Assessing the Stability and Photocatalytic Efficiency of a Biodegradable PLA-TiO₂ Membrane for Air Purification

Hadis Mortazavi Milani, Brent Van Neste, Ewoud Cosaert, and Dirk Poelman*

H. Mortazavi Milani, B. Van Neste, E. Cosaert, D. Poelman

LumiLab, Department of Solid State Sciences, Ghent University, 9000 Ghent, Belgium

Email: Dirk.Poelman@UGent.be

Keywords: biodegradable membrane, PLA, TiO₂, air purification, photocatalytic oxidation, VOCs, environmental sustainability

The potential of a biodegradable polylactic acid (PLA)-TiO2 membrane for air purification is investigated, utilizing the environmentally friendly solvent Cyrene[™]. Through the integration of TiO2 nanoparticles within a PLA matrix, the membrane is used to degrade ethanol as a model volatile organic compound (VOC) under UV light. Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Analysis (EDX), and UV-visible spectrophotometry confirm the porous structure of the membrane, the even distribution of TiO2 and its effective band gap of 3.06 eV, respectively. Ethanol adsorption is best described by the Langmuir isotherm model, suggesting monolayer coverage on a homogeneous surface. Photocatalytic tests demonstrate that the membrane decomposes ethanol (6800 ppm) within 14 minutes under UV light, generating acetaldehyde, acetic acid, formaldehyde and formic acid as intermediates, and ultimately producing CO2 and water. Reusability tests indicate a decrease in decomposition time over successive cycles due to increased TiO2 exposure from the gradual degradation of PLA. However, this degradation poses challenges for continuous use, compromising the membrane's long-term durability.

1. Introduction

The indoor environment, where people spend considerable time, is a crucial element in public health due to its capacity to harbor a range of air pollutants. Among the most prevalent indoor pollutants are volatile organic compounds (VOCs), which are present in various products, including building materials, furniture, cosmetics, and cleaning agents. These chemicals can create health hazards, such as cancer, neurological disorders, and respiratory problems.^[1-3] Photocatalytic Oxidation (PCO) represents a significant advancement in indoor air purification, utilizing titanium dioxide (TiO₂) as an exceptionally effective photocatalyst. When exposed to UV light, TiO₂ produces electron-hole pairs, generating reactive species that effectively oxidize pollutants. This process is particularly efficient in completely mineralizing organic compounds at room temperature, making TiO₂-based PCO a promising technology for indoor air purification.^[4-8] However, the industrial application of photocatalysts in powder form presents

