XXVI SIMPÓSIO BRASILEIRO DE RECURSOS HIDRÍCOS

SOLAR PHOTODECOMPOSITION FOR REMOVING BTEX (BENZENE, TOLUENE, ETILBENZENO E XILENO) COMPOUNDS FROM GROUNDWATER CONTAMINATED BY GASOLINE STATION ACTIVITIES

Priscila Moreira Peres Garcia [1]*; Marcelly Beatriz Navarrette* [2]*; Nilce Ortiz* [3]

Abstract

This study investigates the application of solar photodecomposition to remove BTEX compounds (benzene, toluene, ethylbenzene, and xylenes) from groundwater contaminated by gasoline station activities. By the end of 2024, Brazil had 44,67 fuel stations authorized by the National Agency of Petroleum, Natural Gas and Biofuels (ANP), occupying the 9th position in the ranking of the largest oil consumers. Due to their high toxicity and carcinogenicity, BTEX compounds pose serious risks to both the environment and public health. The photodecomposition process employs TiO_2 as a catalyst, generating hydroxyl radicals through a series of reactions. The primary goal of this research was to develop effective and sustainable technology for treating and removing BTEX from groundwater contaminated using solar photodecomposition. Microstructured titanium dioxide (TiO_2) was synthesized with diatomite to develop a heterogeneous photocatalyst for BTEX degradation. The TiO_2-Diatomite composite was characterized using scanning electron microscopy (SEM) and thermogravimetric analysis. SEM provided detailed insights into the material's microstructure and morphology, while TGA assessed the thermal stability of the photocatalyst in BTEX degradation processes. BTEX concentration measurements used a UV-visible spectrophotometer for benzene determination, with aliquots collected at 30-minute intervals. The methodology involved synthesizing TiO_2-diatomite via the hydrolysis of titanium isopropoxide in the presence of diatomite. The resulting material was characterized and tested using 9.0 g of TiO_2-Dt in 40% BTEX solutions, evaluating the removal efficiency across different catalyst masses (ranging from 0.8 g to 2.5 g). The highest BTEX removal efficiency, 79.0%, was achieved with 1.0 g of TiO_2-Dt.

Keywords – Solar photodecomposition; BTEX; environmental remediation.

---

1) Instituto de Pesquisas Energéticas e Nucleares – IPEN. Avenida Prof. Lineu Prestes, 2242. São Paulo (SP) – Brasil. +55(11) 2810-0000. priscila.garcia1008@gmail.com
2) Instituto de Pesquisas Energéticas e Nucleares – IPEN. Avenida Prof. Lineu Prestes, 2242. São Paulo (SP) – Brasil. +55(11) 2810-0000. beatriznavarrette4@gmail.com
3) 2) Instituto de Pesquisas Energéticas e Nucleares – IPEN. Avenida Prof. Lineu Prestes, 2242. São Paulo (SP) – Brasil. +55(11) 2810-0000. nortizbr@gmail.com

Resumo

Este estudo investiga a aplicação da fotodecomposição solar para a remoção de compostos BTEX (benzeno, tolueno, etilbenzeno e xilenos) de águas subterrâneas contaminadas por atividades de postos de combustíveis. Até o final de 2024, o Brasil possuía 44.67 postos de combustíveis autorizados pela Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP), ocupando a 9ª posição entre os maiores consumidores mundiais de petróleo. Devido à alta toxicidade e potencial carcinogênico, os compostos BTEX representam riscos significativos ao meio ambiente e à saúde pública. O processo de fotodecomposição utiliza dióxido de titânio (TiO_2) como catalisador, gerando radicais hidroxila altamente reativos por meio de diversas reações. O principal objetivo desta pesquisa foi desenvolver uma tecnologia eficaz e sustentável para o tratamento de águas subterrâneas contaminadas com BTEX utilizando a energia solar. Para isso, o TiO_2 microestruturado foi sintetizado com diatomita, formando um compósito para aplicação em fotocatálise heterogênea. A caracterização do material foi realizada por microscopia eletrônica de varredura (MEV) e análise termogravimétrica (TGA), avaliando morfologia e estabilidade térmica. Os testes de fotodecomposição foram conduzidos com 9,0 g de TiO_2-Dt em soluções contendo 40% de BTEX, com amostras coletadas a cada 30 minutos para análise por espectrofotometria UV-visível. Avaliou-se diferentes massas de catalisador (0,8 g a 2,5 g), sendo a maior eficiência de remoção, 79,0%, obtida com 1,0 g de TiO_2-Dt. Os resultados indicam o potencial da fotocatálise solar como alternativa viável para a remediação de águas contaminadas por hidrocarbonetos.

Palavras-Chave – Fotodecomposição solar; BTEX; remediação ambiental.

1. Introduction

According to the National Petroleum Agency (ANP), in 2019, Brazil had 40,970 fuel retail station facilities, ranking 9th among the largest oil consumers (IBP, 2019). The commercialization of petroleum-derived fuels involves monoaromatic hydrocarbons—benzene, toluene, ethylbenzene, and xylenes (BTEX)—which are potentially polluting and have been found in groundwater contamination plumes and other surface water resources. This contamination results from the disposal of contaminated industrial effluents, leakage from fuel station tanks, and accidental road spills. The management of contaminated areas aims to reduce the risk of water contamination and its subsequent impacts on human health by understanding the characteristics of the contaminated site and the effects caused by the pollutants, thereby aiding decision-making regarding appropriate intervention and mitigation measures.

