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Dual functionality of partially hydrophobized SnO_2 nanoparticles in PEPS for efficient elimination of diverse contaminants

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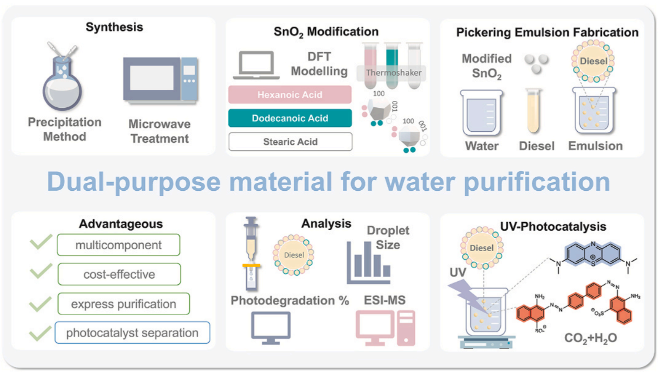
HIGHLIGHTS

- Method to obtain SnO2 NPs with various crystallinity as emulsion stabilizers.
- Partial surface hydrophobization of SnO2 was performed using fatty acids.
- Modeling of SnO2 NPs surfaces to closely resemble real conditions was applied.
- Complete decay of dyes under UV-light in Pickering emulsion photocatalytic systems.
- Separation of the photocatalyst and diesel fuel from purified water was achieved.

GRAPHICAL ABSTRACT



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ABSTRACT

The rapid growth of industries such as pharmaceuticals, textiles, and agriculture, combined with extensive petroleum use, has led to increased wastewater pollution with cyclic organic compounds (COCs) and fuels. To address these issues, new multifunctional materials for existing purification systems are needed. We propose using modified with fatty acids SnO_2 nanoparticles to incorporate petroleum products into emulsions joint with photocatalytic decomposition of COCs. SnO_2 photocatalyst nanoparticles were synthesized via a precipitation

Abbreviations: **BS,**, Band Structure; **CNT**, Carbon Nanotube; **COCs**, Cyclic Organic Compounds; **CR**, Congo Red; **CTAB**, Cetyltrimethylammonium Bromide; **DFT**, Density Functional Theory; **DLS**, Dynamic Light Scattering; DMSO,, Dimethyl Sulfoxide; **DOS**, Density of States; **DS**, Droplet Size; **EDS**, Energy-Dispersive X-ray Spectroscopy; **EDTA**, Ethylenediaminetetraacetic Acid; **ESI-MS**, Electrospray Ionization Mass Spectrometry; **FT-IR**, Fourier-Transform Infrared Spectroscopy; **FWHM**, Full Width At Half Maximum; **HRTEM**, High-Resolution Transmission Microscopy; **HTT**, Hydrothermal Treatment; **HQ**, Hydroquinone; **ICP- AES**, Inductively Coupled Plasma Atomic Emission Spectroscopy; **IPA**, Isopropyl Alcohol; **LC**, Lauryl Chloride; **LQ**, Limits of Quantification; **MB**, Methylene Blue; **MCB**, Monochlorobenzene; **M_Cr**, Monocrystalline; **1-MN**, 1-Methylnaphthalene; **MW**, Microwave; **MWNT**, Multi-Walled Carbon Nanotube; **NB**, Nitrobenzene; **NPs**, Nanoparticles; **OA**, Oriented Attachment; **PD,**, Photodegradation; **P_Cr**, Polycrystalline; **PE**, Pickering Emulsions; **PEPS**, Pickering Emulsions Photocatalytic Systems; **SAED**, Selected Area Electron Diffraction; SNPRs, Self-Assembled Nanoparticle-Stabilized Photocatalytic Reactors; **SSA**, Specific Surface Area; **TEM,**, Transmission Electron Microscopy; **TGA**, Thermogravimetric Analysis; **UV,**, Ultraviolet irradiation; **Vis**, Visible light; **XPS**, X-ray Photoelectron Spectroscopy; **XRD**, X-ray Diffraction Spectroscopy.

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Olga Osmolovskaya: Writing – original draft, Supervision, Methodology, Conceptualization. **Mikhail Osmolowsky:** Conceptualization. **Mikhail Voznesenskiy:** Writing – review & editing, Writing – original draft, Supervision, Software, Resources, Methodology, Investigation, Conceptualization. **Anastasiia Podurets:** Writing – original draft, Visualization, Validation, Investigation. **Natalia Bobrysheva:** Conceptualization. **Evgenii Skripkin:** Validation, Investigation. **Dmitry Kosyrev:** Visualization, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.colsurfa.2024.136063.

Data Availability

Data will be made available on request.

References

[1] K.G. Pavithra, P. S.K, V. Jaikumar, P. S.R, Removal of colorants from wastewater: a review on sources and treatment strategies, J. Ind. Eng. Chem. 75 (2019) 1–19, https://doi.org/10.1016/J.JIEC.2019.02.011.