challenges, including difficulties in continuous flow systems, recovering and reusing nanomaterial catalysts, and potential pressure drops caused by VOC blockages. Immobilizing photocatalysts on polymeric membranes offers a viable solution to these issues.^[9-12] While petroleum-based polymers such as polyimide (PI),^[13] polyacrylonitrile (PAN),^[14] polysulfone (PSF)^[15] and polyvinylidene fluoride (PVDF)^[16] have been widely used in membrane technology, their environmental impact is significant due to their non-renewability and nonbiodegradability. As a result, biodegradable polymeric materials have emerged as environmentally friendly alternatives that reduce ecological effects.^[17,18] Polylactic acid (PLA) is a biodegradable aliphatic polyester derived from renewable sources. It is widely recognized as an environmentally friendly substitute for non-biodegradable plastics. PLA finds applications in the medical, packaging, 3D printing, and textile industries. This versatile material is known for its high melting point, considerable crystallinity, enhanced rigidity, thermal processability, and notable tensile strength. Its production requires 25-55% less energy compared to petrochemical-based polymers. Additionally, PLA is utilized in air pollution control alongside TiO₂ photocatalysts to reduce indoor air pollution.^[19-23] PLA is an appealing green substitute for petroleum-based polymers since it breaks down through hydrolysis when exposed to moisture after a few months.^[23] Although bio-based polymeric membranes are a sustainable solution with reduced environmental impact, specific criteria must be considered for a greener manufacturing process, including using green solvents and reducing waste.^[24] Large volumes of toxic solvents, including tetrahydrofuran (THF), N,N-dimethylformamide (DMF), N,Ndimethylacetamide (DMA), and N-methyl-2-pyrrolidone (NMP), are frequently used throughout the membrane production procedure. Since these non-biodegradable, flammable, highly volatile, toxic, and non-renewable solvents can be hazardous to human health and the environment, substitution with green solvents is necessary.^[25,26] Dihydrolevoglucosenone (CyreneTM) is a bio-based solvent that fits the essential criteria. CyreneTM is prepared in two steps. Firstly, cellulose or cellulose-containing substances are subjected to catalytic pyrolysis to produce levoglucosanone (LGO). Secondly, LGO undergoes catalytic hydrogenation to yield CyreneTM.^[27] CyreneTM is receiving more and more attention because of its similarities to traditional organic aprotic solvents like DMF and NMP regarding miscibility with water, density, and polarity. Cyrene[™], a compound with comparable features to NMP, does not contain the N-alkyl amide group, which is associated with reproductive disorders, DNA mutations, and biological harm. It is also safe to handle, eco-friendly, and highly oxidation-resistant. Upon degradation, it transforms only into water and carbon dioxide. CyreneTM is especially advantageous in membrane preparation due to its high boiling point, complete miscibility with water, and Hansen solubility parameters similar to toxic solvents such as NMP, DMF, and DMA.^[28] In this work, a biodegradable photocatalytic membrane (PLA-TiO₂) has been developed for air purification, using CyreneTM as the solvent. Multiple tests were conducted to determine the membrane's properties, including Scanning Electron Microscope (SEM), Energy Dispersive X-ray Analysis (EDX), UV-vis spectrophotometry and studying the adsorption isotherm of ethanol as a VOC on its surface. A photocatalytic reactor was used to assess the membrane's performance, revealing a multi-step breakdown mechanism of ethanol. The main focus of this work is to evaluate the reusability of this environmentally friendly membrane. Unexpected results related to the membrane's performance during repeated use, prompted further investigation to study the factors affecting its long-term durability and effectiveness.

2. Experimental Section

2.1. Materials

Polylactic acid (PLA, Mn = 55,000 g/mol) was purchased from Goodfellow Co. The P25 TiO₂ nanoparticle photocatalyst was obtained from Evonik Industries AG, Germany. The P25 TiO₂ used in this study is a compound composed of anatase and rutile TiO₂.^[6] Dihydrolevoglucosenone (CyreneTM) was provided by Sigma-Aldrich Co. The ethanol used in the study was of AR grade (\geq 99.9%).

2.2. Preparation of Membrane

The PLA-TiO₂ membrane was prepared using a non-solvent phase inversion technique (NIPS). 1 g PLA, 0.5 g TiO₂, and 8.7 ml CyreneTM were mixed under magnetic stirring for 24 h at 250 rpm at 60 °C. The magnetic stirrer was then turned off to allow the mixture to degas. The photocatalyst-containing solution was cast on a glass substrate (20 cm \times 28 cm) with a thickness of 100 µm using a casting knife film applicator (Elcometer 3580 Doctor Blade, Germany). After casting, the glass plate with a thin polymeric film was exposed to air for 30 seconds before being subjected to phase inversion in a non-solvent (DI water) bath for 3 minutes. Thin polymeric films separated from the glass during the phase inversion. The remaining nonsolvent was then removed from the membrane by drying it in an oven for 20 hours at 60 °C.

