GeoAtos
Revista Geografia em Atos

unesp

APPLICATION OF HETEROGENEOUS PHOTOCATALYSIS IN THE TREATMENT OF INDUSTRIAL EFFLUENTS: A SYSTEMATIC REVIEW

APLICAÇÃO DA FOTOCATÁLISE HETEROGÊNEA NO TRATAMENTO DE EFLUENTES INDUSTRIAIS: UMA REVISÃO SISTEMÁTICA

APLICACIÓN DE LA FOTOCATÁLISIS HETEROGÉNEA EN EL TRATAMIENTO DE AGUAS RESIDUALES INDUSTRIALES: UNA REVISIÓN SISTEMÁTICA

Jefferson LIRA[1]
e-mail: lira.silva@ufpe.br

Rogério Ferreira da SILVA[2]
e-mail: rogerio1986@gmail.com

Gilson Lima da SILVA[3]
e-mail: gilson.lsilva@ufpe.br

How to reference this paper:

LIRA, J.; SILVA, R.; SILVA, L. Application of heterogeneous photocatalysis in the treatment of industrial effluents: a systematic review. **Revista Geografia em Atos**, Presidente Prudente, v. 09, n. 00, e025008. e-ISSN: 1984-1647. DOI: 10.35416/2025.10601

| **Submitted**: 13/08/2024
| **Revisions required**: 17/04/2025
| **Approved**: 09/09/2025
| **Published**: 10/10/2025

Editors: Ph.D. Nécio Turra Neto
Prof. Mrs. Karina Malachias Domingos dos Santos

[1] Federal University of Pernambuco (UFPE), Recife – Pernambuco (PE) – Brazil. Master's degree in Environmental Engineering from the Graduate Program in Civil and Environmental Engineering (PPGECAM), UFPE.
[2] Federal Institute of Pernambuco (IFPE), Recife – Pernambuco (PE) – Brazil. Ph.D. in Chemistry from UFPE. Associate Professor at the Federal Institute of Education, Science and Technology of Pernambuco.
[3] Federal University of Pernambuco (UFPE), Recife – Pernambuco (PE) – Brazil. Ph.D. in Chemical Engineering, with a concentration in Environmental Engineering, from the University of Campinas (UNICAMP). Associate Professor at U
FPE.

ABSTRACT: An effluent loaded with chemicals, dyes, and surfactants has been a problem for the textile industry. An effective treatment is needed to degrade these compounds so that they can be disposed of as required by law. Heterogeneous photocatalysis is one of the promising treatments for this effluent. This study aimed to develop a systematic review using the PRISMA methodology to select articles from the Scopus and Web of Science platforms. 26 articles were selected that fit the research. With the help of the VOSviewer software, maps were created where the main co-authors, countries developing research, and the main keywords used could be identified. In these articles that were found, the various applications of heterogeneous photocatalysis in the treatment of these industrial effluents were observed. It was concluded that the correct disposal of effluent has been a worldwide concern, and from this perspective, new test studies are being developed.

KEYWORDS: Advanced oxidation process. Titanium dioxide. Textile effluent.

***RESUMO**: Um efluente carregado de produtos químicos, corantes e surfactantes tem sido um problema para as indústrias do ramo têxtil, necessitando de um tratamento eficaz na degradação desses compostos, para que seja possível o seu descarte conforme determina a legislação. A fotocatálise heterogênea se caracteriza como um dos tratamentos promissores para o tratamento desse efluente. Este trabalho se propôs a elaborar uma revisão sistemática, utilizando a metodologia PRISMA para seleção de artigos nas plataformas Scopus e Web of Science. Foram selecionados 26 artigos que se enquadraram na pesquisa. Com o auxílio do software VOSviewer, elaboraram-se mapas nos quais foi possível identificar os principais coautores, os países desenvolvedores das pesquisas, bem como as principais palavras-chave utilizadas. Nesses artigos, observou-se as diversas aplicações da fotocatálise heterogênea no tratamento desses efluentes industriais. Concluiu-se que o descarte correto do efluente tem sido uma preocupação mundial; nessa perspectiva, novos estudos e testes vêm sendo desenvolvidos.*

***PALAVRAS-CHAVE**: Processo oxidativo avançado. Dióxido de titânio. Efluente têxtil.*

***RESUMEN**: Un efluente cargado de productos químicos, colorantes y tensioactivos ha supuesto un problema para las industrias textiles. Se necesita un tratamiento eficaz para degradar estos compuestos, de modo que puedan eliminarse según lo exige la ley. La fotocatálisis heterogénea se caracteriza como uno de los tratamientos prometedores para el tratamiento de este efluente. Este trabajo tuvo como objetivo desarrollar una revisión sistemática, utilizando la metodología PRISMA para seleccionar artículos en las plataformas Scopus y Web of Science. Se seleccionaron 26 artículos que se ajustan a la investigación. Con la ayuda del software VOSviewer, se crearon mapas que muestran a los principales coautores, los países en desarrollo de la investigación, así como las principales palabras clave utilizadas. En estos artículos encontrados se observaron las diversas aplicaciones de la fotocatálisis heterogénea en el tratamiento de estos efluentes industriales. Se concluyó que la correcta disposición del efluente ha sido una preocupación mundial, desde esta perspectiva se han desarrollado nuevos estudios de prueba.*

***PALABRAS CLAVE**: Proceso oxidativo avanzado. Dióxido de titanio. Efluente textil.*

Introduction

During the textile finishing process, a large volume of water is required for the treated fabrics to achieve the desired outcome. Consequently, this generates wastewater with a highly diverse composition due to the chemical agents employed in modifying denim during processing. Many of the components in this effluent are chemicals that, when discharged into aquatic environments, have the potential to alter the physicochemical properties of the receiving bodies of water (Ramos *et al.*, 2020).

Because of the substantial demand for water in textile finishing processes, a correspondingly large amount of wastewater is produced. This effluent is laden with chemical compounds and exhibits high toxicity. The toxicity of textile waste is among the most critical concerns regarding environmental impacts. These compounds may persist in aquatic environments for approximately 50 years, jeopardizing ecosystem stability and threatening surrounding life (Viana, 2019).

For this reason, textile wastewater must be treated effectively—both to enable its reuse and to prevent excessive costs to the industry as well as severe environmental damage upon disposal. However, the quality parameters of recycled effluent may vary depending on the treatment processes employed in a textile plant (Macedo, 2022).

Among the alternative technologies available for the treatment of industrial effluents, Advanced Oxidation Processes (AOPs) have proven particularly promising, as they are efficient in the mineralization of recalcitrant organic compounds, such as those found in textile wastewater (Wolff *et al.*, 2022).

AOPs demonstrate high degradability of extremely toxic and recalcitrant compounds, primarily due to the generation of highly oxidizing species, most notably hydroxyl radicals (•OH). These radicals are strong, non-selective oxidants, with a high oxidation potential of 2.8 V—greater than other oxidizing agents involved in the process (Dória *et al.*, 2018).

Teixeira and Jardim (2004) state that AOPs are broadly divided into two categories: homogeneous and heterogeneous. Heterogeneous processes involve the presence of catalysts, whereas homogeneous processes do not. They further note that heterogeneous AOP systems can be subdivided into irradiation and non-irradiation processes. Irradiation processes require a light source, which may be UV solar light or an artificial light source.

This study aimed to conduct a systematic review using the PRISMA methodology for the selection of articles from the Scopus and Web of Science databases, focusing on the applications of heterogeneous photocatalysis with titanium dioxide in wastewater treatment.

Materials and Methods

To ensure a more precise analysis of the selected studies, the systematic review was divided into three stages: database search, bibliometric analysis, and systematic analysis.