Despite the negative effects on human health, groundwater contamination by BTEX compounds remains neglected and untreated by municipal systems, thus increasing the risk of diseases associated with the ingestion of contaminated water from supply wells.

Benzene and other alkylbenzenes are aromatic molecules with a single benzene ring. Within this class of monocyclic hydrocarbons, BTEX compounds—benzene, toluene, ethylbenzene, and xylene—stand out. These compounds are widely found in petroleum derivatives and are used in various industrial sectors, including the production of plastics, solvents, pharmaceuticals, and fuels. Among BTEX compounds, benzene was selected for this study due to its high level of hazard and environmental prevalence.

BTEX compounds are often overlooked in remediation efforts due to their obscure presence in water. Although BTEX compounds pose greater analytical challenges than polycyclic aromatic hydrocarbons (PAHs), they are more prevalent in the environment and can originate from a variety of sources, including petrochemical industry waste, surface runoff, domestic sewage, and municipal landfills—as well as from groundwater plumes that may have migrated far from the original contamination site. Studies such as Andrade et al. (2010) have reported the presence of BTEX in drinking water, highlighting significant health risks.

These compounds are common contaminants in both soil and water and are frequently released into the environment through industrial effluents and accidental spills during the production, transportation, and storage of petroleum and its derivatives.

Environmental contamination by BTEX is especially significant near oil refineries, where gasoline—containing 10% to 60% of these compounds—is processed (GÜLENSOY and ALVAREZ, 1999). Oil refineries generate large quantities of solid waste classified as hazardous by NBR 10004 due to their flammable, corrosive, toxic, or pathogenic properties (GAFAROV et al., 2006). These wastes contain oils, fats, organic compounds, and metals, many of which are carcinogenic and mutagenic (JANBANDHU and FULEKAR, 2011).

Biodegradation of hydrocarbons such as BTEX is a more sustainable and efficient method for environmental remediation. The low solubility and high hydrophobicity of many hydrocarbons make them less bioavailable to microorganisms. However, microorganisms can produce biosurfactants that cleave hydrocarbon molecules, making them more accessible. These biosurfactants offer several advantages over synthetic surfactants, including biodegradability, environmental compatibility, low toxicity, high selectivity, and effectiveness under extreme temperature, pH, and salinity conditions.

Chronic exposure to benzene can cause serious health issues such as leukemia, lymphoma, depression, immunosuppression, and peripheral neuropathy (JANBANDHU and FULEKAR, 2011). Bioremediation is an effective approach for treating effluents and contaminated sites with benzene. In this process, benzene is aerobically degraded by microorganisms through an oxidative process in which oxygenase enzymes introduce oxygen atoms into the aromatic ring, promoting ring cleavage and making carbon atoms accessible for conversion into low- or non-toxic products (CAVALCA et al., 2000; TIBURTIUS et al., 2004).

This study underscores the importance of sustainable methods, such as bioremediation, in the remediation of areas contaminated by BTEX. Understanding the degradation mechanisms and applying biotechnological strategies can offer effective and environmentally friendly solutions to mitigate the impacts of these toxic compounds. Continued research in this field is essential to developing remediation strategies that are both efficient and safe for the environment and human health.

Environmental legislation in Brazil began to take shape in the 1980s, when environmental groups started actively participating in governmental and public sectors. Today, Brazilian environmental protection laws are widely recognized and internationally accepted. Key measures include the creation of Environmental Protection Areas and the enactment of the Environmental Crimes Law in 1998, which established penalties for environmental violations.

One of the most significant regulations concerning water quality is CONAMA Resolution 357/05, which defines quality standards for classifying freshwater as suitable for human consumption. According to this resolution, the maximum permissible concentration of benzene in drinking water is 0.005 mg/L (CONAMA 357/05, 2005). This regulation sets limits for various contaminants to ensure water potability.

Acceptable contaminant limits may vary depending on water use. For instance, CONAMA Resolution 396/2008 establishes Maximum Permitted Values (MPVs) and Practical Quantification Limits (PQLs) for groundwater. For water intended for domestic supply after conventional treatment, the benzene limit is 5 µg/L, and for recreational use, it is 10 µg/L (CONAMA 396, 2008).

However, determining these parameters accurately is challenging due to a lack of specific data on the health effects of low concentrations of organic compounds. Many aromatic compounds, such as benzene, are not effectively removed by conventional water treatment methods. Chlorination with hypochlorite, for example, is considered ineffective due to the persistence of these compounds. Therefore, Advanced Oxidation Processes (AOPs) are necessary, including ozonation, hydrogen peroxide, UV radiation, and combinations such as O_3/H_2O_2, O_3/UV, H_2O_2/UV, O_3/H_2O_2/UV, and Fenton’s reagent (a mixture of hydrogen peroxide and ferrous ions) (Azbar et al., 2004).

In addition to AOPs, biotechnological approaches like microbial bioremediation have shown promise in removing persistent organic pollutants. These processes involve the microbial degradation of contaminants into less toxic or harmless byproducts, such as carbon dioxide, water, and biomass. Bioremediation presents several advantages, including in situ treatment and reduced risks associated with hazardous chemicals.