2.3. Methods

Scanning Electron Microscopy (SEM, a FEI Quanta 200 F instrument at high vacuum) was used to characterize the morphology of the PLA and PLA-TiO₂ membrane. The membrane was affixed to a grid using carbon tape and subsequently a gold coating was applied using a sputter coater (EMITECH Polaron SC7620) to avoid surface charge buildup. Energy-dispersive X-ray spectroscopy (EDX, Hitachi S-3400N equipped with a Thermo Scientific UltraDry EDS detector) was used for quantitative analysis of elements in the membrane. Diffuse reflectance measurements were carried out using a Perkin Elmer Lambda 1050 UV-Vis-NIR spectrophotometer equipped with an integrating sphere detector, with a scan range of 250–600 nm and 2 nm wavelength resolution. All spectra were monitored in reflectance mode under ambient conditions. The measured diffuse reflectance spectra were converted to absorbance spectra using the Kubelka–Munk (K–M) function.^[29] The band gap energy of TiO₂ on a film was calculated from the absorbance results, assuming an indirect band gap of TiO₂.

2.4. Photocatalytic Setup

Photocatalytic decomposition of ethanol was performed in a quartz tube batch reactor with a volume of 0.3 L (**Figure 1**). The photocatalytic membrane, containing TiO₂ particles, was fixed on the surface of the stainless steel tube inside the reactor. The quartz tube was exposed to UV light from 4 sides by 48 UV LED lamps (CUN66B1B, Seoul Viosys) (12 lamps on each side) with a total output power of 17 W at 365 nm. The distance between the UV LED lamps and the photocatalytic membrane was 3.0 cm. The photocatalytic decomposition of ethanol (as a VOC) was analyzed by quadrupole mass spectrometry (QMS, Hiden Analytical Ltd., Warrington, U.K.). In order to better analyze the photocatalytic reaction of TiO₂ and the simulation of the air inside the reactor with ambient air, N₂ was replaced by Ar (40 atomic mass units (amu)) because the atomic mass unit of N₂ (28 amu) is close to numerous organic fragments of ethanol. The reactor was flushed with a gas mixture of Ar (80%) and O₂ (20%) for 30 minutes (4 lit/min), and then the outlet valve was closed to ensure that only Ar and O₂ were inside the reactor. After that, 5 μ L (equivalent to a concentration of 6800 ppm) of ethanol as a VOC was injected into the reactor. After 90 minutes of stabilization in the dark to ensure that the adsorption-desorption equilibrium between the ethanol and the TiO₂ particles was established,

the reactor was exposed to UV LED lamps irradiation. The wavelength of the UV LED lamps (365 nm) is suitable for the excitation of TiO_2 with a band gap of 3.0-3.2 eV. Simultaneously, fans were turned on to cool the heatsinks of the LED arrays. The QMS continuously monitored time-dependent gas samples from the reactor chamber.

The ethanol decomposition, which produces intermediates and by-products, was evaluated by measuring the mass-to-charge ratio (m/z) at different atomic mass units according to the NIST mass spectrum. Organic fragments that are decomposed and created during the photocatalytic process have different intensities at different atomic mass units, which overlap with each other. In order to distinguish these fragments and analyze the data from QMS, these overlaps were considered to calculate the real amount of different fragments.



Figure 1. Schematic experimental setup for photocatalytic measurement.

3. Results and Discussion

3.1. Morphological Characterization

Figure 2 displays the SEM images of two membranes, a PLA membrane (Figure 2a) and a PLA-TiO₂ membrane (Figure 2b). The SEM image clearly shows that TiO₂ particles are distributed evenly across the surface of the PLA membrane. Additionally, there are some microvoids present in the membrane's structure. The elemental compositions of the PLA-TiO₂ membrane from the mapping have been summarized in Table 1.



Figure 2. SEM images of (a) blank PLA membrane and (b) PLA-TiO₂ membrane with a scale bar of 5 μ m.

