IOP Conference Series:
Earth and
Environmental Science

PURPOSE-LED PUBLISHING™

PAPER • **OPEN ACCESS**

Photocatalysis mechanism of activated carbon of *Dillenia Indica* and TiO_2 (AC/TiO_2) composites for the removal of the emerging pharmaceutical contaminants

To cite this article: Nurazvirahida Azhari *et al* 2025 *IOP Conf. Ser.: Earth Environ. Sci.* **1548** 012028

View the article online for updates and enhancements.

You may also like

- Possible space collision simulation of the Mozi satellite during the period from 2025 Oct. 27 to 2025 Nov. 3
Yeluo Yu, Hu Jiang, Jiji Cai et al.
- Research on grid-related performance laboratory testing for variable speed pumped storage unit
Yian Yan, Shanying Li, Huan Xie et al.
- Failure mechanism analysis of the crack located at the neck of stainless steel flange
Meng Yuan, Yuan Yao, Wenfang Zhu et al.

This content was downloaded from IP address 217.74.153.144 on 05/10/2026 at 17:24

Photocatalysis mechanism of activated carbon of *Dillenia Indica* and TiO_2 (AC/TiO_2) composites for the removal of the emerging pharmaceutical contaminants

Nurazvirahida Azhari[1], Masitah Hasan[1,3*], Zulfakar Mokhtar[2,3], Naimah Ibrahim[1,3], Farrah Aini Dahalan[1,3], Muhammad Adli Hanif[1], and Nur Salsabila Kamarudin[1]

[1] Faculty of Civil Engineering & Technology, Universiti Malaysia Perlis, Kompleks Pusat Pengajian Jejawi 3, 02600 Arau, Perlis, Malaysia.
[2] Faculty of Chemical Engineering & Technology, Universiti Malaysia Perlis, Kompleks Pusat Pengajian Jejawi 3, 02600 Arau, Perlis, Malaysia.
[3] Centre of Excellence, Water Research and Environmental Sustainability Growth (WAREG), Universiti Malaysia Perlis, Kompleks Pusat Pengajian Jejawi 3, 02600 Arau, Perlis, Malaysia.

*E-mail: masitah@unimap.edu.my

Abstract. This research investigates the removal of diclofenac (DCF) from water through photocatalysis by using titanium dioxide (TiO_2) and activated carbon made from *Dillenia indica* (DI) fruit peels. The researchers created activated carbon through chemical activation before they combined it with TiO_2 to boost its photocatalytic capabilities. Scientists used ultraviolet-visible (UV-Vis) spectroscopy to determine the photocatalytic performance of the samples. The study investigated how different operational factors including catalyst dosage between 0.4 to 1.6 g/L and starting pollutant levels from 50 to 200 mg/L affected the degradation process. The experimental findings showed that DCF removal occurred at high rates while the Langmuir–Hinshelwood model provided kinetic information through its combination of adsorption and surface reaction processes. The analysis showed that surface saturation probably caused the apparent rate constants (K_{app}) to drop when initial DCF concentrations got higher. The kinetic data showed strong linearity with R^2 values between 0.9270 and 0.9659 which proves the reaction follows first-order kinetics. The research demonstrates that the Langmuir–Hinshelwood model provides an exact description of the degradation process which enables scientists to enhance photocatalytic systems for water pharmaceutical removal.

1. Introduction

Pharmaceutical pollution exists when pharmaceutical substances together with their metabolic waste products reach natural environmental systems. The pollution generates severe dangers which endanger both environmental systems and human health (Kayode-Afolayan et al., 2022). Among pharmaceutical contaminants, non-steroidal anti-inflammatory drugs (NSAIDs) such as

Content from this work may be used under the terms of the Creative Commons Attribution 4.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

ibuprofen, ketoprofen, naproxen, and diclofenac (DCF) are a major concern in aquatic systems. The primary characteristics of these substances include their water-attracting properties and their chemical resistance which causes them to persist in wastewater discharge (Lin et al., 2023).The primary characteristics of these substances include their water-attracting properties and their chemical resistance which causes them to persist in wastewater discharge (Lin et al., 2023).