Database Search

The literature search was conducted in two distinct databases: Scopus and Web of Science. Both platforms were selected due to their wide coverage, credibility, and recognition within the scientific community, as well as their indexing of highly relevant journals.

National and international scientific articles retrieved from these databases were analyzed, using the keywords “titanium dioxide” and “textile dyes,” with the search restricted to publications between 2019 and 2023.

The selection of studies followed the steps outlined in the PRISMA methodology:

- Identification: at this stage, the keywords mentioned above were searched in Scopus and Web of Science. More than 200 articles were identified across both databases;
- Screening: filters were applied to refine the search, prioritizing publications from 2019 to 2023. After applying this filter, the number of articles was reduced to 139;
- Eligibility: titles and abstracts were read to exclude studies unrelated to the scope of this research. At this stage, 66 articles were excluded, leaving 73;
- Inclusion: following the previous steps, the remaining articles were read in full. Of these 73 articles, only 26 met the research objectives.

Bibliometric Analysis

The bibliometric analysis was carried out using the VOSviewer software to generate bibliometric networks. The colors of the sets represent the clusters (groupings constructed by the software), consisting of circles interconnected by arcs. The size of the circles indicates their impact in the analysis, while the thickness of the arcs represents the strength of the connections between them. The networks were generated with the purpose of assessing co-authorship relationships, the countries conducting the research, and the keywords used in the studies.

Systematic Analysis

In this stage, the articles retrieved from the previously mentioned databases were examined. Based on this analysis, two tables were created to summarize the selected studies.

The selection of the articles followed the PRISMA methodology (Moher *et al.*, 2009), which is divided into four stages: identification, screening, eligibility, and inclusion.

Results and Discussion

From the analyses conducted, it was possible to achieve the objectives established at the outset, namely: (i) to select articles from the aforementioned databases related to the research topic; (ii) to generate maps with the support of VOSviewer software, illustrating research networks on the proposed theme, including authors, keywords, countries, among other relevant information; and (iii) to prepare tables with a concise description of the studies, their methodologies, and their main findings.

Database Search

Bibliometric Analysis

In the first analysis conducted with VOSviewer, co-authorship relationships in the selected studies were examined. A high degree of parity among the cited researchers was observed, with the exception of Younas U., a scholar of significant relevance in this field, whose work has addressed the topic extensively in recent years. It was also found that Younas U. has research links across both clusters represented in the figure, confirming his prominence in the area under study. Figure 1 illustrates the correlation among the most frequently cited co-authors in the Scopus database.

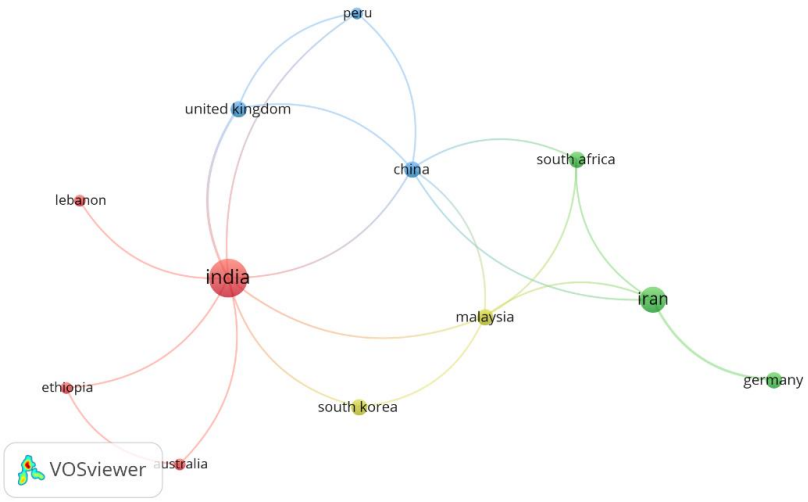
Figure 1 – Correlation of co-authors in the Scopus Database

Source: Authors (2024).

The significant relevance of Dr. Umer Younas – Younas U. – is due to his extensive body of work in the field of environmental chemistry, particularly regarding the treatment and investigation of effluents. Examples include his studies *Efluentes industriais de fertilizantes: Caracterização físico-química e avaliação de parâmetros de qualidade da água (2017)* and *Atividade fotocatalítica de luz visível aprimorada de TiO2 co-dope com Fe, Co e S para degradação de Cango vermelho (2021),* dentre tantos outros que poderiam aqui serem citados.

The countries of origin of the authors conducting research on this subject are presented in Figure 2. India stands out in particular, both in comparison with European countries and in terms of its hegemony within the Asian continent, competing with numerous developed countries, while China appears in one of the clusters. This considerable volume of research developed in India on topics related to the area was also highlighted by Marques and Conceição (2022) and Silva and Longo (2022), who further noted that such prominent participation is linked to the country's high production of waste generated by the textile industry as well as its substantial demand.

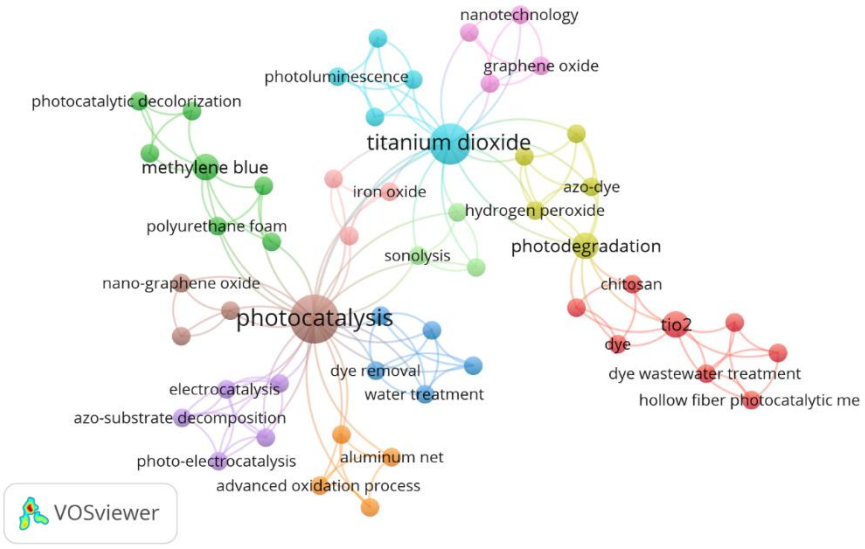
Figure 2 – correlation of countries developing research published in Scopus



Source: Authors (2024).

It is noteworthy that American countries are absent from the studies identified. Only Peru, from South America, appears in the networks, establishing connections with the United Kingdom, China, and India. This underscores the need for further research development and the establishment of new partnerships among researchers, given the relevance of the topic under investigation, or alternatively, the pursuit of publication in higher-impact journals within the scientific community. Figure 3 presents the most frequently used keywords in the studies retrieved from the Web of Science database.