Thus, the application of advanced water treatment and environmental remediation technologies is crucial for ensuring safe water supplies and protecting public health. This study explores different strategies for removing benzene and other BTEX compounds from water, emphasizing sustainable and effective methods to mitigate the environmental impacts of these pollutants.

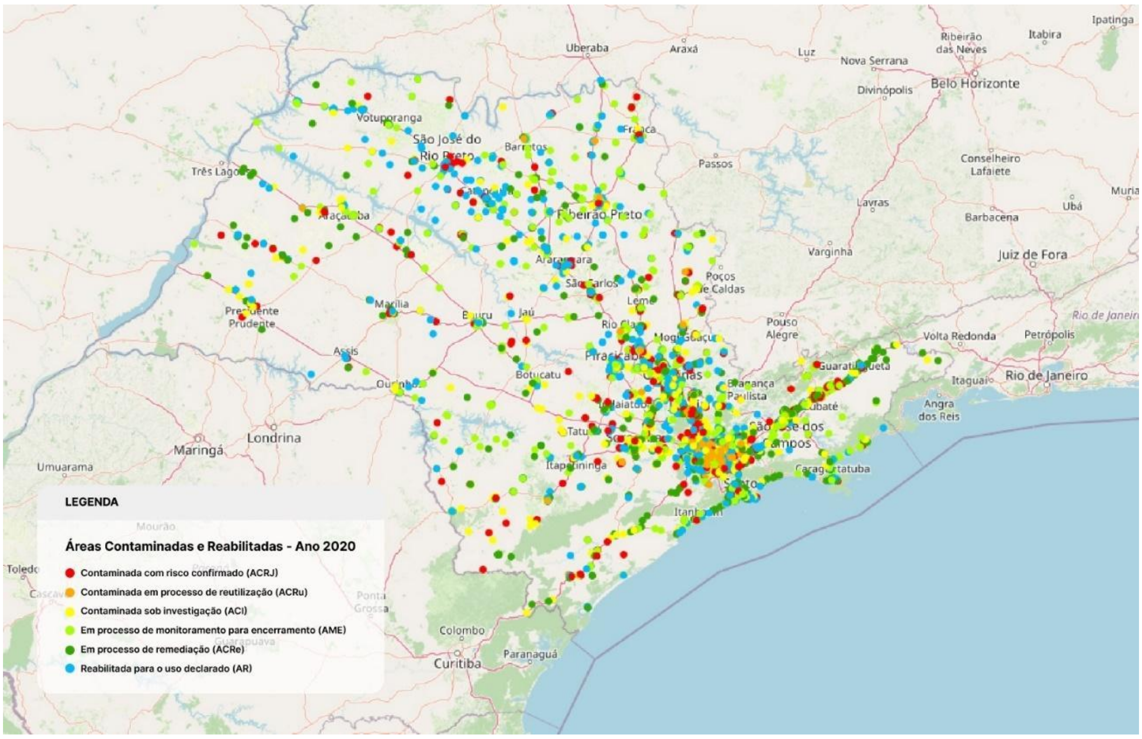
Various remediation techniques have been implemented to treat BTEX-contaminated water, especially in spill-affected areas. The most commonly employed methods are bioremediation and natural attenuation. However, these approaches often face limitations due to the extended time required to meet water quality standards.

Regulatory agencies responsible for identifying and managing contaminated areas have reported an increase in contamination cases related to the operation and installation of fuel stations (Figure 1). This trend is evident in environmental inventories conducted by state agencies in São Paulo and Minas Gerais, which have accumulated extensive experience in managing contaminated areas (Minas Gerais, 2015; CETESB, 2014). The increase is partly attributed to the enactment of CONAMA Resolution No. 273/2000 (Brazil, 2000), which mandates the investigation of environmental liabilities as a condition for the environmental licensing of fuel and service stations. In this context, the development of new technologies for the treatment and removal of BTEX has become increasingly urgent.

The environmental management procedures for contaminated areas are outlined in CONAMA Resolution No. 420/2009 (Brazil, 2009), which defines criteria and reference values for soil quality, prevention, investigation, and groundwater contamination thresholds. The resolution also mandates specific protection measures when substances posing risks to human health or the environment are detected, which must be implemented by the appropriate authorities.

Contaminated areas have remained a significant concern for public managers. The state of São Paulo was a pioneer in surveying and registering such areas. Since 2002, the São Paulo State Environmental Agency (CETESB), under the State Secretariat for the Environment, has maintained an inventory identifying the sectors most responsible for soil and groundwater contamination. According to the latest report, fuel stations are the leading contributors, accounting for 3,825 entries (74%)—significantly more than industries (17%), commercial establishments (5%), waste disposal facilities (3%), and other sources such as accidents, agriculture, or unknown causes (1%) (CETESB, 2020).

Figure 1 - Map showing the gas station distribution and contaminated areas.