Research studies have demonstrated that pharmaceutical compounds at minimal concentrations create harmful effects on aquatic species by disrupting their natural conduct and breeding patterns and bodily operations. The environment faces a major public health crisis because antibiotics spread through the environment lead to the development of resistant bacteria which threaten human health (Samreen et al., 2021). The established treatment methods which include ozonation and hydrogen peroxide oxidation and Fenton processes fail to achieve total elimination of these contaminants.

Heterogeneous photocatalysis with TiO_2 has become a leading method for treating wastewater. The scientific community prefers TiO_2 because it provides an affordable solution through its chemical stability and non-toxic properties and powerful photocatalytic capabilities (Teixeira et al. 2016). The powder form of TiO_2 creates problems because its particles tend to stick together while making it hard to remove from treated water (Shahid et al. 2015). Scientists have been studying TiO_2 immobilization on high-surface-area supports because this method boosts photocatalytic efficiency and minimizes material waste and operational expenses (Hanafiah et al. 2022). The photocatalytic degradation of propranolol and mebeverine and carbamazepine with TiO_2 nanostructures under UV and UV-visible light shows this method can remove pharmaceutical pollutants from wastewater effectively.

Activated carbon serves as a highly effective support material for TiO_2 but its production from standard raw materials requires expensive manufacturing processes. The research study investigates activated carbon production from *Dillenia indica* (DI) fruit peels to develop a cost-efficient support system for TiO_2. The research team works to produce a photocatalyst system which should clean DCF from water sources while reducing the entire treatment expenses. The study examines the photocatalytic properties and reaction rates and fundamental processes to understand how sustainable composite materials function in removing pharmaceutical contaminants from water sources.

2. Material and method

2.1 Preparation of activated carbon from Dillenia indica (DI)

Freshly harvested peels of DI fruits were initially rinsed thoroughly with tap water to remove surface impurities. The cleaned peels were then subjected to sun-drying for five days to eliminate excess moisture, followed by oven-drying at 110°C to ensure complete removal of residual water molecules (Anisuzzaman et al., 2015). Once fully dried, the peels were cut into smaller fragments to increase surface area, which enhances adsorption efficiency in the final activated carbon product (Aljeboree et al., 2017). Chemical activation was carried out using phosphoric acid (H_3PO_4) at an impregnation ratio of 2 to 1 (weight of H_3PO_4 relative to the dry biomass). The samples were immersed in the acid for 24 hours to allow thorough penetration and coating. Subsequently, the impregnated material was placed in a petri dish and oven-dried at 110°C for 2 hours. Final activation was conducted in a tube furnace at 500°C for 2 hours, yielding the activated carbon (Adebisi et al., 2017). The activated carbon that has been cooled down to room temperature was washed with distilled water to remove the trace of acid. The washing process

was done repeatedly to remove the acid inside the compound thoroughly. The pH of the activated carbon was monitored to ensure it reaches pH 6 to 7. The aid of another chemical, which are 0.1 M of sodium hydroxide (NaOH) and hydrochloric acid (HCl), were applied. When reaching constant natural pH, the DI activated carbon was dried in the oven at 105°C overnight, and DI activated carbon are ready to be used.

2.2 Preparation of catalyst

The deposition of TiO_2 onto activated carbon derived from DI was performed using a thermal impregnation method followed by high-temperature treatment (El-Sheikh et al., 2004). A slurry of 20 g TiO_2 was heated and stirred with 300 mL of distilled water at a temperature of 70°C. AC was added with a ratio of TiO_2 being 1:2 respectively. The mixture was then maintained under continuous stirring at 70°C for 120 min. Initially, the activated carbon (black) and TiO_2 (white) were distinctly visible, but the mixture gradually transformed into a gray color. From this observation, in can be inferred that an interaction between AC and TiO_2 had developed. The mixture was settled for 15 min and then the supernatant was decanted, and the precipitate was dried in the oven at a temperature of 200°C for 12 hrs. The catalyst was named as TiO_2/AC.

2.3 Diclofenac (DCF) solution preparation

The adsorbates solution were prepared in a large amount before running the experiments. The stock solutions of 1 000 mg/L were prepared for each of the adsorbates. In preparing the stock solution, denatured ethanol, C_2H_5OH, was needed as a solubilizing agent. DCF is less soluble in water. Thus, a solvent is further required to solubilize the prepared solution. 0.1 g of adsorbates powder was weighed using the analytical balance and being dissolved in 1 L of volumetric flask containing aqueous mixtures of distilled water and ethanol.