[2] J. Ahmed, A. Thakur, A. Goyal, Industrial wastewater and its toxic effects. Biological Treatment of Industrial Wastewater, The Royal Society of Chemistry, 2021, pp. 1–14, https://doi.org/10.1039/9781839165399-00001.

[3] P.A, S.S. Robert, W. Peters, Thomas E. White, Young Ku, Carole L. Engelder, Wastewater treatment-physical and chemical methods, Water Pollut. Control Fed. 58 (1986) 481–490.

[4] H. Wu, J. Zhang, H.H. Ngo, W. Guo, Z. Hu, S. Liang, J. Fan, H. Liu, A review on the sustainability of constructed wetlands for wastewater treatment: design and operation, Bioresour. Technol. 175 (2015) 594–601, https://doi.org/10.1016/j.biortech.2014.10.068.

[5] G. Crini, E. Lichtfouse, Advantages and disadvantages of techniques used for wastewater treatment, Environ. Chem. Lett. 17 (2019) 145–155, https://doi.org/10.1007/s10311-018-0785-9.

[6] P. Shumbula, C. Maswanganyi, N. Shumbula, in: M. Nageeb Rashed (Ed.), Type, Sources, Methods and Treatment of Organic Pollutants in Wastewater, Persistent Organic Pollutants (POPs), 2022, p. 20, https://doi.org/10.5772/intechopen.101347.

[7] A.A. Beni, M. Saleh, S. Adel, M. Zaeimdar, A. Ghadi, V. Hassani, K. Jalalvandi, S. A. Abdollahi, in: Başak Kılıç Taşeli (Ed.), Petroleum Wastewater Treatment, Sewage Management, 2023, https://doi.org/10.5772/intechopen.109853.

[8] M.A. Hussein, A.A. Mohammed, M.A. Atiya, Application of emulsion and Pickering emulsion liquid membrane technique for wastewater treatment: an overview, Environ. Sci. Pollut. Res. 26 (2019) 36184–36204, https://doi.org/10.1007/s11356-019-06652-3.

[9] A. Nishat, M. Yusuf, A. Qadir, Y. Ezaier, V. Vambol, M. Ijaz Khan, S. Ben Moussa, H. Kamyab, S.S. Sehgal, C. Prakash, H.H. Yang, H. Ibrahim, S.M. Eldin, Wastewater treatment: a short assessment on available techniques, Alex. Eng. J. 76 (2023) 505–516, https://doi.org/10.1016/j.aej.2023.06.054.

[10] Z. Gricius, G. Øye, Recent advances in the design and use of Pickering emulsions for wastewater treatment applications, Soft Matter 19 (2023) 818–840, https://doi.org/10.1039/d2sm01437h.

[11] S. Cheriyamundath, S.L. Vavilala, Nanotechnology-based wastewater treatment, Water Environ. J. 35 (2021) 123–132, https://doi.org/10.1111/wej.12610.

[12] B. Bethi, S.H. Sonawane, B.A. Bhanvase, S.P. Gumfekar, Nanomaterials-based advanced oxidation processes for wastewater treatment: a review, Chem. Eng. Process. - Process. Intensif. 109 (2016) 178–189, https://doi.org/10.1016/J.CEP.2016.08.016.

[13] S. Taghipour, S.M. Hosseini, B. Ataie-Ashtiani, Engineering nanomaterials for water and wastewater treatment: review of classifications, properties and applications, N. J. Chem. 43 (2019) 7902–7927, https://doi.org/10.1039/c9nj00157c.

[14] S. Mishra, B. Sundaram, A review of the photocatalysis process used for wastewater treatment, Mater. Today Proc. (2023), https://doi.org/10.1016/J.MATPR.2023.07.147.

[15] J.L. Wang, L.J. Xu, Advanced oxidation processes for wastewater treatment: formation of hydroxyl radical and application, Crit. Rev. Environ. Sci. Technol. 42 (2012) 251–325, https://doi.org/10.1080/10643389.2010.507698.

[16] A. Kurt, B.K. Mert, N. Özengin, Ö. Sivrioğlu, T. Yonar, Treatment of antibiotics in wastewater using advanced oxidation processes (AOPs). Physico-Chemical Wastewater Treatment and Resource Recovery, InTech, 2017, pp. 176–211, https://doi.org/10.5772/67538.

[17] N. Fessi, M.F. Nsib, Y. Chevalier, C. Guillard, F. Dappozze, A. Houas, L. Palmisano, F. Parrino, Photocatalytic degradation enhancement in pickering emulsions stabilized by solid particles of bare TiO2, Langmuir 35 (2019) 2129–2136, https://doi.org/10.1021/acs.langmuir.8b03806.

[18] T. Burdyny, J. Riordon, C.T. Dinh, E.H. Sargent, D. Sinton, Self-assembled nanoparticle-stabilized photocatalytic reactors, Nanoscale 8 (2016) 2107–2115, https://doi.org/10.1039/c5nr05859g.

[19] W. Zhai, G. Li, P. Yu, L. Yang, L. Mao, Silver phosphate/carbon nanotube-stabilized pickering emulsion for highly efficient photocatalysis, J. Phys. Chem. C. 117 (2013) 15183–15191, https://doi.org/10.1021/jp404456a.

