https://doi.org/10.1016/j.micromeso.2011.11.051>.

Tổng hợp hợp chất xúc tác quang ZSM-5/TiO₂ bằng phương pháp nhúng phủ và đánh giá khả năng loại bỏ isopropanol (IPA)

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TÓM TẮT

Việc kết hợp TiO₂ với zeolite ZSM-5 đã được nghiên cứu nhằm thúc đẩy hoạt tính xúc tác quang để xử lý các hợp chất hữu cơ dễ bay hơi (VOC) liên tục. Trong nghiên cứu này, các vật liệu xúc tác composite giữa ZSM-5 và TiO₂ thương mại với nhiều tỷ lệ khác nhau đã được lắng đọng thành công lên các ống thủy tinh hình trụ bằng phương pháp nhúng phủ. Để cải thiện độ ổn định của hệ huyền phù và giảm thiểu sự lắng đọng của các hạt nặng, chất phụ gia carboxymethyl cellulose (CMC) đã được đưa vào hỗn hợp. Các đặc tính hình thái và thành phần cấu tạo đã được đặc trưng bằng phương pháp SEM-EDX, cho thấy sự phân bố đồng đều sau khi áp dụng phương pháp nhúng phủ, đồng thời biểu thị mức độ sai lệch nhỏ chỉ từ 4% đến 12% giữa hàm lượng khối lượng thực tế và lý thuyết. Hiệu suất xúc tác quang được đánh giá thông qua khả năng loại bỏ khí isopropanol (IPA) bằng cách sử dụng một hỗn hợp mô phỏng không khí kết hợp với phân tích sắc ký khí (GC-FID). Các yếu tố bao gồm độ ẩm, nồng độ VOC, cường độ ánh sáng UV và khối lượng chất xúc tác đã được khảo sát ảnh hưởng của chúng đến hiệu suất của chất xúc tác quang, từ đó đưa ra kết luận về điều kiện hoạt động tối ưu nhất. Kết quả phân tích sắc ký khí (GC) về hàm lượng VOC sau xử lý khẳng định hoạt tính tốt của các vật liệu chứa ZSM-5 và TiO₂ ở các tỷ lệ thích hợp (2:8 và 6:4) so với việc chỉ sử dụng đơn lẻ TiO₂, với hiệu suất xúc tác quang cao hơn (đạt lần lượt 47,7% và 42,9%). Độ ẩm và nồng độ VOC càng cao thì năng suất của chất xúc tác quang càng giảm. Thêm vào đó, thử nghiệm hoạt tính theo thời gian đã chứng minh độ bền và độ ổn định cấu trúc của mẫu composite tối ưu, khi vật liệu này duy trì hiệu suất chuyển hóa ổn định ở mức xấp xỉ 46% trong 6 giờ hoạt động liên tục. Bên cạnh đó, việc tăng gấp đôi khối lượng chất xúc tác lắng đọng từ 0,1 g lên 0,2 g không làm tăng đáng kể hiệu suất xúc tác quang, điều này chỉ ra rằng hiệu suất xử lý chủ yếu bị chi phối bởi tỷ lệ của các thành phần được tiếp xúc trực tiếp với ánh sáng hơn là tổng khối lượng lớp phủ. Về mặt định lượng, việc tăng cường độ đèn UV từ 2 lên 4 bóng đã thúc đẩy đáng kể quá trình tạo ra các gốc tự do hydroxyl và làm tăng gấp đôi hiệu suất xử lý tối đa. Do đó, điều kiện phù hợp nhất và quy trình chế tạo chất xúc tác cần được khảo sát kỹ lưỡng để nâng cao hiệu quả xử lý khí VOC.

Từ khoá: Zeolite ZSM-5, TiO₂, Phương pháp nhúng phủ, Loại bỏ isopropanol, Hoạt tính xúc tác quang

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