2.4 Reactor set-up

The reactor setup for photocatalysis, which employs a UV lamp with a wavelength of 254 nm and a power intensity of 200 mW/cm^2 (Sankyo Denki Co. Ltd.), typically involves a carefully designed system to harness ultraviolet light energy for the activation of photocatalytic materials. The key components of such a setup include a reaction chamber, a UV light source, and a photocatalyst-coated substrate. The reaction chamber is often made of transparent materials to allow efficient transmission of UV light and may be equipped with appropriate inlets and outlets for the introduction of reactants and removal of products.

2.5 Experimental procedure in photocatalytic batch reactor

A photocatalytic batch reactor was utilized to evaluate the photocatalytic degradation performance of DCF. The photocatalytic degradation of DCF was carried out in a batch reactor. The reaction occurs at atmospheric pressure at a temperature of 30°C. DCF solution with a concentration of 50 mg/L was prepared by diluting the stock solution (1 000 mg/L). A total volume of DCF solution and a calculated amount of photocatalyst were charged into the batch reactor. The amount of catalyst loading used in this experiment was 0.4, 0.8, 1.2 and 1.6 g/L. The contents were then stirred by using magnetic stirrer. Accordingly, the ultra-violet (UV) lamp was turned on to initiate the photocatalytic reaction. Samples were withdrawn (5 mL) through the sampling ports using pipette at 1-hour intervals for the next 8 hours. Then, to assess the adsorption process without UV lamp samples were withdrawn (5 mL) through the sampling ports using pipette at 1-hour intervals for the next 8 hours. TiO_2/AC were used as catalysts. These samples were immediately stored in 5 mL screw cap amber glass before being subjected to analysis. The analysis was done with ultraviolet-visible (UV-Vis) spectroscopy.

3. Results and discussions

3.1 Effect of catalyst loading

Figure 1 shows the effect of catalyst loading on the photocatalytic degradation of DCF with an initial concentration of 50 mg/ L over a period of 480 min. The study compares four different catalyst loadings, namely 0.4, 0.8, 1.2, and 1.6 g/L. Among the various catalyst loadings studied, 0.8 g/L (98%) emerges as the optimal choice. This loading exhibits a significantly better degradation efficiency compared to the lower loading of 0.4 g/L (82%), as evidenced by the lower final pollutant concentration. Although increasing the catalyst loading to 1.2 g/L (93%) and 1.6 g/ L (99%) does result in slightly higher degradation efficiencies, the improvements are marginal and come with diminishing returns. These higher loadings may introduce issues such as light scattering and agglomeration of catalyst particles, which reduce the effective surface area available for the photocatalytic reaction (Jallouli et al., 2018). Therefore, 0.8 g/L strikes the best balance between efficiency and practical application, making it the most effective catalyst loading for the photocatalytic degradation process. In order to demonstrate the normalized concentration of DCF for the experiments, the adsorption (under dark) process was conducted. The result showed only 4% DCF was found to be degraded in the presence of TiO_2/AC (figure not shown). The results obtained clearly indicated that the UV light played important role in the photocatalysis process.

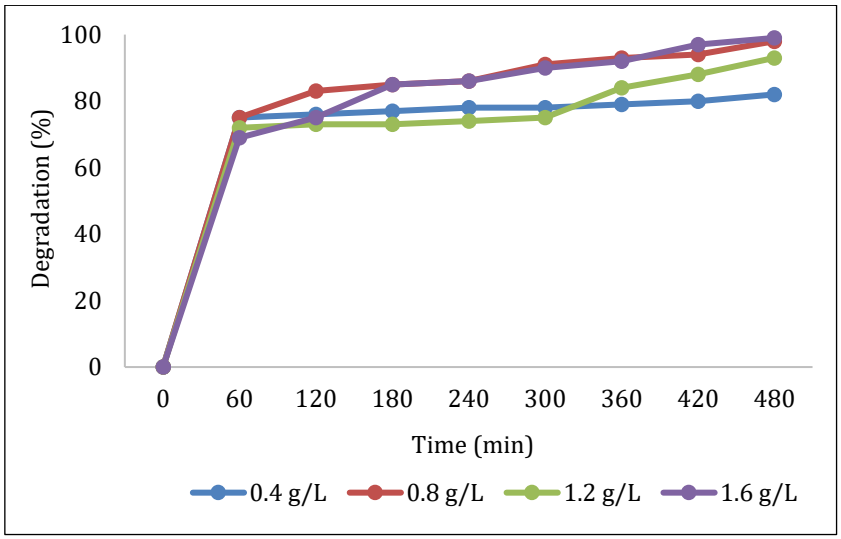


Figure 1. Degradation of DCF at different initial catalyst loading.