Figure 3 – Most frequently used keywords in publications analyzed in Web of Science

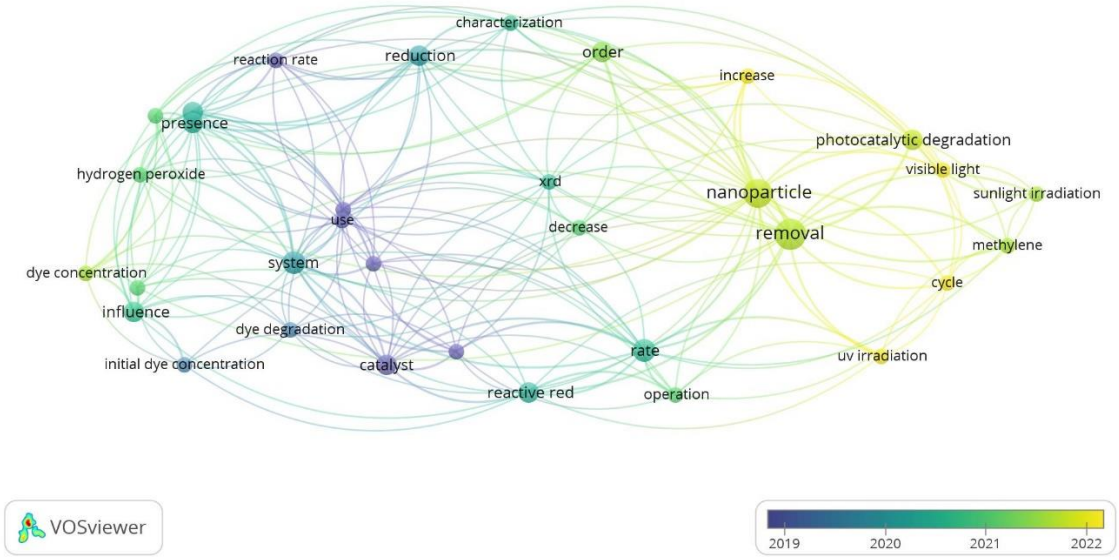


Source: Authors (2024).

As also demonstrated by Marques and Conceição (2022), there is a balance in the research being developed. Their study highlights the term "*photocatalysis*" as the fourth most frequently researched keyword in the context of wastewater treatment, with 20 occurrences in their dataset. In addition to this expression, other relevant terms such as "*oxidative process*" also appear, among others.

With the support of VOSviewer software, it was further possible to analyze the timeline of research development with respect to keywords, as illustrated in Figure 4.

Figure 4 – Keyword Timeline



Source: Authors (2024).

This analysis revealed an increase in the number of studies beginning in mid-2022, particularly involving the expression "*photocatalytic degradation*" in correlation with the terms "*removal*", "*reduction*", and "*nanoparticle*." Such growing interest in the subject is likely related to the demands of the textile industry and the increasing concern with environmental issues.

Systematic analysis

Following the review of the selected articles, two tables were compiled—one for each database examined. Tables 1 and 2 present summarized information from each study, including their main conclusions and the methodologies employed in the research.

Table 1 – Articles retrieved from the Scopus database

REFERENCES	METHODOLOGY	RESULTS
Lima *et al.*, 2023	In this study, a structured monolithic photoreactor with calcined brass of high surface area was employed as a substrate for TiO2-P25. The immobilization of TiO2 onto the monoliths was carried out using the washcoating process. The films were characterized by XRD and diffuse reflectance.	Preliminary calcination temperature tests of brass revealed the formation of ZnO and CuO semiconductors on the brass surface, suggesting that the monoliths can act as photocatalysts. Furthermore, brass calcined at 500 °C exhibited greater formation of both oxides (ZnO and CuO) and higher photocatalytic efficiency. The TiO2/brass monolith achieved over 59% degradation for an initial dye concentration of 12.5 $mg \cdot L^{-1}$.

Mousavi *et al.*, 2022	In this research, a heterogeneous photocatalyst based on a magnetic carbon nanocomposite derived from Fe-MOFs with surface carboxylic acid functional groups (Fe@C–COOH) was obtained. Subsequently, α-Fe_2O_3@C@SiO_2/TiO_2 was successfully synthesized to coat the surface of the intermediate TiO_2 particles. Moreover, the photocatalytic performance of the magnetic nanocomposite α-Fe_2O_3@C@SiO_2/TiO_2 was investigated in terms of dye degradation and photocatalytic activity against Reactive Yellow 145 (RY145).	Structural characterization of the synthesized materials confirmed that these methods generate oxygen-containing functional groups, such as –OH, –C=O, and –COOH, which enhance the polarity and hydrophilicity of the photocatalyst. The photocatalytic oxidation of RY145 under UVc light was analyzed using the apparent first-order reaction rate, and the Langmuir–Hinshelwood kinetic model provided the best fit. Optimal composite performance was observed at pH 2, with a photocatalyst dose of 15 mg/100 mL, an RY145 concentration of 150 mg/L, at 25 °C under UVc lamp irradiation for 90 min, yielding an apparent reaction rate of 0.0165 min^{-1}.
Sudhagar *et al.*, 2022	The hydrothermal method was employed to synthesize the anatase phase of TiO_2 nanoparticles, TiO_2/La_2O_3 composites, and TiO_2/Al_2O_3 composites. Photocatalytic studies were comparatively evaluated through the degradation of the textile dyes methylene blue (MB) and crystal violet (CV).	The degradation process was conducted under both UV and visible light irradiation. The efficiencies achieved by TiO_2, TiO_2/La_2O_3 and TiO_2/Al_2O_3 were 87%, 95%, 45% and 80%, 92%, 29%, respectively, for methylene blue (MB) and crystal violet (CV) under UV light, whereas under visible light, they were 34%, 27%, 84% and 29%, 24%, 81%, respectively, for MB and CV.
Assis *et al.*, 2021	The photocatalytic decolorization of industrial dyes Novacron Blue (NB) and Novacron Yellow (NY) was investigated using TiO2 based composites with natural palygorskite (Pal-Ti10 and Pal-Ti30). The concentrations analyzed were 10 ppm and 30 ppm; the composites were synthesized with 10% and 30% (w/w) titanium on palygorskite; two pH values, 2.0 and 6.0, were tested, as well as light intensities of 9 W and 18 W.	Tests conducted at pH 2.0, using the Pal-Ti30 composite, 18 W power, and 10 ppm dye concentration showed 100% color removal for both dyes within 90 min. The bleaching process followed a pseudo-first-order kinetic model, and the apparent rate constants (K_app) were 0.0216 min^{-1} and 0.0193 min^{-1} for NB and NY dyes, respectively. Total organic carbon (TOC) results indicated mineralization of 61.70% and 58.06% for NB and NY, respectively, after 90 min of treatment, with byproducts detected by GC–MS.
Chandrabose *et al.*, 2021	In this study, the simultaneous removal of mixed dye pollutants (anionic and cationic) was analyzed by combining adsorption and photocatalysis processes. MoS_2/TiO_2 nanocomposites were synthesized with varying weight percentages of 2.5, 5, 10, 20, 30, and 50% of flower-like MoS_2 nanoparticles, pre-synthesized using a two-step hydrothermal method.	The proposed two-stage integrated adsorption and photocatalysis process, using 50% and 2.5% TiO_2 coated with MoS_2, respectively, achieved complete methylene blue dye removal approximately five times faster than the conventional single-stage water treatment process (adsorption or photocatalysis alone). Moreover, the feasibility of the two-stage method was demonstrated for the removal of mixed dye pollutants (anionic and cationic), showing excellent performance even when the pollutant dye concentration was doubled.
Imran *et al.*, 2021	The photocatalytic activity of TiO2 under visible light was enhanced when it was co-doped with Fe, Co, and S via the sol–gel method. The resulting nanophotocatalysts were characterized by XRD, SEM-EDX, FT-IR, UV-Vis, and UV-DRS. The concentration ratios of Fe and S	The dye was degraded within approximately 1.2 h, achieving 99.3% degradation. The anatase phase of TiO_2 was confirmed by XRD analysis, while the bandgap energy of TiO_2 decreased from 3.2 eV to 1.6 eV after the addition of Fe, Co, and S. Furthermore, due to its outstanding photocatalytic and optical properties, the material can be efficiently exploited for solar-driven water treatment, potentially