PLA-TiO ₂ Membrane	Weight [%]	Weight % Error	Atomic [%]	Atomic % Error
carbon (C)	39.7	+/- 0.2	53.0	+/- 0.3
oxygen (O)	40.1	+/- 0.2	40.2	+/- 0.2
titanium (Ti)	20.2	+/- 0.2	6.76	+/- 0.04

Table 1. Elementa	l compositions o	f PLA-TiO ₂ membrane	from EDX mapping.
-------------------	------------------	---------------------------------	-------------------

3.2. Optical Characterization

The UV-vis absorbance spectra of TiO₂, PLA-TiO₂ membrane, and blank PLA membrane were analyzed, as depicted in **Figure 3**. The results revealed that the blank PLA membrane did not absorb any UV-visible light in the range of 250-600 nm, while both PLA-TiO₂ membrane and TiO₂ powder exhibited absorbance of UV light with wavelengths less than 400 nm. Based on the absorbance spectrum, it can be inferred that the 365 nm wavelength of UV light is adequate for exciting electrons of TiO₂ nanoparticles immobilized in the PLA membrane to generate reactive species during the photocatalytic reaction. Furthermore, the energy band gap (E_g) of TiO₂ was calculated to be 3.06 eV from the absorption spectra of TiO₂ powder (inset figure).^[30]



Figure 3. UV-visible absorbance spectrum of TiO_2 , blank PLA membrane and PLA- TiO_2 membrane. The inset shows the Tauc plot of TiO_2 for band gap determination.

3.3. Ethanol Adsorption Isotherm

Equilibrium adsorption isotherms are essential for studying the adsorption capacity and mechanisms of an adsorbent. In this method, ethanol at varying concentrations is introduced into the reactor, volatilized, and the equilibrium adsorbed quantity is determined by comparing the ethanol detected in the gas phase using QMS with the initial injected amount. The experimental data is then analyzed and fitted to three possible isotherms: Langmuir, Freundlich, and Dubinin-Radushkevich (D-R), as shown in Table **2**.



Table 2. Equation, parameters and obtained R^2 for different adsorption isotherms.

Figure 4. Relationship between the adsorption capability (q_e) and equilibrium concentration (C_e) (a), linearized Langmuir (b), Freundlich (c) and Dubinin-Radushkevich (d) isotherm plots for adsorption of ethanol on a PLA-TiO₂ membrane.

The Langmuir model describes adsorption as a single layer of adsorbate on a uniform surface, with q_e representing the equilibrium loading and q_{max} indicating the maximum adsorption capacity. C_e is the equilibrium solute concentration, and K_L represents the adsorption energy constant. Conversely, the Freundlich model explains multilayer adsorption on heterogeneous surfaces, where K_f shows the adsorption capacity and 1/n the adsorption intensity. The D-R model uses a Gaussian energy distribution to describe adsorption on heterogeneous surface, where the constant K_{DR} is associated with the mean free energy of adsorption, and the Polanyi potential is represented by ϵ . As shown in **Figure 4**a, the equilibrium amount of ethanol adsorbed on the photocatalytic membrane increases by increasing the equilibrium

concentration of ethanol injected until it reaches the maximum possible adsorbate concentration q_{max} of 5.1 mg/g. Furthermore, the Freundlich and Dubinin-Radushkevich isotherms (Figure 4c, 4d) did not properly fit the experimental data. However, the Langmuir isotherm (Figure 4a) fitted well, indicating monolayer coverage of ethanol on a homogeneous surface of the photocatalytic membrane. The q_{max} can also be calculated from the Langmuir isotherm, which is 5.1 mg/g, matching well with what is calculated from the experimental data.^[31-34]

3.4. Photocatalytic Reaction

Figure 5 illustrates the photocatalytic decomposition of ethanol, showing the normalized concentrations of the breakdown products upon UV illumination as a function of time, in the presence of a PLA-TiO₂ membrane. Results obtained from mass spectrometry reveal that the photocatalytic reaction of ethanol has multiple steps. As shown in figure, ethanol is completely decomposed in about 14 min. Simultaneously, intermediates, including acetaldehyde, acetic acid, formaldehyde, and formic acid, are produced and decomposed during the photocatalytic reaction. Ultimately, carbon dioxide and water are the final products of this reaction (**Equation 1-5**).^[35] Based on the data presented in Figure 5, the following reaction scheme can be proposed for the mineralization of ethanol:

Ethanol:	$CH_3CH_2OH + 0.5 O_2 \rightarrow CH_3CHO + H_2O$	(1)
Acetaldehyde:	$CH_3CHO + 0.5 O_2 \rightarrow CH_3COOH$	(2)
Acetic acid:	$CH_3COOH + O_2 \rightarrow HCHO + CO_2 + H_2O$	(3)
Formaldehyde:	$HCHO + 0.5 O_2 \rightarrow HCOOH$	(4)
Formic acid:	$HCOOH + 0.5 O_2 \rightarrow CO_2 + H_2O$	(5)

3.5. Photocatalytic VOC Decomposition Mechanism

Given the band gap of TiO₂ (as shown in Figure 3), UV light at 365 nm permits electrons to promote from the valence band maximum (VBM) to the conduction band minimum (CBM), with holes remaining in the VBM. These energized electrons can then react with oxygen to form superoxide ('O₂⁻), while the holes can react with adsorbed H₂O molecules to produce hydroxyl radicals ('OH) as shown in **Figure 6**.^[36] This active species can then break down adsorbed ethanol on the TiO₂ surface into acetaldehyde. As there is less water than oxygen in the gas phase, superoxides have the primary role. Acetaldehyde can also be oxidized further into acetic acid, formaldehyde, and formic acid, respectively. Finally, formic acid can be oxidized into carbon dioxide and water.^[38] It is worth noting that there is a potential difference between the CBM and VBM of rutile and anatase phases in TiO₂ P25. The solid-solid interface between both phases is expected to boost photocatalytic efficiency by promoting charge separation and obstructing recombination.^[37,38]

3.6. Photocatalyst Reusability Test

In gas-phase photocatalysis, the efficiency and lifespan of photocatalysts can be diminished when intermediate products strongly bond to the catalyst sites. The absence of water presents a challenge in removing products and intermediates from the surface. Even the degradation of small molecules like ethanol and acetaldehyde can result in deactivation after just a few recycle tests with pollutant concentrations in the ppm range. The decline in photocatalytic activity is



Figure 5. Photocatalytic decomposition of ethanol. All concentration values are normalized to the maximum value.

attributed to changes in the adsorption properties of the photocatalyst surface.^[39] To delve deeper into this matter, the PLA-TiO₂ membrane underwent five consecutive recycling runs under identical conditions, with an initial ethanol concentration of 6800 ppm. In every measurement cycle, the membrane was exposed to UV light for 30 min. The results, presented in **Figure 7**, reveal an intriguing pattern: the decomposition time for each consecutive cycle was 14, 7, 5, 4, and 3 minutes respectively. This outcome may be attributed to the gradual breakdown of the thin polymer layer that covers part of the TiO₂ particles when exposed to UV



Figure 6. Photocatalytic decomposition mechanism.

light, generating more and more active sites for ethanol decomposition.^[40] Additionally, as shown in the figure, an increase in the number of cycles results in a lower initial ethanol concentration in the gas phase. This effect is due to the presence of more accessible TiO_2 for ethanol molecules, leading to more ethanol adsorption on the surface of the photocatalyst.



Figure 7. Ethanol concentration as a function of time after initiation of UV irradiation for 5 cycles of photocatalytic measurements.



Figure 8. SEM images of unexposed PLA-TiO₂ membrane (a) and membrane after 1-5 reusability cycles (b-f) with a scale bar of 5 μ m.



Figure 9. Average fractions of atomic percentages of Ti to C per cycle of PLA-TiO₂ membrane.

Figure 8 illustrates the SEM images of a PLA-TiO₂ membrane before UV exposure (Figure 8a) and the membrane after each reusability cycle (Figure 8b-8f). As the number of measurement cycles increases, the surface of the PLA undergoes degradation, resulting in rougher structures. This degradation leads to a visibly larger amount of TiO₂ powder in the images. Following each cycle, an EDX analysis was performed to determine the atomic percentage of C and Ti present near the sample surface. As the polymer degrades, the detectable levels of carbon decrease while the atomic percentages of Ti increase. **Figure 9** depicts the average Ti/C ratio for each cycle, demonstrating a steady increase as more photocatalytic measurement cycles are conducted. This increase indicates a higher detection of Ti and lower levels of C, which suggests a higher amount of adsorbed ethanol. The finding aligns with the SEM images of the membrane.