3.2 Effect of initial concentration

The graph in figure 2 illustrates the percentage degradation of different initial concentrations of 50, 100, 150, and 200 mg/L with dosage of 0.8 g over time. For the 50 mg/L initial concentration, the degradation is the most rapid, achieving nearly 100% degradation within the first 180 min and maintaining this level up to 480 min. The 100 mg/L concentration shows a steady increase in degradation, reaching approximately 90% by 480 min. The 150 mg/L concentration also demonstrates a gradual increase, achieving around 80% degradation by the end of the 480-minute period. Lastly, the 200 mg/L concentration, while showing the slowest initial rate of degradation, catches up significantly, reaching close to 90% by 480 min. These trends indicate that while lower initial concentrations degrade faster, higher initial concentrations eventually achieve comparable

levels of degradation, albeit over a longer time span. According tu Ruziwa et al., 2023, with increasing pharmaceutical concentration, a larger fraction of the photocatalyst surface becomes occupied by adsorbed molecules, thereby diminishing the number of accessible active sites and restricting light absorption essential for effective degradation.

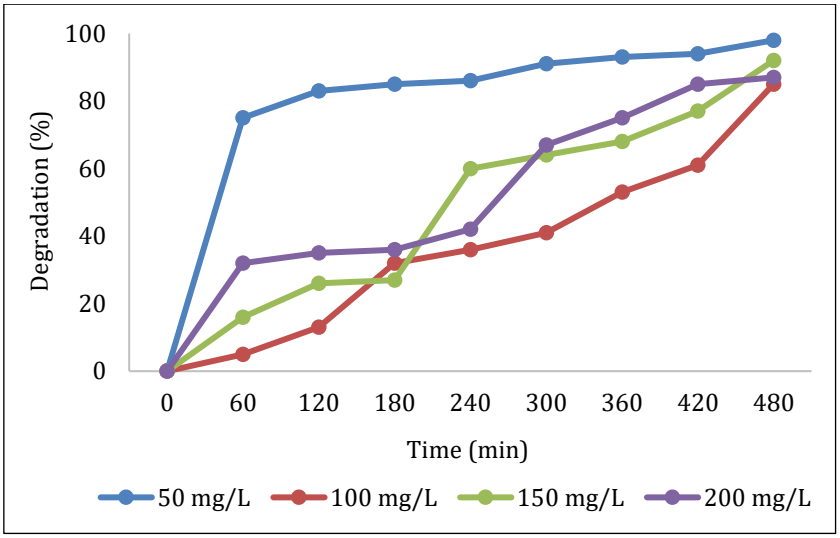


Figure 2. Degradation of DCF at different initial DCF concentration.

3.3 Kinetic study of photocatalytic diclofenac (DCF) degradation

The kinetic order and apparent rate constant of the disappearance of DCF was determined. Degradation kinetic studies for different concentrations from from 50 to 200 mg/L are shown in figure 3. The x-axis displays time in minutes, and the y-axis displays the natural logarithm of the ratio of the concentration (C) at time, t, to the initial concentration (Co), indicated as ln (C/Co). The data for each concentration was fitted with a linear regression line, confirming the first-order kinetic behaviour, as a straight line is obtained for each concentration. The rate constants decrease slightly with increasing initial concentration, a possible saturation effect or changes in reaction dynamics at higher concentrations. The values of K_{app} are summarized in table 1. From table 1, the apparent rate constant for TiO_2/AC decreases with the increasing of initial concentration. The high R^2 values (close to 1) indicate a good fit for the linear model, confirming the consistent first-order kinetic behaviour across different concentrations. A study on tetracycline was conducted by Karcıoğlu et al. (2025), using MXene/ZnO as integrated photocatalytic adsorbents. Their findings indicated that the first-order kinetic models provided the best fit. This investigation provides important insights into the reaction mechanism, enabling improved optimization for applied systems.