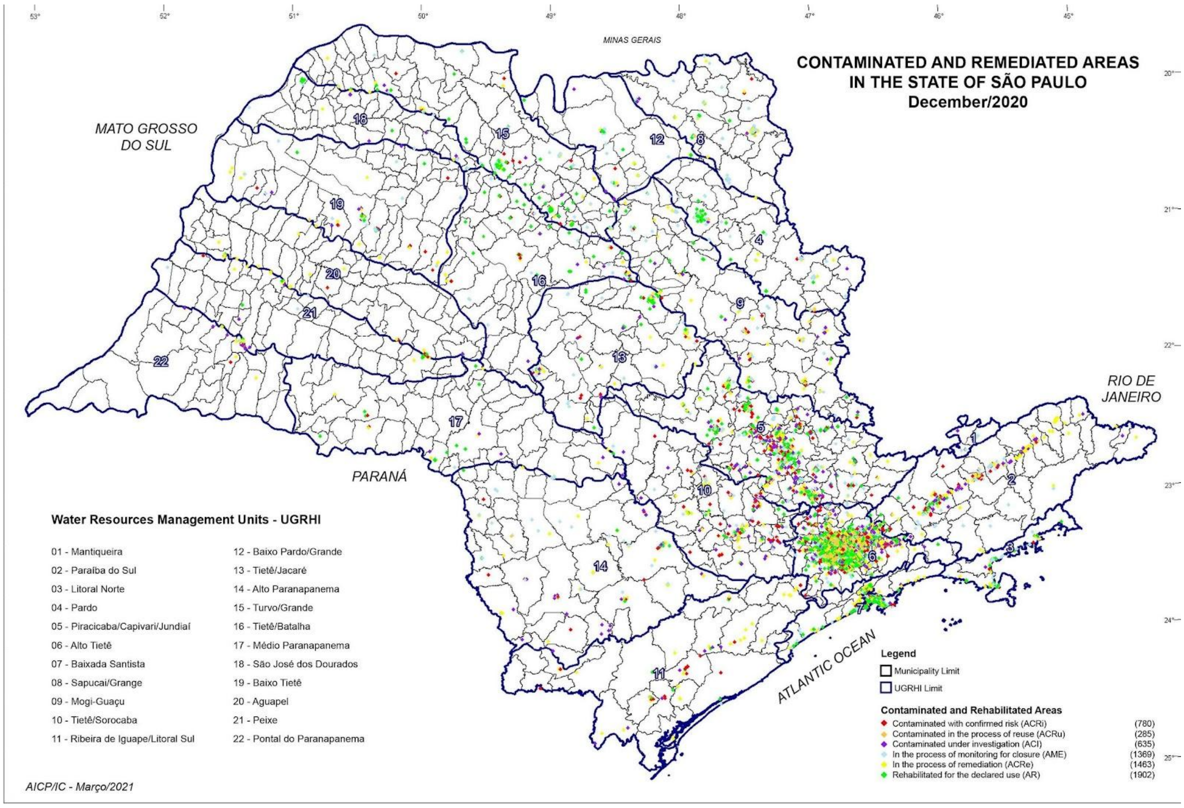


Fonte: DATAGEO, 2020.

The growing interest in mapping areas contaminated by petroleum-derived fuels stems from the complexity, toxicity, and environmental mobility of the monoaromatic compounds in the BTEX group (benzene, toluene, ethylbenzene, and xylenes), which are commonly found in fuels. According to Andrade et al. (2010), BTEX compounds are toxic to both the environment and human health, acting as central nervous system depressants and demonstrating greater chronic toxicity than aliphatic hydrocarbons (also present in petroleum and its derivatives), even at concentrations in the order of µg/L.

Once it was established that the commercialization of automotive fuels is the primary activity responsible for soil and groundwater contamination in the aforementioned states, it became evident that this issue warrants serious attention from environmental agencies across other federal entities. The distribution of contaminated areas, as shown in Figure 2, closely mirrors the layout of the state's main highway system.

Figure 2 - Map showing the gas station distribution and contaminated areas.



Source: CETESB, 2020.

This study explores the use of solar photodecomposition to remove BTEX compounds from groundwater contaminated by gas station activities. The main objective was to develop an effective technology for treating and eliminating BTEX using solar-based processes. To achieve this, microstructured titanium dioxide (TiO_2) was synthesized with diatomite, targeting heterogeneous photocatalysis of BTEX compounds. The combined effects of BTEX adsorption by the TiO_2-diatomite composite and its subsequent photodegradation under solar radiation proved effective for contaminant removal. Furthermore, modeling with the Thomas and Yoon-Nelson equations demonstrated that solar photodecomposition using efficient catalysts is a promising strategy for mitigating groundwater contamination by organic pollutants.

The second phase of the study involved treating synthetic water samples contaminated with BTEX through photodecomposition processes. The concentration of gasoline in these synthetic samples was equivalent to levels reported by environmental agencies in contaminated groundwater. Treatment employed microstructured titanium dioxide (TiO_2) synthesized with diatomite, used as a biotemplate catalyst commonly applied in heterogeneous photocatalysis. This catalyst design offers several advantages: high hydroxyl radical production efficiency, potential for reuse, and the ability to harness solar energy as a clean and sustainable power source during the reaction (Suri et al., 1993).

In Brazil, the use of heterogeneous solar photocatalysis is particularly promising due to the country's favorable solar conditions. The abundance of solar radiation makes the process both viable and sustainable by leveraging renewable energy resources (Luiz, 1985). Solar energy presents a compelling solution for meeting wastewater treatment demands through advanced oxidation processes, particularly in regions with high solar insolation. Brazil's consistently high levels of global irradiation support the feasibility and effectiveness of solar-driven remediation technologies.