	precursor salts were fixed at 1% each, while Co varied between 0.5% and 1.5%.	providing a more cost-effective solution for wastewater remediation.
Poolwong *et al.*, 2021	Three-dimensional hierarchical mesoporous titanium dioxide structures (3D-HPT) were synthesized via self-assembled emulsion polymerization. Polymethyl methacrylate (PMMA) and Pluronic 123 (P123) were employed as soft templates and co-templates to facilitate the formation of hierarchical 3D porous structures. The TiO_2 crystalline structure, morphology, and the degradation of Remazol Red dye were investigated.	The 3D-HPT structure exhibited significantly enhanced adsorption of Remazol dye and facilitated efficient photocatalytic degradation. Remarkably, 3D-HPT was able to adsorb approximately 40% of 24 ppm Remazol dye in the dark, which is superior to 3D-T and commercial anatase under the same conditions (approximately 5%). Furthermore, 3D-HPT completely decolorized Remazol dye within only 20 minutes, three times faster than commercial anatase, making it one of the most active photocatalysts reported for Remazol dye degradation.
Elbadawy *et al.*, 2021	This study aims to examine the photocatalytic degradation of the textile pollutant Acid Red 37 under UV irradiation in a bench-scale batch photoreactor, designing an optimal system of nanometallic oxides TiO_2, ZnO, and their mixtures in different weight ratios. The photocatalysts were synthesized and fully characterized by XRD, EDS, and TEM.	The highest photodegradation was observed under UV irradiation with a TiO_2:ZnO ratio of 3:1 at pH 6.5, for a textile dye concentration of 1.0×10^{-4} mol/L. The photocatalytic degradation efficiency of the studied systems follows the order: UV/ZnO < UV/TiO_2 < UV/TiO_2/ZnO < UV/TiO_2/ZnO/H_2O_2 < UV/TiO_2/ZnO/$Na_2S_2O_8$ < UV/TiO_2/ZnO/$NaIO_4$. The system designated as UV/TiO_2/ZnO/(1,1–5,5)x10^{-3}M$NaIO_4$ exhibited the highest photocatalytic degradation efficiency, with the highest apparent quantum yield (11.1–16.6%) and the lowest electrical energy per order (37.0–22.2 kWh), indicating the lowest energy consumption compared to the other catalytic systems examined.
Niazi *et al.*, 2021	In this work, two sunlight-responsive photocatalysts were prepared, including TiO_2 nanoparticles (NPs) and TiO_2/graphene quantum dot (GQDs) nanocomposites, for the degradation of the textile dye Reactive Black 5 (RB5).	Results showed that 100% of 50 ppm RB5 could be degraded by TiO_2 NPs and TiO_2/GQDs in 60 and 30 minutes of solar irradiation, respectively. Thus, much higher photocatalytic activity in RB5 degradation was achieved with TiO_2/GQDs under solar irradiation compared to pure TiO_2 NPs, due to their smaller bandgap (2.13 eV) and lower electron–hole recombination rate.
Alahiane *et al.*, 2020	This research analyzed the application of industrially produced nonwoven fibers coated with TiO_2 for adsorption coupled with the photocatalytic degradation of the synthetic textile dye Direct Red 80.	The tested TiO_2 catalyst, which exhibited significant adsorption capacity due to its high specific surface area, proved to be an effective photocatalyst for the studied dye degradation. The effect of inorganic ions (Na_2SO_4, NaCl, $NaNO_3$, CH_3COONa, $NaHCO_3$ and Na_2HPO_4) was also investigated. A pseudo-first-order kinetic reaction was described using the Langmuir–Hinshelwood model, and the rate constant and adsorption equilibrium constant were calculated ($k = 1.1873$ mg/L·min and $K\_LH = 0.0660$ L/mg, respectively). The highest photodegradation efficiency was observed at pH 3. The presence of HPO_4^{2-}, HCO_3^-, and CH_3COO^- ions decreased the photodegradation rate, whereas Cl^- and NO_3^- increased the reaction rate.
Mpelane *et al.*, 2020	In this study, a novel carbon-doped titanium dioxide-fly ash nanocomposite supported on a poly(acrylonitrile) membrane (C-TiO_2-CFA/PAN) was prepared and evaluated for the removal of textile	The optimal loading of the C-TiO_2-CFA photocatalyst on the PAN membrane was 2% w/w, achieving degradation efficiencies of 99.86% and 99.20% for MO and GY dyes, respectively, at pH 3.5, using a 10 ppm dye concentration under solar irradiation within 300 minutes. The novel 2% C-TiO_2-CFA/PAN

	dyes (methyl orange [MO] and golden yellow [GY]) from water.	photocatalytic membrane demonstrated high effectiveness in removing textile dyes from water. Three reuse cycles were conducted, and no significant changes in photocatalytic efficiencies were observed.
Kumaran *et al.*, 2020	This work focuses on the synthesis of graphene oxide (GO) using the modified Hummers method. The prepared nanocomposite was employed as a photocatalyst for the treatment of wastewater contaminated with dyes.	The synthesized nanocomposite was employed as a catalyst to remove the organic dye Orange ME2RL from synthetic wastewater through photocatalysis, while varying parameters such as pH, contact time, dye concentration, and catalyst dosage. It was found that the highest color removal, for a dye concentration of 60 mg/L, was obtained with a catalyst dosage of 25 mg, a contact time of 24 minutes, and a pH value of 6. The stability and reusability of the catalyst were also investigated. The color removal efficiency of the catalyst was 99.6%, 99.2%, 98.8%, 98.3%, and 98% for the first, second, third, fourth, and fifth reuse cycles, respectively. These findings confirm that the catalyst can be applied in subsequent practical applications.
Ribeiro *et al.*, 2020	In this study TiO_2 films supported on polyethylene terephthalate (TiO_2/PET) sheets and monolithic formats were prepared from recycled PET bottles. The preparation method was based on the washcoating of a TiO_2 suspension with different formulations (additives and loaded photocatalyst) to achieve adequate adhesion.	TiO_2/PET sheets and monoliths exhibited homogeneous coating and good stability after five reuse cycles. TiO_2/PET monolith achieved degradation levels of approximately 30% and 75% for initial dye concentrations of 25 mg/L and 15 mgL^{-1}, respectively. Monolithic immobilized systems proved to be a promising technology due to their low cost and reduced consumption of reagents and catalysts. Furthermore, this type of system is particularly promising for continuous processes.
Hussein *et al.*, 2019	This study evaluated the photocatalytic activities of analytical reagent grade TiO2 (AR) to identify a low-cost photocatalyst for dye degradation. Different conditions were observed in the presence of TiO_2 suspensions. The effects of several parameters, such as titanium dioxide mass and methylene violet (MVT) concentration, on photocatalytic degradation were investigated.	The results obtained demonstrate that MVT can be effectively degraded by a TiO_2 assisted process in aqueous dispersions under UVT irradiation. The photocatalytic degradation of the dye followed first-order kinetics, and parameters such as TiO_2 mass dosage and dye concentration influenced the degradation efficiency. The findings indicated that both catalyst loading and initial dye concentration significantly affected the degradation performance of TiO_2 powders.
Mounteer *et al.*, 2019	Four reactive dyes and three vat dyes were mixed in different combinations and treated (10 mg/L of each dye, 0.5 mg/L TiO_2, pH 4) to assess the influence of different dyes on ADMI color, chemical oxygen demand (COD), and acute toxicity.	The TiO_2/UV system was able to reduce ADMI color in mixtures by 74–85%, but only by 28% in raw textile mill effluent. COD reductions were much lower, due to the low COD values of the mixtures (< 100 mg/L) and the recalcitrant nature of the components in the raw effluent. Although toxicity was reduced, the textile effluent remained highly toxic after photocatalysis, which was expected given the low COD removal achieved.