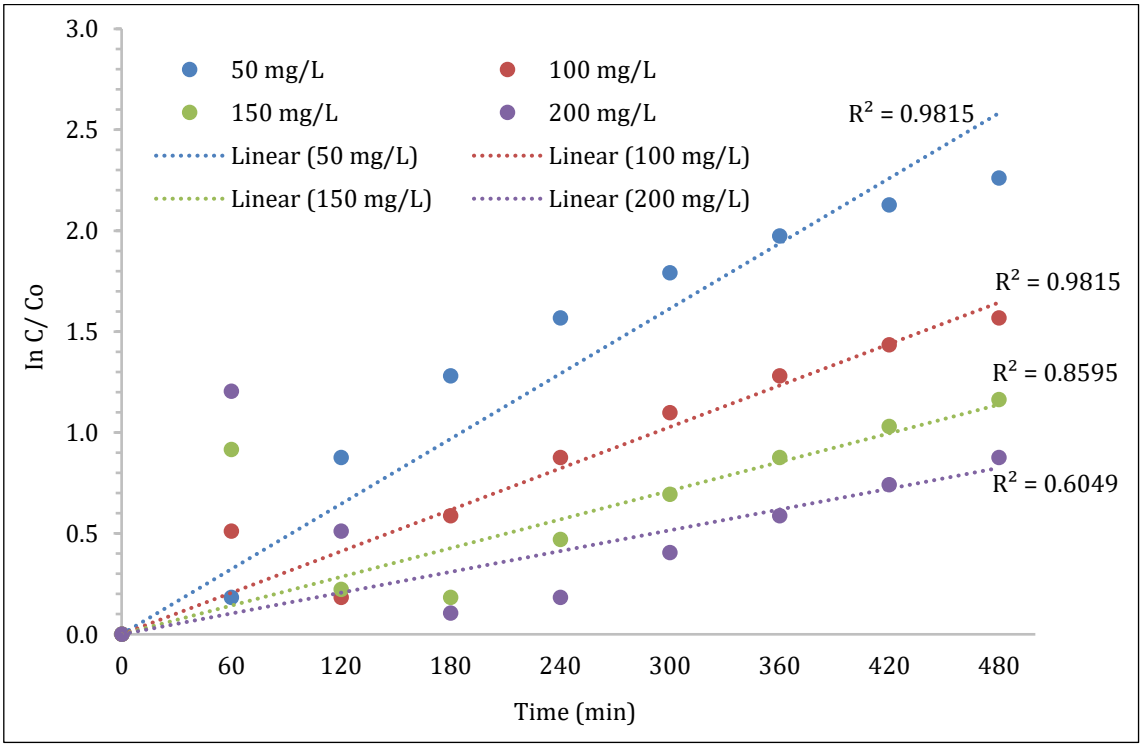


Figure 3. Relationship of $\ln(C/C_0)$ with irradiation duration indicating first-order behavior.

Table 1. Kapp obtained at different initial DCF concentrations.

Concentration (mg/L)	K_{app} (min^{-1})	R^2
50	0.0054	0.9270
100	0.0034	0.9340
150	0.0023	0.9381
200	0.0017	0.9659

4. Conclusion

Kinetic analysis showed DCF degradation follows first-order kinetics because ln (C/C_0) shows a direct linear relationship with irradiation time. The rate constants showed a small decline at higher starting concentrations which indicates potential saturation or changing reaction mechanisms yet the R^2 values stayed high to prove the model's accuracy. The degradation process showed strong sensitivity to catalyst dosage and initial DCF concentration because the right amount of catalyst prevents TiO_2 particles from clumping which preserves their active sites. The process started to remove lower concentrations of pollutants at a faster rate, but longer exposure times produced similar results for higher concentrations. The study shows that AC/TiO_2 composites function as effective photocatalytic materials for removing pharmaceutical contaminants from water sources.