Figure 10. SEM images of the unexposed blank PLA membrane (a) and after consecutive 1 to 5 cycles of UV exposure (b-f) with a scale bar of 5 μ m.

However, based on these experiments, it is still unclear whether the breakdown of PLA is a or photocatalysis (UV result of photolysis (UV impact) and TiO₂ impact). Two different measurements were taken to clarify this: a PLA membrane without TiO₂ and a PLA-TiO₂ membrane were both exposed to UV without ethanol injection. The SEM images of both the unexposed and exposed PLA membranes for 1 to 5 consecutive 30-minute cycles of UV can be seen in Figure 10. From the figure, it can be concluded that there is no noticeable difference between the unexposed and exposed membranes after 150 minutes of UV exposure. This suggests that the PLA membrane can withstand UV radiation with a wavelength of 365 nm, and that photolysis does not play a significant role in the degradation of PLA. The SEM images in Figure 11 depict the unexposed PLA-TiO₂ (Figure 11a) membrane and the same membrane after 150 minutes of UV exposure (Figure 11b). The images illustrate that the PLA membrane decomposes under photocatalytic conditions, even in the absence of ethanol injection. Furthermore, Figure 12 illustrates the weight loss of the PLA-TiO₂ membrane after each cycle, showing that almost 55% of PLA was degraded through the photocatalysis process after 150 minutes of UV exposure. These findings suggest that while PLA-TiO₂ shows potential for photocatalytic activity and eco-friendly characteristics, its degradation over time may restrict its practical lifespan and effectiveness in continuous-use applications.



Figure 11. SEM images of the unexposed PLA-TiO₂ membrane (a) and after UV exposure for 150 min without ethanol injection with a scale bar of 5 μ m.



Figure 12. The percentages of weight loss of PLA-TiO₂ membrane after each photocatalytic measurement.

4. Conclusion

Developing and applying a PLA-TiO₂ biodegradable membrane for indoor air purification is a highly promising route to provide excellent photocatalytic efficiency. Using the environmentally friendly solvent CyreneTM, this study integrates TiO₂ nanoparticles into a polylactic acid (PLA) matrix, promoting the degradation of volatile organic compounds (VOCs) and aligning with sustainable manufacturing principles. The structure of the membrane shows a homogenous distribution of TiO₂ nanoparticles on the PLA membrane. The band gap of TiO₂ particles was calculated at 3.06 eV based on the UV-vis spectrum. The ethanol adsorption follows the Langmuir isotherm, indicating a monolayer coverage of ethanol on a homogeneous membrane surface. The results of photocatalytic measurement with this membrane reveal a 14-minute degradation time of 6800 ppm ethanol under UV light irradiation with the multiple-step mechanism. Intermediates, including acetaldehyde, acetic acid, formaldehyde, and formic acid, are produced and degraded to the final products, CO₂ and water, during the photocatalytic process.

The experimental findings from the reusability test demonstrate that while the unique structure of the PLA-TiO₂ membrane enhances photocatalytic activity with successive uses, the biodegradable nature of PLA poses challenges for long-term durability. As PLA undergoes gradual photocatalytic degradation, there is a noticeable decline in the mechanical stability of the membrane, which limits its practical lifespan and effectiveness in continuous-use scenarios. This study underscores the need for a balanced approach to using biodegradable polymers in environmental applications. While they offer significant environmental benefits, their inherent degradability can restrict their utility in applications requiring long-term stability and durability. Future research should focus on enhancing the longevity of biodegradable photocatalytic membranes, possibly by exploring cross-linking PLA or blending it with other durable biopolymers to maintain its effectiveness while still leveraging its eco-friendly properties. These improvements could pave the way for more sustainable and practical air purification solutions, addressing the dual challenges of VOC degradation and environmental conservation.