2. Materials and Methods

2.1. Photocatalytic Mechanism

Heterogeneous catalytic reactions involve a series of physical transport steps that can influence the overall reaction rate. In photocatalytic systems, these steps occur sequentially, as described by Vazzoler (2019):

1) Initial movement of reactants or microorganisms through a boundary layer adjacent to the catalyst surface.
2) Internal transport within the catalyst pores allows the reactants to reach the active sites (intraparticle diffusion).
3) The interaction of reactants with the catalyst surface leads to adsorption.
4) Chemical conversion at the active sites, followed by the release of products (desorption).
5) Transport of products within the pores, moving toward the catalyst's external surface.
6) Dispersion of products through the external boundary layer, enabling their release into the surrounding fluid.

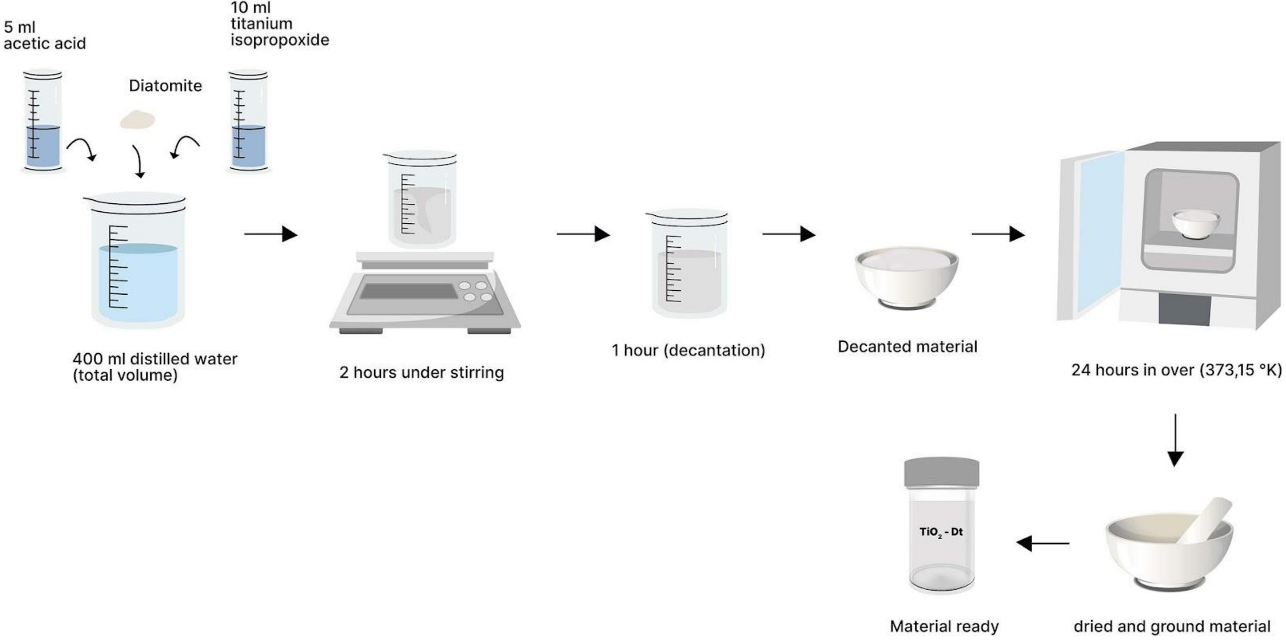
The primary chemical transformations involved in photocatalytic decomposition and disinfection occur during steps 3 and 4, where the catalyst's surface area plays a critical role. However, the other steps in the sequence can also influence the overall efficiency of the process. Typically, the slowest step acts as the rate-limiting factor, ultimately determining the system's reaction kinetics.

Kinetic studies of these systems aim to determine the reaction rate and identify the factors influencing it. To this end, pseudo-first-order, pseudo-second-order, and intraparticle diffusion models are commonly applied (Ray et al., 2017).

2.2. Synthesis of Diatomite + TiO_2

The TiO_2-Dt semiconductor was synthesized using a magnetic stirrer in a beaker containing distilled water, glacial acetic acid, titanium isopropoxide, and natural diatomite (Ortiz et al., 2018). After the addition of all reagents, the volume was adjusted to 400 mL with distilled water, and the resulting suspension was stirred for 2 to 3 hours. Following decantation and filtration, the solid obtained from the sol-gel process was placed in an oven at an average temperature of 373 K for 24 hours to form the TiO_2-Dt microstructures. The resulting material underwent drying and storage and was later used in solar photodecomposition experiments (Figure 3).

Figure 3 - Steps of the TiO_2-Diatomite synthesis process.



Source: Author.

2.3. Photodecomposition Processes

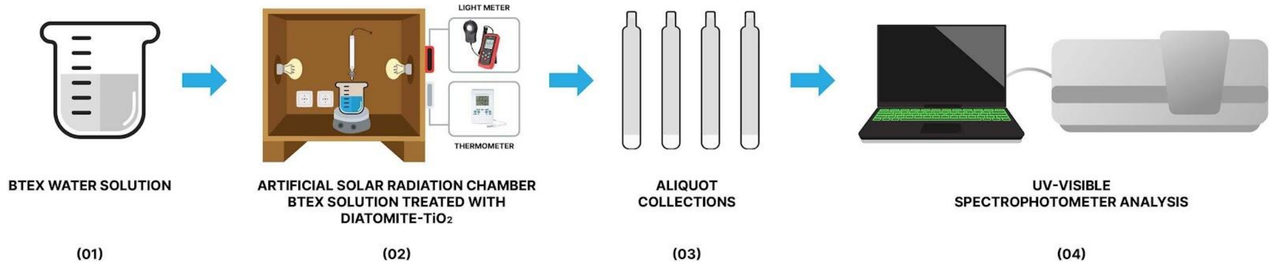
The parameters evaluated in the photodecomposition process included: the use of 9.0 g of TiO_2-Dt (titanium dioxide with diatomite), synthetic BTEX solutions prepared in the laboratory with distilled water, stirring time, exposure to artificial solar radiation, pH adjusted to 5.0, light intensity of 380 lux, and a controlled temperature range between 295 K and 298 K.