Source: Authors (2024).

Table 2 – Articles searched on the Web of Science platform

REFERENCES	METHODOLOGY	RESULTS
Le *et al.*, 2023	Photocatalytic PVDF hollow-fiber membranes were prepared by coating with polydopamine (PDA) for 1–4 h, followed by coating with titanium dioxide (TiO_2) nanoparticles.	The results showed that TiO_2 adhered firmly to the PDA pretreated membrane after ultrasonic treatment. The PDA layer protected the membranes from UV irradiation. The PVDF-TiO_2 membrane without PDA pretreatment was destroyed after 24 hours of UV exposure, whereas the membranes treated with PDA for 2 hours remained intact even after 9 days of continuous irradiation. Compared with the original membrane, the application of PVDF membranes coated with PDA for 2 hours and TiO_2 for 1 hour increased the rejection of Reactive Red 239 and the flux recovery rates by 13% and 40%, respectively, achieving 60% COD removal. The permeate flux and dye rejection rate remained stable after 5 cycles (20 h of operation).
Helmy *et al.*, 2023	This study focused on the use of response surface methodology (RSM) to evaluate its predictive and optimization capability in the application of advanced oxidation processes (AOPs) for the removal of recalcitrant pollutants from industrial wastewater.	The findings indicated that the percentage of dye removal was mainly influenced by the tested variables as well as by their synergistic effects, as observed from the experimental results. Performance analysis of the developed RSM models revealed a high coefficient of determination (significantly greater than $R^2 = 0,99$), thus ensuring satisfactory predictive equations for the second-order regression models. The observed results demonstrated that, for a dye concentration of 50 ppm, H_2O_2 0,9 ml, pH 3,4, TiO_2 loading of 0.6 g, and UV irradiation time of 60 min, a maximum degradation of 92% was achieved. The degradation of dye RR-147 was found to be most effectively carried out by the UV/H_2O_2/TiO_2 system.
Keerthana *et al.*, 2022	A GO-TiO_2 nanocomposite was synthesized using the solvothermal method from graphene oxide (GO) nanoparticles and titanium dioxide (TiO_2) nanoparticles, which were individually synthesized via the modified Hummers method and the sol–gel method, respectively.	The synthesized nanocomposite effectively reduced all dyes investigated in this study compared to the standard TiO_2 photocatalyst. The biocompatibility of this GO–TiO_2 nanocomposite was evaluated using zebrafish embryos, and the results demonstrated that GO–TiO_2 was safe for the embryos, causing neither hatching delays nor developmental abnormalities.
Das *et al.*, 2022	Here, the conjugate of graphene oxide (GO) and titanium dioxide nanoparticles ($nTiO_2$) was proposed for the photocatalytic degradation of two toxic azo dyes, Congo Red (CR) and Methylene Blue (MB), under solar irradiation.	The nanoconjugates exhibited excellent degradation potential for Congo Red (CR) and Methylene Blue (MB) under sunlight irradiation. Among all the photocatalysts synthesized with varying amounts of GO and $nTiO_2$, some demonstrated the highest degradation efficiencies. At pH 7.0, 95% degradation of CR (40 ppm) and MB (20 ppm) was achieved in less than 80 min. When the nanoconjugates were recycled five times, their degradation capacity was maintained at 85% after the third cycle; however, degradation efficiency declined in the last two cycles, reaching 75% after the fifth reuse.
Sultana *et al.*, 2021	A series of bifunctional nanohybrids containing different ratios of chitosan and titanium dioxide (TiO_2) was prepared through the precipitation technique	The nanohybrid prepared with 80% TiO_2 (p/p) and 20% chitosan (w/w), referred to as $T_{0.80}CS_{0.20}$ removed 98.8% of RO in just 8 min at pH 2.0 under solar irradiation, in a dye solution of 60 mg L^{-1}. This performance was mainly attributed to the

	and applied for the removal of a model anionic azo dye, Remazol Orange 3R (RO), from aqueous solution.	simultaneous roles of adsorption and photodegradation activities of the nanohybrids. The adsorption performance of $T_{0,80}CS_{0,20}$ was investigated in terms of the Langmuir isotherm under dark conditions, and its maximum adsorption capacity for RO was found to be 243.9 mg^{-1}.
Chandan *et al.*, 2021	This study investigates combined adsorption and photocatalysis in the degradation of a textile dye using a microporous polymer nanocomposite loaded with TiO_2 nanoparticles at different weights (0.1–0.5 g) embedded in polyurethane (PU) foam. The degradation of Methylene Blue (MB) dye, as a model aqueous pollutant, was carried out using pure TiO_2 nanoparticles, unloaded PU foam, and TiO_2-loaded PU foam under both UV and solar irradiation.	It was observed that degradation (attributed to TiO_2 nanoparticles) and adsorption (attributed to PU foam) occurred simultaneously under both solar and UV irradiation. This mechanism was confirmed by analysis and comparison of MB dye degradation results for pure TiO_2 nanoparticles (85% dye degradation in 40 min), unloaded PU foam (40% degradation in 40 min), and TiO_2 — loaded PU foam (95% degradation in 20 min). Experimental data demonstrated pseudo-first-order kinetics under UV irradiation (rate constant of 0.016 h^{-1}), whereas solar irradiation followed first-order kinetics with a rate constant of 0.265 whereas solar irradiation followed first-order kinetics with a rate constant of 0.265 h^{-1}.
De Luca *et al.*, 2019	Systems were prepared for the degradation of the azo dye Reactive Black 5, some containing only titanium dioxide and others combining titanium dioxide with hydrogen peroxide.	From the analyses, it is evident that Reactive Black 5 azo dye, in the absence of photocatalytic agents, is highly photostable; indeed, after thirty minutes of UV irradiation, only an 8.9% reduction was recorded. Even in the presence of hydrogen peroxide alone, the dye exhibited little change in photostability, with approximately 11.2% degradation after thirty minutes of UV exposure. In contrast, titanium dioxide plays a crucial role in the UV-induced photodegradation of Reactive Black 5, and the photocatalytic activity of TiO_2 can be enhanced through the simultaneous use of hydrogen peroxide. The use of hydrogen peroxide alone is insufficient to achieve complete dye photodegradation, although its presence does improve the photoactivity of titanium dioxide.
Pereira *et al.*, 2019	A magnetic photocatalyst consisting of TiO_2 supported on a composite surface (C/Fe) was prepared from red mud, tar, and TiO_2 (here referred to as TiO_2/C/Fe). The optimal condition (240 mg TiO_2, pH 10, OD 7,6 mg L^{-1}, I 1,20 $mWcm^{?2}$ and A 143 cm^2), was established to degrade organic matter both in real textile wastewater and in a synthetic solution containing 40 mg L^{-1} RB using TiO_2/C/Fe.	The magnetic photocatalyst demonstrated that the reaction rate constant increased sevenfold when optimal conditions were employed for RB decolorization. In textile effluent tests, TiO_2 and TiO_2/C/Fe achieved 99% and 46% decolorization, respectively. Additionally, reductions in chemical oxygen demand (COD), soluble solids, and turbidity were observed, with greater efficiency than conventional physico-chemical industrial treatments. Thus, TiO_2/C/Fe was photoactive and exhibited magnetic properties.
Santana *et al.*, 2019	The magnetic photocatalyst demonstrated that the reaction rate constant increased sevenfold when the optimal conditions were applied for RB decolorization. In experiments with textile effluents, TiO_2 and TiO_2/C/Fe achieved 99% and 46% decolorization, respectively. In addition,	The UV/H_2O_2/ TiO_2 system showed the highest efficiency, with 99% dye degradation achieved in 50 minutes, followed by the UV/H_2O_2/ TiO_{2sp} system with 93% degradation. Considering that the supported catalyst presents operational advantages and high degradation rates, factorial design was applied to this system, achieving complete degradation (100%) within 35 minutes. The use of artificial neural networks proved effective in