Acknowledgments

This research was funded by Ghent University, grant number 01G00319. The authors wish to thank the FWO for the medium-sized research infrastructure project L-SCAN I003222N. Olivier Janssens is acknowledged for providing SEM images. We are thankful to Saba Emami Afshar for assistance with the schematic illustration of the reactor.

Conflicts of Interest

The authors declare no conflict of interest.

Data Availability Statement

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

Received: ((will be filled in by the editorial staff))

Revised: ((will be filled in by the editorial staff))

Published online: ((will be filled in by the editorial staff))

References

- [1] M. Malayeri, F. Haghighat, C. Lee, Build. Environ. 2019, 154, 309.
- [2] Y. Li, W. Ma, Chemosphere 2021, 280, 130667.
- [3] J. Mo, Y. Zhang, Q. Xu, J. J. Lamson, R. Zhao, Atmos. Environ. 2009, 43, 2229.
- [4] S. Wang, H. Ang, M. O. Tade, Environ. Int. 2007, 33, 694.
- [5] A. H. Mamaghani, F. Haghighat, C. Lee, Appl. Catal. B: Environ. 2017, 203, 247.
- [6] E. Cosaert, C. Wolfs, S. D. Lambert, G. J. Heynderickx, D. Poelman, *Molecules* 2020, 26, 6584.
- [7] R. G. Ghamsari, M. Mohseni, N. Esmaeilian, A. Naderifar, B. Dabir, *Environ Sci Pollut Res* 2023, 30, 94097.
- [8] L. Zhang, C. Huang, L. Yang, Y. Zhou, S. Yao, K. Sun, N. Geng, G. Huang, L. Liang, Y. Xie, H. Cao, T. Yang, H. Zhu, B. Zou, T. Liu, *Surf. Interfaces.* 2024, 48, 104327.
- [9] Y. Zhang, Y. Wang, R. Xie, H. Huang, M. K. H. Leung, J. Li, D. Y. C. Leung, *Environ. Sci. Tech.* 2022, 56, 16582.
- [10] S. A. Mousa, H. Abdallah, S. A. Khairy, *Sci Rep.* **2023**, *13*, 22150.
- [11] H. Mortazavi Milani, A. A. Sabbagh Alvani, R. Salimi, H. Sameie, D. Poelman, *J Mater Sci.* **2021**, *56*, 16339.
- [12] M. A. Hanif, H. Shin, D. Chun, H. G. Kim, L. K. Kwac, Y. S. Kim, *Membranes* 2023, 13, 50.
- [13] C. Hu, C. Wang, M. Tsai, R. L. G. Lecaros, W. Hung, H. Tsai, K. Lee, J. Lai, J. Chem. Eng. 2022, 450, 138008.
- [14] A. Anand, E. Aneggi, C. Boaretti, A. Lorenzetti, A. Trovarelli, M. Modesti, M. Roso, J. Environ. Chem. Eng. 2024, 12, 111595.
- [15] X. Chen, W. Zhou, Z. Chen, L. Yao, J. Mol. Eng. Mater. 2017, 5, 1750005.
- [16] E. Erusappan, S. Thiripuranthagan, R. Radhakrishnan, M. Durai, S. Kumaravel, T. Vembuli, N. J. Kaleekkal, *J. Environ. Chem. Eng.* 2021, *9*, 105776.
- [17] N. M. Ainali, D. Kalaronis, E. Evgenidou, D. N. Bikiaris, D. A. Lambropoulou, *Macromol* **2021**, *1*, 201.
- [18] W. Han, D. Rao, H. Gao, X. Yang, H. Fan, C. Li, L. Dong, H. Meng, Nano Energy 2022, 97, 107237.
- [19] M. Kaseem, K. Hamad, Z. U. Rehman, *Materials* **2019**, *12*, 3659.
- [20] P. Chanklom, T. Kreetachat, R. Chotigawin, K. Suwannahong, ACS Omega 2021, 6, 10629.
- [21] S. Palmieri, M. Pierpaoli, L. Riderelli, S. Qi, M. L. Ruello, J. Compos. Sci. 2020, 4, 79.
- [22] T. M. Joseph, A. Kallingal, A. M. Suresh, D. K. Mahapatra, M. S. Hasanin, J. Haponiuk, S. Thomas, *Int J Adv Manuf Technol.* **2023**, *125*, 1015.
- [23] H. A, Le Phuong, N. A. Izzati Ayob, C. F. Blanford, N. F. Mohammad Rawi, G. Szekely, ACS Sustainable Chem. Eng. 2019, 7, 11885.
- [24] M. Morales-Jiménez, D. A. Palacio, M. Palencia, M. F. Meléndrez, B. L. Rivas, Membranes 2023, 13, 625.