Two LED lamps installed in a solar chamber simulated sunlight, allowing photodecomposition to take place under controlled conditions. The BTEX solutions were prepared and diluted at different concentrations (BTEX in distilled water), reflecting values typically reported in the literature for contaminated groundwater.

The experiments were carried out in the laboratory over a period of 2 hours. After preparing the sample containing BTEX and TiO_2-Dt and introducing it into the photodecomposition column, aliquots were collected at 0, 30, 60, 90, and 120 minutes. The concentration of benzene was monitored as an indicator of BTEX degradation using a UV-VIS spectrophotometer.

These measurements enabled the assessment of photodecomposition efficiency over time. Figure 4 illustrates the photodecomposition process. The UV-VIS spectrophotometric analysis was used to monitor the degradation of BTEX by measuring benzene concentration in each aliquot at its characteristic absorption wavelength of 268 nanometers (nm).

Figure 4 - Photodecomposition process carried out in the laboratory.



Source: Author.

1 – BTEX solution with TiO_2-Dt.
2 – Artificial solar radiation chamber.
3 – Aliquot collections.
4 – Analysis with UV-visible spectrophotometer.

3. Results and Discussion

During the research, the experiments were carried out in a controlled laboratory environment. The initial photodecomposition tests aimed to evaluate the effects of varying the initial concentrations of BTEX in aqueous solutions, the influence of different amounts of photocatalyst synthesized using TiO_2 with diatomite as a template (TiO_2-Dt), and the impact of temperature variations within the range of 298 K to 313 K on the photodecomposition process.

In general, photodecomposition processes are effective within a temperature range of 293 K to 353 K, with values outside this range potentially having a significant effect on the efficiency of organic compound removal (Buth, 2009).

3.1. The mass of Semiconductor Material

Optimizing the process parameters could determine the optimal semiconductor mass for maximum efficiency and more effectively evaluate BTEX removal.

3.2. Characterization of theTiO$_2$ - Dt

Titanium dioxide with diatomite was synthesized in the laboratory under controlled conditions. The resulting synthetic material was subsequently subjected to photodecomposition tests and physicochemical characterization using Scanning Electron Microscopy (SEM) and thermogravimetric analysis (TGA).

The microstructural analysis provided morphological information, including the orientation and quality of the reinforcing fiber interface, the interface between the matrix and the dispersed phase in immiscible blends, as well as the presence of impurities, bubbles, cracks, and surface irregularities.

The thermogravimetric heating ramp ranged from 273 K to 1123 K, during which changes in the semiconductor's mass were monitored. A significant mass loss of 93.3% was observed at temperatures above 873 K, relative to the initial sample mass of 7.1 mg. This substantial reduction is attributed to the use of diatomite, a material with higher volatility, as a structural agent.

3.3. Infrared Analysis of TiO_2-Dt before and after the Process

The infrared analysis of the synthesized photocatalyst showed that the characteristic silica peaks remained unchanged before and after the photodecomposition process. Nevertheless, the structural peaks of the Si-Ti bond remain the same.

3.4. Photodecomposition Process

The photodecomposition tests were performed using spectrophotometric methods based on a calibration curve prepared with standard solutions. Concentration measurements of the resulting complexes were carried out using a UV-Visible spectrophotometer.

An experimental design matrix was applied to evaluate key process parameters, including the mass ratio between the initial BTEX concentration (determined by benzene content) and the amount of diatomite doped with TiO_2, as well as the system's pH values and the temperature of the photodecomposition process.

The results enabled the construction of benzene concentration curves in solution at various percolation time intervals through the photodecomposition columns. These experiments identified the optimal photodecomposition conditions, equilibrium concentrations, saturation times, and the influence of pH and temperature on process efficiency. Some tests were conducted by varying the initial BTEX concentrations and by adding different masses of the TiO_2-Dt semiconductor over a period of 2 hours.

The tests conducted with a 60% BTEX solution in water and 1.0 g of TiO_2-Dt yielded satisfactory results, as shown in Table 1.

Table 1 - Semiconductor total mass and respective removals.