[20] M.F. Nsib, A. Maayoufi, N. Moussa, N. Tarhouni, A. Massouri, A. Houas, Y. Chevalier, TiO2 modified by salicylic acid as a photocatalyst for the degradation of monochlorobenzene via Pickering emulsion way, J. Photochem. Photobio. A Chem. 251 (2013) 10–17, https://doi.org/10.1016/j.jphotochem.2012.10.007.

[21] N. Fessi, M.F. Nsib, Y. Chevalier, C. Guillard, F. Dappozze, A. Houas, L. Palmisano, F. Parrino, Pickering emulsions of fluorinated TiO2: a new route for intensification of photocatalytic degradation of nitrobenzene, Langmuir 36 (2020) 13545–13554, https://doi.org/10.1021/acs.langmuir.0c02285.

[22] W. Wu, S. Gao, W. Tu, J. Chen, P. Zhang, Intensified photocatalytic degradation of nitrobenzene by Pickering emulsion of ZnO nanoparticles, Particuology 8 (2010) 453–457, https://doi.org/10.1016/j.partic.2010.05.006.

[23] B. Su, X. Ma, L. Ran, S. Wu, B. Hou, Improving the photodegradation efficiency of POPs in oily sewage: design and synthesis of G-C3N4-based photocatalysts incorporating a pickering emulsion catalytic strategy, J. Environ. Chem. Eng. 11 (2023), https://doi.org/10.1016/j.jece.2023.111297.

[24] E.C. Emenike, J. Adeleke, K.O. Iwuozor, S. Ogunniyi, C.A. Adeyanju, V.T. Amusa, H.K. Okoro, A.G. Adeniyi, Adsorption of crude oil from aqueous solution: a review, J. Water Process Eng. 50 (2022), https://doi.org/10.1016/j.jwpe.2022.103330.

[25] Use of Sorbent Materials in Oil Spill Response, (n.d.).

[26] How Oil Harms Animals and Plants in Marine Environments, (n.d.). 〈https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/how-oil-harms-animals-and-plants-marine-environments.html〉 (accessed October 2, 2024).

[27] H. Dai, K. Li, D. Yang, Controllable regulation of diesel oil-in-water pickering emulsion stability by multiresponsive recyclable magnetic polymer brush microvessels, ACS Appl. Mater. Interfaces 16 (2024) 17715–17727, https://doi.org/10.1021/acsami.4c03069.

[28] C. Sun, J. Yang, M. Xu, Y. Cui, W. Ren, J. Zhang, H. Zhao, B. Liang, Recent intensification strategies of SnO2-based photocatalysts: a review, Chem. Eng. J. 427 (2022) 131564, https://doi.org/10.1016/j.cej.2021.131564.

[29] Y. Waseda, E. Matsubara, K. Shinoda, Scattering and diffraction, X-Ray Diffr. Crystallogr. (2011) 67–106, https://doi.org/10.1007/978-3-642-16635-8_3.

[30] L. Abello, B. Bochu, A. Gaskov, S. Koudryavtseva, G. Lucazeau, M. Roumyantseva, Structural characterization of nanocrystalline SnO2 by X-ray and Raman spectroscopy, J. Solid State Chem. 135 (1998) 78–85, https://doi.org/10.1006/jssc.1997.7596.

[31] A. Podurets, D. Kolokolov, M.K.S. Barr, E. Ubyivovk, M. Osmolowsky, N. Bobrysheva, J. Bachmann, O. Osmolovskaya, Enhanced visible-light photocatalytic activity of core–shell oxide nanoparticles synthesized by wet chemical precipitation and atomic layer deposition, Appl. Surf. Sci. 533 (2020) 147520, https://doi.org/10.1016/j.apsusc.2020.147520.

[32] A. Podurets, V. Odegova, K. Cherkashina, A. Bulatov, N. Bobrysheva, M. Osmolowsky, M. Voznesenskiy, O. Osmolovskaya, The strategy for organic dye and antibiotic photocatalytic removal for water remediation in an example of Co-SnO2 nanoparticles, J. Hazard Mater. 436 (2022) 129035, https://doi.org/10.1016/j.jhazmat.2022.129035.

[33] D.S. Kolokolov, A.A. Podurets, V.D. Nikonova, P.N. Vorontsov-Velyaminov, N. P. Bobrysheva, M.G. Osmolowsky, O.M. Osmolovskaya, M.A. Voznesenskiy, SnO2 nanoparticles with different aspect ratio and structural parameters: fabrication, photocatalytic efficiency dependences and fast organic dyes degradation, Appl. Surf. Sci. 599 (2022) 153943, https://doi.org/10.1016/j.apsusc.2022.153943.

[34] A. Podurets, M. Khalidova, L. Chistyakova, N. Bobrysheva, M. Osmolowsky, M. Voznesenskiy, O. Osmolovskaya, Experimental and computational study of Ni-doped SnO2 as a photocatalyst and antibacterial agent for water remediation: the