	reductions in chemical oxygen demand, soluble solids, and turbidity were observed, showing greater efficiency than conventional physico-chemical industrial treatments. Thus, TiO_2/C/Fe proved to be photoactive and exhibited magnetic properties.	predicting textile dye degradation, with an absolute error of 0.0181. Following treatment, dye toxicity was reduced.
Basturk *et al.*, 2019	In the present study, nano-TiO_2 was used as a catalyst for the photocatalytic decolorization of the dyes Methylene Blue (MB) and Reactive Red 198 (RR198) in aqueous phase. The color removal rates were 95% and 66% for RR198 and MB, respectively.	Efficient photocatalytic removal of the selected dyes decreased with increasing initial dye concentration but improved with higher catalyst dosage as well as greater irradiation intensity. The effect of pH varied according to the dye type, whether anionic or cationic. Kinetic data revealed that decolorization followed the Langmuir–Hinshelwood model. Thermodynamic parameters indicated that the process was both feasible and exothermic. The application of photocatalytic methods proved to be a viable option for the removal of aniline and azo dyes.
Suhadolnik *et al.*, 2019	The degradation of the dye Reactive Red 106 was investigated under photoelectrocatalytic operation. The water-based degradation products were identified by ultra-high-performance liquid chromatography (UHPLC), coupled with ultraviolet-visible (UV-vis) or mass spectrometry (MS) detectors.	The solution was successfully decolorized (100%) under microfluidic operation or within the confined volume of a beaker. However, the rate within the latter setup was faster, while distinct intermediate species were formed in the anodic and cathodic electrochemical cells. The maximum conversion achieved at the anode side was 80% of the initial dye concentration, whereas 63% of the dye was degraded at the cathode side. Finally, an expanded inlet configuration was designed to enable treatment of larger feedstock capacities.

Source: Authors (2024).

Tables 1 and 2 present the studies selected according to the previously cited PRISMA methodology. The selected works were those aligned with the aim of this study, namely, the use of heterogeneous photocatalysis with titanium dioxide as the catalyst.

From the articles analyzed, it is clear that research on this subject has been steadily advancing. The findings show that the most recent studies primarily focus on combining two or more elements to obtain a more efficient catalyst, as in the case of the study on the combination of TiO_2 — Titanium Dioxide and $C_6H_{11}NO_4$ — Chitosan, applied in the treatment of a model effluent. The results obtained were more than satisfactory for the intended purpose.

It was also observed that many studies explore the incorporation of additional elements to enhance the treatment efficiency, such as the addition of hydrogen peroxide (H_2O_2) and the sulfur (S) doping of TiO_2, aiming to achieve even more satisfactory results compared to those obtained using the catalyst alone, without any additional component.

The review further revealed the diversity of photocatalysis applications as well as the potential of titanium dioxide. Lima *et al*. (2023) demonstrated the photocatalytic power of TiO_2,

reporting a 59% higher dye degradation for a dye with an initial concentration of 12.5 mg L^{-1}, when compared to other elements tested as catalysts, such as ZnO and CuO. Similarly, Sudhagar *et al.* (2022) employed the hydrothermal method to synthesize the anatase phase of TiO_2 nanoparticles and TiO_2/La_2O_3 and TiO_2/Al_2O_3. The degradation process was carried out under both UV and visible light irradiation. The efficiencies achieved by TiO_2, TiO_2/La_2O_3 and TiO_2/Al_2O_3 were 87, 95, 45% and 80, 92, 29%, respectively, for the dyes MB and CV under UV light, while under visible light the efficiencies were 34%, 27%, 84% and 29%, 24%, 81%, respectively, for Methylene Blue and Crystal Violet.

Imran *et al*. (2021) used TiO_2 co-doped with Fe, Co, and S via the sol–gel method to treat a model effluent. The dye used to create this effluent was degraded within approximately 1.2 h, achieving a degradation rate of 99.3%. The anatase phase of TiO_2 was confirmed by XRD analysis, while the bandgap energy of pure TiO_2 was reduced to 1.6 eV after the incorporation of Fe, Co, and S. Elbadawy *et al*. (2021), in turn, investigated ZnO-doped TiO_2 and its mixtures in varying weight ratios to study the photocatalytic degradation of the textile dye pollutant Acid Red 37 under UV irradiation, using a bench-scale batch photoreactor designed to optimize a nanometal oxide system.

Elbadawy *et al.*, (2021) found that the most effective photodegradation under UV irradiation was achieved with a (3:1) ratio of TiO_2:ZnO at pH = 6,5 when the textile dye concentration was $1{,}0 \times 10^{-4}$mol/L. The degradation efficiencies of the photocatalytic systems studied followed the order: UV/ZnO < UV/TiO_2 < UV/TiO_2/ZnO < UV/TiO_2/ZnO/H_2O_2 < UV/TiO_2/ZnO/$Na_2S_2O_8$ < UV/TiO_2/ZnO/$NaIO_4$. The system designated UV/TiO_2/ZnO/(1,1–5,5)x10^{-3}M$NaIO_4$ exhibited the highest photocatalytic degradation efficiency, with the greatest apparent quantum yield (11.1–16.6%) and the lowest electrical energy per order (37.0–22.2 kWh), indicating reduced energy consumption compared to the other catalytic systems examined.

In the studies reviewed, it was observed that one of the main factors influencing the application of photocatalysis with titanium dioxide is pH, whether using TiO_2 alone or in combination with other elements. For instance, Mousavi *et al*. (2022) employed titanium dioxide with a magnetic carbon nanocomposite derived from Fe-MOFs containing surface carboxylic acid functional groups (Fe@C–COOH) and found the optimal performance of the composite at pH = 2, with a photocatalyst dosage of 15 mg/100 mL and a dye concentration of 150 mg/L of RY145.

Similarly, Assis *et al.* (2021), who tested pH values of 2.0 and 6.0 for the photocatalytic decolorization of industrial dyes Novacron Blue (NB) and Novacron Yellow (NY), using TiO_2-based composites with natural palygorskite (Pal-Ti10 and Pal-Ti30), demonstrated that experiments carried out at pH 2.0 with the Pal-Ti30 composite, under 18 W power and 10 ppm dye concentration, resulted in 100% color removal for both dyes within 90 minutes. Moreover, Total Organic Carbon (TOC) analysis confirmed mineralization levels of 61.70% and 58.06% for NB and NY, respectively, after 90 minutes of treatment. This same duration of 90 minutes was also applied by Mousavi *et al*. (2022), who likewise reported satisfactory outcomes.

A wide variation in pH values was observed across the studies analyzed. For example, Assis *et al*. (2021) worked at pH 2.0; Mpelane *et al*. (2020) tested at pH 3.5; and Elbadawy (2021) employed pH 6.5. These findings demonstrate the flexibility of photocatalysis, which can be applied in the treatment of both neutral and acidic effluents.

Final considerations

From the analysis of the 26 articles selected from the two databases, it is evident that research in this field is advancing toward intelligent and sustainable solutions for the degradation of components in various types of effluents. The development of catalysts that are less harmful to the environment, capable of reuse, and suitable for cost-effective treatment systems that enable the reutilization of treated effluents has been a recurring focus. Studies have also explored the integration of chemical and biological processes, including post-treatment analyses of previously treated effluents, which have yielded promising results for environmentally safe discharge.