References

Adebisi, G. A., Chowdhury, Z. Z., & Alaba, P. A. (2017). Equilibrium, kinetic, and thermodynamic studies of lead ion and zinc ion adsorption from aqueous solution onto activated carbon prepared from palm oil mill effluent. *Journal of Cleaner Production, 148,* 958–968. https://doi.org/10.1016/j.jclepro.2017.02.029

Aljeboree, A. M., Alshirifi, A. N., & Alkaim, A. F. (2017). Kinetics and equilibrium study for the adsorption of textile dyes on coconut shell activated carbon. *Arabian Journal of Chemistry, 10*(S1), S3381–S3393. https://doi.org/10.1016/j.arabjc.2014.01.020

Anisuzzaman, S. M., Joseph, C. G., Taufiq-Yap, Y. H., Krishnaiah, D., & Tay, V. V. (2015). Modification of commercial activated carbon for the removal of 2,4-dichlorophenol from simulated wastewater. *Journal of King Saud University – Science, 27*(4), 318–330. https://doi.org/10.1016/j.jksus.2015.02.003

El-Sheikh, A. H., Newman, A. P., Al-paffaee, H., Phall, S., Cresswell, N., & York, S. (2004). Deposition of anatase on the surface of activated carbon. *Surface and Coatings Technology, 187*(2–3), 284–292. https://doi.org/10.1016/j.surfcoat.2004.02.016

Hanafiah, Z. M., Mohtar, W. H. M. W., Manan, T. S. B. A., Bachi, N. A., Abdullah, N. A., Hamid, H. H. A., ... Rasdi, N. W. (2022). The occurrence of non-steroidal anti-inflammatory drugs (NSAIDs) in Malaysian urban domestic wastewater. *Chemosphere, 287,* 132134. https://doi.org/10.1016/j.chemosphere.2021.132134

Jallouli, N., Pastrana-Martínez, L. M., Ribeiro, A. R., Moreira, N. F. F., Faria, J. L., Hentati, O., Silva, A. M. T., & Ksibi, M. (2018). Heterogeneous photocatalytic degradation of ibuprofen in ultrapure water, municipal and pharmaceutical industry wastewaters using a TiO_2/UV-LED system. *Chemical Engineering Journal, 334,* 976–984. https://doi.org/10.1016/j.cej.2017.10.045

Karcıoğlu Karakaş, Z., & Dönmez, Z. (2025). A Sustainable Approach in the Removal of Pharmaceuticals: The Effects of Operational Parameters in the Photocatalytic Degradation of Tetracycline with MXene/ZnO Photocatalysts. Sustainability, 17(5), 1904. https://doi.org/10.3390/su17051904

Kayode-Afolayan, S. D., Ahuekwe, E. F., & Nwinyi, O. C. (2022). Impacts of pharmaceutical effluents on aquatic ecosystems. *Scientific African, 17,* e01288. https://doi.org/10.1016/j.sciaf.2022.e01288

Lin, J., Zhang, Y., Bian, Y., Zhang, Y., Du, R., Li, M., Tan, Y., & Feng, X. (2023). Non-steroidal anti-inflammatory drugs (NSAIDs) in the environment: Recent updates on the occurrence, fate, hazards and removal technologies. *Science of the Total Environment, 904,* 166897. https://doi.org/10.1016/j.scitotenv.2023.166897

Ruziwa, D. T., Oluwalana, A. E., Mupa, M., Meili, L., Selvasembian, R., Nindi, M. M., Sillanpaa, M., Gwenzi, W., & Chaukura, N. (2023). Pharmaceuticals in wastewater and their photocatalytic degradation using nano-enabled photocatalysts. *Journal of Water Process Engineering, 54,* 103880. https://doi.org/10.1016/j.jwpe.2023.103880

Samreen, Ahmad, I., Malak, H. A., & Abulreesh, H. H. (2021). Environmental antimicrobial resistance and its drivers: A potential threat to public health. *Journal of Global Antimicrobial Resistance, 27,* 101–111. https://doi.org/10.1016/j.jgar.2021.08.008

Shahid, M., McDonagh, A., Kim, J. H., & Shon, H. K. (2015). Magnetised titanium dioxide (TiO_2) for water purification: Preparation, characterisation and application. *Desalination and Water Treatment, 54*(4–5), 979–1002. https://doi.org/10.1080/19443994.2014.903849

Teixeira, S., Gurke, R., Eckert, H., Kühn, K., Fauler, J., & Cuniberti, G. (2016). Photocatalytic degradation of pharmaceuticals present in conventionally treated wastewater by nanoparticle suspensions. *Journal of Environmental Chemical Engineering, 4*(1), 287–292. https://doi.org/10.1016/j.jece.2015.10.045