- [25] W. J. Lee, P. S. Goh, W. J. Lau, A. F. Ismail, N. Hilal, *Membranes* **2021**, *11*, 235.
- [26] S. A. Naziri Mehrabani, V. Vatanpour, I. Koyuncu, Sep. Purif. Technol. 2021, 298, 121691.
- [27] Y. Wang, M. Dai, G. Luo, J. Fan, J. H. Clark, S. Zhang, Chemistry 2023, 5, 2322.
- [28] T. Marino, F. Galiano, A. Molino, A. Figoli, J. Membr. Sci. 2019, 580, 224.
- [29] P. Kubelka, F. Munk, Z. Techn. Phys. 1931, 12, 593.
- [30] C. Regmi, S. Lotfi, J. C. Espíndola, K. Fischer, A. Schulze, A. I. Schäfer, *Catalysts* **2020**, *10*, 725.
- [31] S. Momeni, R. Ahmadi, I. Nabipour, *Environ Sci Pollut Res* 2019, 26, 37162.
- [32] W. Zou, B. Gao, Y. S. Ok, L. Dong, *Chemosphere* **2019**, *218*, 845.
- [33] T. A. Osmari, R. Gallon, M. Schwaab, E. Barbosa-Coutinho, J. C. Pinto, *Adsorpt Sci Technol* **2013**, *31*, 433.
- [34] A. Azmi, k. S. Lau, S. X. Chin, P. S. Khiew, S. Zakaria, C. H. Chia, *Cellulose* 2021, 28, 2241.
- [35] M. R. Nimlos, E. J. Wolfrum, M. L. Brewer, J. A. Fennell, G. Bintner, *Environ. Sci. Tech.* **1996**, *30*, 3102.
- [36] Y. Liang, L. Zhang, C. Huang, J. Xiong, T. Liu, S. Yao, H. Zhu, Q. Yang, B. Zou, S. Wang, J. Colloid. Interface Sci. 2024, 662, 426.
- [37] G. Li, K. A. Gray, Chem. Phys. 2007, 339, 173.
- [38] D. O. Scanlon, C. W. Dunnill, J. Buckeridge, S. A. Shevlin, A. J. Logsdail, S. M. Woodley, C. R. Catlow, M. J. Powell, R. G. Palgrave, I. P. Parkin, G. W. Watson, T. W. Keal, P. Sherwood, A. Walsh, A. A. Sokol, *Nat. Mater* 2013, *12*, 798.
- [39] E. Pargoletti, L. Rimoldi, D. Meroni, G. Cappelletti, *Int. Mater. Rev.* 2022, 67, 864.
- [40] R. Han, R. Zhou, C. O'Rourke, A. Mills, J. Photochem. Photobiol. A Chem. 2023, 443, 114843.

Table of Contents (ToC)

This research examines the use of a biodegradable PLA-TiO₂ membrane for air purification, utilizing CyreneTM as an environmentally friendly solvent. The membrane has shown efficient ethanol degradation under UV light, indicating promising potential for reducing indoor air pollutants. The membrane's reusability is highlighted, showcasing the challenges posed by its biodegradable nature for long-term durability.

ToC Figure