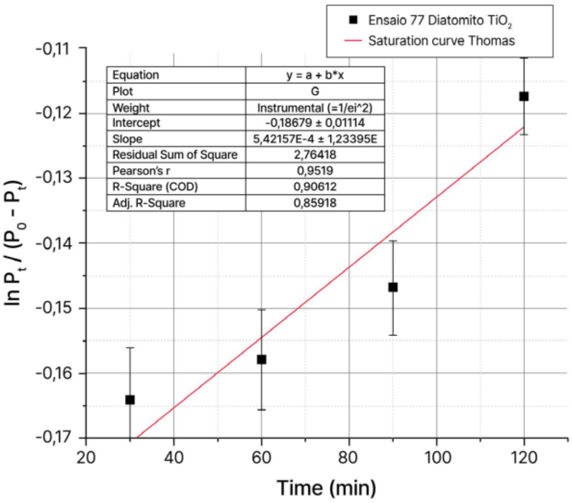
TESTS	**Semiconductor TiO_2 - Dt (g)**	**Percentage BTEX (%)**	**Removal (%)**
1	0.5	60	88.3
2	1.5	60	70.4
3	0.8	40	85.0
4	1.0	40	75.0
5	1.0	40	73.0

Source: Author.

The results indicate that moderate amounts of catalyst, ranging from 0.5 g to 1.5 g, are more effective for BTEX removal, whereas larger quantities may reduce the efficiency of the photodecomposition reaction. This behavior is commonly observed in heterogeneous photocatalytic systems. Excessive catalyst loading can lead to light scattering and shading effects, which hinder the penetration of solar radiation necessary to activate the photocatalytic material. Additionally, high catalyst concentrations may promote particle agglomeration, thereby decreasing the effective surface area available for the reaction. Another contributing factor is mass transfer limitation, which can impair the diffusion of contaminants to the catalyst's active sites.

The application of the Thomas model, used to estimate photodecomposition performance, enabled the evaluation of the BTEX removal capacity of the catalytic material. The results of the Thomas model demonstrated efficient photodecomposition in tests using TiO_2-Dt with 40% BTEX solutions, particularly when 1.2 g of TiO_2-Dt was applied, indicating enhanced removal capacity with increased catalyst mass. However, this increase was not proportional, reinforcing the existence of an optimal catalyst concentration range to maximize process efficiency, as illustrated in Figure 5.

Figure 5 - Thomas model calculation for 1.2 g TiO_2-Dt and 40% BTEX.



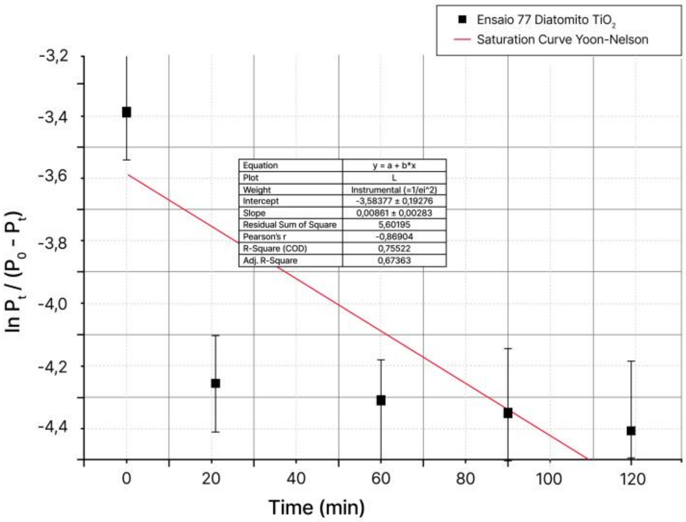
Equation	y = a + b*x
Plot	G
Weight	Instrumental (=1/ei^2)
Intercept	-0,18679 ± 0,01114
Slope	5,42157E-4 ± 1,23395E
Residual Sum of Square	2,76418
Pearson's r	0,9519
R-Square (COD)	0,90612
Adj. R-Square	0,85918

Source: Author.

The Thomas model calculations revealed that both the amount of TiO_2-Dt and the BTEX concentration significantly influenced the efficiency of BTEX removal. The 60% BTEX solution showed better performance when treated with TiO_2-Dt, particularly at higher catalyst masses. The coefficient of determination ($R^2 = 0.952$) indicates a strong correlation between the experimental data and the Thomas model.

The Yoon-Nelson model also demonstrated efficient photodecomposition performance, with short breakthrough times and effective removal capacity. Figure 6 presents the results of the Yoon-Nelson model calculations. The R^2 value of 0.869 indicates a reasonable fit to the model; however, the correlation could be improved with additional experimental data.

Figure 6 - Yoon-Nelson model calculation for 1.2 g TiO_2-Dt and 40% BTEX.



Source: Author.

Table 2 presents the values of the Thomas (K_{Th}) and Yoon-Nelson (K_{YN}) rate constants reported in the literature and those obtained in the present study, allowing for a comparison of contaminant removal rates across different works.

Table 2 - KTh and KYN values obtained in the literature and this study.

REFERENCE	**THOMAS CONSTANT - K_{Th} (ml/mg/h)**	**YOON-NELSON CONSTANT - K_{YN} (1/ min) 10^{-5}**
In this study	From 0,0092 to 7,76	From 0,0016 to 5,42
El-Aswar, E.I. et al. Removal of ciprofloxacin Journal of Molecular Liquids 403 (2024)	From 0,055 to 3,54 Depending on the bed height, flow rate, and initial concentration	From 0,0091 to 0,0134 Depending on the bed height, flow rate, and initial concentration
Lv, N. Li, X. Phosphorous removal from wastewater using Ca modified attapulgite: fixed bed column performance and breakthrough curves analysis. Journal of Environmental Management (2023) 328.	From 0,083 to 0,36	From 0,086 to 0,11

Source: Autor.