The diverse applications of heterogeneous photocatalysis with titanium dioxide highlight the versatility of this approach, ranging from the treatment of liquid effluents to gaseous emissions. Applications include domestic sewage treatment as well as the purification of gases released during industrial processing, indicating that further research and additional experimental trials are warranted to expand the scope of heterogeneous photocatalysis.

The maps generated using Vosviewer software illustrated the extensive network of researchers worldwide dedicated to developing solutions for environmental preservation and sustainability. They also highlighted countries currently playing a significant role in advancing this cause and raising awareness of strategies to prolong the health of the planet and foster a balanced relationship between humans and nature. The ultimate goal is to achieve a productive

harmony in which the rational sphere does not harm the irrational environment, ensuring mutual benefit without detrimental consequences.

REFERENCES

ALAHIANE, S.; SENNAOUI, A.; SAKR, F.; DINNE, M.; QOURZAL, S.; ASSABBANE, A. Synchronous role of coupled adsorption-photocatalytic degradation of Direct Red 80 with nanocrystalline TiO_2-coated non-woven fibres materials in a static batch photoreactor. **Groundwater for Sustainable Development**, v. 11, 2020. DOI: 10.1016/j.gsd.2020.100396.

ASSIS, L. M.; DAMASCENO JUNIOR, E. M.; ALMEIDA, J. M. F.; SILVA, I. N.; BARBOSA, R. V.; SANTOS, L. M.; DIAS, E. F.; FERNANDES, N. S.; MARTINEZ-HUITLE, C. A. Photocatalytic degradation of Novacron blue and Novacron yellow textile dyes by the TiO_2/palygorskite nanocomposite. **Environmental Science and Pollution Research**, 2021. DOI: 10.1007/s11356-021-15519-5.

BASTURK, E.; IŞIK, M.; KARATAS, M. Removal of aniline (Methylene blue) and azo (reactive red 198) dyes by photocatalysis via nano TiO_2. **Desalination and Water Treatment**, v. 143, p. 306–313, 2019. DOI: 10.5004/dwt.2019.23522

CHANDAN, M. R.; GOYAL, S.; RIZWAN, M.; HUSSAIN SHAIK, A. Removal of textile dye from synthetic wastewater using microporous polymer nanocomposite. **Bulletin of Materials Science**, 2021. DOI: 10.1007/s12034-021-02559-3S

CHANDRABOSE, G.; DEY, A.; GAUR, S. S.; PITCHAIMUTHU, S.; JAGADEESAN, H.; BRAITHWAITE, N. S. J.; SELVARAJ, V.; KUMAR, V.; KRISHNAMURTHY, S. Removal and degradation of mixed dye pollutants by integrated adsorption-photocatalysis technique using 2-D MoS_2/TiO_2 nanocomposite. **Chemosphere**, v. 279, 2021. DOI: 10.1016/j.chemosphere.2021.130467

DAS, S.; SINGH, V.; PAUL, S. Surface conjugation of titanium dioxide nanoparticles on nano-graphene oxide enhances photocatalytic degradation of azo dyes under sunlight. **Environmental Science and Pollution Research**, v. 29, n. 26, p. 40226–40240, 2022. DOI: 10.1007/s11356-022-18796-w

DE LUCA, P.; FOGLIA, P.; SICILIANO, C.; NAGY, J. B.; MACARIO, A. Water contaminated by industrial textile dye: study on decolorization process. **Environments - MDPI**, v. 6, n. 9, 2019. DOI: 10.3390/environments6090101

DÓRIA, A. R.; GONZAGA, I. M. D.; PUPO, M. M. S.; BANDA, G. R. S.; EGUILUZ, K. I. B. Processos oxidativos avançados: fundamentos e aplicações no tratamento de efluentes industriais. *In*: CONECTE – XI Congresso de Engenharia, Ciência e Tecnologia, 2018. **Anais** […]. *[S. l.]*, 2018.

ELBADAWY, H. A.; SADIK, W. A.; ELHUSSEINY, A. F.; HUSSEIN, S. M. Design of economic photocatalytic system with low energy consumption, and high quantum yield, for the degradation of acid red 37 textile dye. **Process Safety and Environmental Protection**, v. 148, p. 1191–1206, 2021. DOI: 10.1016/j.psep.2021.02.036

HELMY, M.; HEGAZY, M.; MOHAMED, A.; HASSAN, K. Predicting the degradation of reactive red-147 dye in textile wastewater using response surface methodology technique. **Applied Water Science**, v. 13, n. 1, 2023. DOI: 10.1007/s13201-022-01826-w

HUSSEIN, F. H.; AJOBREE, A. M.; MUSA, Z. O.; ABDULRAZZAK, F. H.; ALQARAGOLY, M. B.; ALKAIM, A. F. Is it photocatalytic degradation of textile dyes a friendly method? Methyl violet dye as a model for application in aqueous solutions in the presence of commercial TiO2. **International Journal of Recent Technology and Engineering**, v. 8, n. 2, Special Issue 3, p. 1455–1457, 2019. DOI: 10.35940/ijrte.B1268.0782S319

IMRAN, M.; SAEED, Z.; PERVAIZ, M.; MEHMOOD, K.; EJAZ, R.; YOUNAS, U.; NADEEM, H. A.; HUSSAIN, S. Enhanced visible light photocatalytic activity of TiO_2 co-doped with Fe, Co, and S for degradation of Cango red. **Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy**, v. 255, 2021. DOI: 10.1016/j.saa.2021.119644

KEERTHANA, V.; GIRIGOSWAMI, A.; JOTHIKA, S.; KAVITHA, D.; GOPIKRISHNA, A.; SOMANATHAN, T.; GIRIGOSWAMI, K. Synthesis, characterization and applications of GO–TiO_2 nanocomposites in textile dye remediation. **Iranian Journal of Science and Technology, Transaction A: Science**, v. 46, n. 4, p. 1149–1161, 2022. DOI: 10.1007/s40995-022-01337-y

KUMARAN, V.; SUDHAGAR, P.; KONGA, A. K.; PONNIAH, G. Photocatalytic degradation of synthetic organic reactive dye wastewater using GO-TiO_2 nanocomposite. **Polish Journal of Environmental Studies**, v. 29, n. 2, p. 1683–1690, 2020. DOI: 10.15244/pjoes/109027

LE, T. M. H.; WANG, R.; SAIRIAM, S. Self-protecting PVDF-PDA-TiO_2 membranes towards highly efficient and prolonged dye wastewater treatment by photocatalytic membranes. **Journal of Membrane Science**, v. 683, 2023. DOI: 10.1016/j.memsci.2023.121789

LIMA, F. S.; MEDEIROS, A. R.; ROSENBERGER, A. G.; BALLMANN, E.; DRAGUNSKI, D. C.; MUNIZ, E. C.; CAETANO, J. Photodegradation of dyes using electrospun polymeric membranes containing titanium oxide and iron. **Materials Chemistry and Physics**, v. 309, 2023. DOI: 10.1016/j.matchemphys.2023.128278

MACEDO, J. S. **Avaliação do uso de água e geração de efluentes no processo de beneficiamento de jeans**: estudo de caso lavanderias industriais de Toritama/PE. 2022. Thesis (Master's Degree in Development and Environment) – Universidade Federal de Pernambuco, Recife, 2022.

MOHER, D.; LIBERATI, A.; TETZLAFF, J.; ALTMAN, D. G. The PRISMA Group – Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. **PLoS Med**, 2009.