When the values obtained in this study are compared with those reported in the literature, they are found to be of the same order of magnitude, although they exhibit a wider range of variation. This suggests that the parameters used in the photodecomposition process are efficient, applicable, and still offer potential for further optimization and stabilization.

The optimization of the photocatalytic decomposition process represents a promising alternative for the treatment of groundwater contaminated with BTEX compounds. The results demonstrated that TiO_2 microstructured with diatomite was capable of removing up to 100% of BTEX from contaminated water. Furthermore, the process facilitates the recovery of fuel leaked from gasoline storage tanks. The photocatalytic decomposition tests confirmed that solar radiation is essential for the complete degradation of BTEX compounds, highlighting the critical role of solar photocatalysis in contaminant removal.

The combination of TiO_2-Dt and solar photocatalysis proved to be an effective strategy for water remediation, offering a sustainable and accessible solution. Thermogravimetric analysis confirmed the stability of the photocatalyst, underlining its relevance for maintaining high process efficiency.

The developed system is applicable in both open and closed environments, and field tests using natural solar radiation confirmed its effectiveness. Solar energy can also be used to power the system, making it autonomous and cost-effective.

Optimizing the photodecomposition process could provide a viable alternative to conventional water disinfection methods currently used in the country.

4. Conclusion

The results of this study confirm that the combination of diatomite and TiO_2—prepared via the hydrolysis of titanium isopropoxide and microstructured using natural diatomite as a template—yields a material with exceptional properties for use as a semiconductor in solar photocatalytic decomposition processes. Through a series of experiments, the parameters of the solar photocatalytic process were optimized, achieving complete (100%) removal of BTEX compounds from contaminated water.

These findings demonstrate both the feasibility and efficiency of using solar photocatalytic decomposition for the treatment of BTEX-contaminated groundwater. The process not only effectively removed the contaminants but also offers a sustainable solution aligned with the urgent need to preserve water quality. The promotion and application of solar photocatalytic decomposition could represent a practical and environmentally friendly alternative for treating contamination caused by gasoline derivatives.

Furthermore, the photocatalytic decomposition tests significantly enhanced BTEX removal from contaminated water. Solar radiation played a key catalytic role, accelerating the degradation of BTEX compounds adsorbed onto the TiO_2-Dt surface. Samples exposed to solar radiation exhibited faster and more efficient BTEX reduction, underscoring the importance of photocatalysis as a crucial complement to the adsorption process.

ACKNOWLEDGMENTS

To CAPES – Coordination for the Improvement of Higher Education Personnel for the research scholarship process n° 88887.757078/2022-00.

REFERENCES

ANDRADE, JA; AUGUSTO, F.; JARDIM ICSF. (2010). *Bioremediation of soils contaminated by petroleum and its derivatives.* Eclectic Chemistry, v. 35, no. 3, p. 17 - 43. http://dx.doi.org/10.1590/S0100-46702010000300002.

AGÊNCIA NACIONAL DE PETRÓLEO, GÁS NATURAL E BIOCOMBUSTÍVEIS - ANP - Brasil (2021). *Brazilian statistical yearbook for oil, natural gas and biofuels*. Rio de Janeiro. http://www.anp.gov.br/conteudo-do-menu-superior/31-dados-abertos/6010-anuario-estatistico

BUTH, D. F. (2009). *Degradação fotocatalítica da tetraciclina em solução aquosa empregando* TiO_2 *suportado.* Dissertação de Mestrato – Universidade Federal do Rio Grande do Sul. Porto Alegre.

COMPANHIA AMBIENTAL DO ESTADO DE SÃO PAULO – CETESB (2021). *Contaminated areas management manual.* http://areascontaminadas.cetesb.sp.gov.br/manual-de-gerenciamento/

EL-ASWAR, E.I. et al. (2024). *Removal of ciprofloxacin*. Journal of Molecular Liquids 403p.

INSTITUTO BRASILEIRO DE PETRÓLEO E GÁS (2012). Rio de Janeiro. https://www.ibp.org.br/observatorio-do-setor/snapshots/maiores-consumidores-de-petroleo-e-lgn-em-2019/

LV, N. LI, X. (2023). *Phosphorous removal from wastewater using Ca modified attapulgite: fixed bed column performance and breakthrough curves analysis*. Journal of Environmental Management 328p.

LUIZ, A.M. (1985). *How to Take Advantage of Solar Energy*. São Paulo. Editora Edgard Blücher Ltda., 191p.

ORTIZ, N.; SILVA, A.; LIMA, G. N. S.; HYPPOLITO, F. P. (2018). *Using Solar-*TiO_2 *and Biocarbon to Decompose and Adsorb Amoxicillin from Polluted Waters.* International Journal of Chemistry; Vol. 10, No. 1.

RAY, S. K.; DHAKAL, D. K. Y. K.; LEE, S. W. (2017). *Cu-alfa-*$NiMoO_4$ *photocatalyst for degradation of methylene blue with pathways and antibacterial performance*. Journal of Photochemistry and Photobiology A: Chemistry, v. 348, p. 18 - 32.

SURI, R. P. S. et al. (1993). *Heterogeneous photocatalytic oxidation of hazardous organic contaminants in water*. Water Environmental. Research, v.65, n.5, p. 665 - 73.

VAZZOLER, A. (2019). *Cálculo de reatores catalíticos gás-sólido*. Volume 1, 1°edição, Vitória.