MOUNTEER, A. H.; ARCANJO, G. S.; COIMBRA, E. C. L.; DA SILVA, L. M. M. ADMI color and toxicity reductions in raw textile mill effluent and dye mixtures by TiO_2/UV is limited by presence of vat dyes. **Environmental Science and Pollution Research**, v. 26, n. 5, p. 4260–4265, 2019. DOI: 10.1007/s11356-018-2814-4

MOUSAVI, S. E.; YOUNESI, H.; BAHRAMIFAR, N.; TAMUNAIDU, P.; KARIMI-MALEH, H. A novel route to the synthesis of α-Fe_2O_3@C@SiO_2/TiO_2 nanocomposite from the metal-organic framework as a photocatalyst for water treatment. **Chemosphere**, v. 297, 2022. DOI: 10.1016/j.chemosphere.2022.133992.

MPELANE, A.; KATWIRE, D. M.; MUNGONDORI, H. H.; NYAMUKAMBA, P.; TAZIWA, R. T. Application of novel C-TiO_2-CFA/PAN photocatalytic membranes in the removal of textile dyes in wastewater. **Catalysts**, v. 10, n. 8, p. 1–17, 2020. DOI: 10.3390/catal10080909

NIAZI, Z.; GOHARSHADI, E. K.; MASHREGHI, M.; JORABCHI, M. N. Highly efficient solar photocatalytic degradation of a textile dye by TiO_2/graphene quantum dots nanocomposite. **Photochemical and Photobiological Sciences**, v. 20, n. 1, p. 87–99, 2021. DOI: 10.1007/s43630-020-00005-7

PEREIRA, L. de O.; LELO, R. V.; COELHO, G. C. M.; MAGALHÃES, F. Degradation of textile dyes from synthetic and wastewater samples using TiO_2/C/Fe magnetic photocatalyst and TiO_2. **Journal of the Iranian Chemical Society**, v. 16, n. 10, p. 2281–2289, 2019. DOI: 10.1007/s13738-019-01694-3

POOLWONG, J.; KIATBOONYARIT, T.; ACHIWAWANICH, S.; BUTBUREE, T.; KHEMTHONG, P.; KITYAKARN, S. Three-dimensional hierarchical porous TiO_2 for enhanced adsorption and photocatalytic degradation of remazol dye. **Nanomaterials**, v. 11, n. 7, 2021. DOI: 10.3390/nano11071715

RAMOS, M. D. N.; CLAUDIO, C. C.; REZENDE, P. H. V.; CABRAL, L. P.; SANTOS, L. A.; COSTA, G. G.; MESQUITA, P. L.; AGUIAR, A. (2020). Critical analysis of the characteristics of industrial effluents from the textile sector in Brazil. **Revista Virtual de Química**, v. 12, n. 4, p. 913–929, 2020. DOI: 10.21577/1984-6835.20200073

RIBEIRO, L. N.; FONSECA, A. C. S.; SILVA, E. F. M.; OLIVEIRA, E. D. C.; RIBEIRO, A. T. S.; MARANHÃO, L. C. A.; PACHECO, J. G. A.; MACHADO, G.; ALMEIDA, L. C. (2020). Residue-based TiO_2/PET photocatalytic films for the degradation of textile dyes: a step in the development of green monolith reactors. **Chemical Engineering and Processing - Process Intensification**, v. 147, 2020. DOI: 10.1016/j.cep.2019.107792

SANTANA, I. L. S.; BARBOSA, A. A.; SILVA, M. G.; AQUINO, R. V. S.; NEVES, N. S. C. S.; Silva, J. P.; FERREIRA, I. H. R.; ROCHA, O. R. S. (2019). Titanium dioxide immobilization in recycled aluminum net for degradation of textile dye by heterogeneous photocatalysis through neural networks. **Revista Eletrônica em Gestão, Educação e Tecnologia Ambiental**, v. 23, p. 27, 2019. DOI: 10.5902/2236117037718

SILVA, D. P.; LONGO, R. M. A sustentabilidade na indústria da moda: uma análise bibliométrica sobre o tema nos últimos 10 anos. *In*: SUSTENTARE, IV.; WIPIS, VII. Workshop Internacional Sustentabilidade, Indicadores e Gestão de Recursos Hídricos, 2022. **Anais** [...]. *[S. l.]*, nov. 2022.

SUDHAGAR, S.; KUMAR, S. S.; PREMKUMAR, I. J. I.; VIJAYAN, V.; VENKATESH, R.; RAJKUMAR, S.; SINGH, M. UV- and visible-light-driven TiO_2/La_2O_3 and TiO_2/Al_2O_3 nanocatalysts: synthesis and enhanced photocatalytic activity. **Applied Physics A: Materials Science and Processing**, v. 128, n. 4, 2022. DOI: 10.1007/s00339-022-05293-7

SUHADOLNIK, L.; POHAR, A.; NOVAK, U.; LIKOZAR, B.; MIHELIČ, A.; ČEH, M. Continuous photocatalytic, electrocatalytic and photo-electrocatalytic degradation of a reactive textile dye for wastewater-treatment processes: batch, microreactor and scaled-up

operation. **Journal of Industrial and Engineering Chemistry**, v. 72, p. 178–188, 2019. DOI: 10.1016/j.jiec.2018.12.017

SULTANA, T.; DEY, S. C.; MOLLA, M. A. I.; HOSSAIN, M. R.; RAHMAN, M. M.; QUDDUS, M. S.; MONIRUZZAMAN, M.; SHAMSUDDIN, S. M.; SARKER, M. Facile synthesis of TiO_2/Chitosan nanohybrid for adsorption-assisted rapid photodegradation of an azo dye in water. **Reaction Kinetics, Mechanisms and Catalysis**, v. 133, n. 2, p. 1121–1139, 2021. DOI: 10.1007/s11144-021-02009-5

TEIXEIRA, C. P. A. B.; JARDIM, W. F. **Processos oxidativos avançados**: conceitos teóricos. Campinas: Universidade Estadual de Campinas, 2004. (Caderno Temático, v. 3).

VIANA, M. A. **Avaliação da eficiência de estação de tratamento de efluente de lavanderia de beneficiamento de jeans no arranjo produtivo local têxtil do agreste pernambucano – um estudo de caso**. 2019. 104 f. Thesis (Master's Degree in Environmental Engineering) – Universidade Federal Rural de Pernambuco, Recife, 2019.

WOLFF, G. S.; BERGER, C.; ELIAS, M. A.; KUREK, A. P.; SUAVE, J. Fotocatálise heterogênea: uma revisão sobre os métodos promissores de imobilização de dióxido de titânio. **Revista Técnico-Científica do IFSC**, v. 1, n. 12, p. 1–?, 2022.

CRediT Author Statement

- **Acknowledgements**: I would like to express my gratitude to the Federal University of Pernambuco (UFPE) for the significant support provided to the research carried out.
- **Funding**: This research received no external funding.
- **Conflicts of interest**: The authors declare no conflicts of interest. This work is the result of academic research.
- **Ethical approval**: Yes, the study adhered to scientific ethical standards; however, it was not subject to review by an ethics committee.
- **Data and material availability**: All materials used in this study were obtained digitally from research platforms recognized by the academic and scientific community, and the materials are available for access upon request.
- **Authors' contributions**: Jefferson Lira was the principal author and researcher of the article. Gilson Lima and Rogério Ferreira served as advisor and co-advisor, respectively, guiding and supervising the research and reviewing the manuscript.

Processing and editing: Editora Ibero-Americana de Educação
Proofreading, formatting, standardization and translation