Journal of Posthumanism
2024
Volume: 4, No: 3, pp. 0
ISSN: 2634-3576 (Print) | ISSN 2634-3584 (Online)
posthumanism.co.uk

DOI: https://doi.org/10.63332/joph.v4i3.3370

Comparative Study of the Oxidation Efficiency of Wastewater from the Petrochemical Industry Through the Fenton Process and Ozonation, Lima, 2023

Katherin Marilus Paucar Rodríguez[1]

Abstract

Background: This study aimed to assess and compare how well the Fenton and ozonation processes can clean wastewater from the petrochemical industry in Lima, 2023. Methods: A practical research approach with a semi-experimental design was used to ensure careful data gathering and examination. Results: The physical and chemical analysis of the wastewater showed that important factors, such as pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and oil and grease (O&G), were above the Maximum Allowable Values (MAV) set by environmental rules. The Fenton process showed moderate to high removal rates, achieving reductions of 40% for BOD, 28% for COD, and 57% for O&G. In contrast, the ozonation process had lower effectiveness, with maximum removal rates of 22%, 12%, and 28% for BOD, COD, and O&G, respectively. Conclusions: Statistical tests confirmed significant differences in treatment effectiveness over time. Moreover, the cost analysis showed that the Fenton process was more economical compared to ozonation. Based on the test results, the Fenton method is suggested as a better and more cost-efficient option for cleaning petrochemical wastewater, helping to enhance environmental management practices in industrial areas.

Keywords: *Wastewater Oxidation, Petrochemical Industry, Fenton Process, Ozonation Process.*

Introduction

Globally, there is growing concern about the increasing production of effluents (Jain et al. , 2023), particularly in recent years, where wastewater from the petrochemical industry—often referred to as oily water—has emerged as a significant societal issue (Gupta et al. , 2017, cited in Ma Fu-Xin et al. , 2022).

Within the petrochemical sector, the oil industry is one of the primary contributors to water pollution, posing substantial risks for the environment and businesses alike (Ibrahim et al. , 2022). For instance, global oil production generates approximately 4,400 million tons of oil annually, and in the refining process, each ton of oil results in the production of between 3. 00 and 3. 50 cubic meters of petrochemical wastewater (Zhang and Fan, 2016; Siddique et al. , 2017, cited in Tian et al. , 2020). In Latin America, the petrochemical industry produces an alarming 430,000 tons of waste materials every day (Segovia-Hernández et al. , 2022).

The environmental impact stems largely from the pollutants associated with the final use of diesel fuel and other related processes (Khattak et al., 2021). Notably, oil refineries release residual water that contains harmful substances such as sulfur and nitrates (Andreides et al., 2021). These industries consume significant amounts of fresh water while simultaneously

[1] Universidad Cesar Vallejo, Email: kapaucarro@ucvvirtual.edu.pe, (Corresponding Author)

generating vast quantities of wastewater (Hu et al. , 2020). This wastewater is laden with both organic (OC) and inorganic (IC) pollutants that pose serious environmental and health risks (Sevda et al. , 2020).

Research has highlighted the dangers certain organic pollutants in petrochemical effluents pose to human health. For instance, workers exposed to volatile organic compounds from the industry have reported instances of cancer (Hajizadeh et al. , 2018). Consequently, it is imperative that water contaminated with petroleum derivatives and processing additives undergo treatment to eliminate these harmful compounds before being reintroduced into the environment. One proposed solution is the use of oxidation processes for treating this wastewater, as they offer advanced treatment capabilities with high efficiency in removing organic matter (Fardin et al. , 2021).

Oxidation methods such as ozonation and Fenton's process are particularly effective, often breaking down pollutants like carbon monoxide (CO) and chlorine (Cl) in large quantities or even completely (Bahri et al. , 2018). Studies indicate that the Fenton process may enhance the oxidation efficiency of wastewater resistant to organic pollutant degradation (Dehboudeh et al. , 2020).

In recent years, environmental regulations surrounding the discharge of industrial wastewater—especially from the petrochemical sector—have become increasingly stringent. Legal frameworks, such as the European Water Framework Directive (Directive 2000/60/EC) and the U. S. Clean Water Act, impose strict limits on pollutants, including Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5), and total hydrocarbons (European Commission, 2020; United States Environmental Protection Agency [EPA], 2021).

Countries in Latin America, including Peru, have implemented similar rigorous standards that mandate compliance with maximum allowable limits for pH, suspended solids, hydrocarbons, and heavy metals before any industrial effluents can be discharged into natural water bodies (Ministerio del Ambiente del Perú, 2017). Non-compliance can result in significant financial penalties, mandatory remediation actions, and reputational harm.

Advanced oxidation processes (AOPs), such as the Fenton process and ozonation, present a compelling solution in the face of stringent regulatory pressures. These methods are lauded for their high efficiency in pollutant removal while minimizing the production of secondary pollutants (Oturan and Aaron, 2017). Furthermore, the introduction of hybrid AOP systems offers an efficient and cost-effective approach to meeting increasingly rigorous environmental standards (Ghanbari and Moradi, 2017).

Recent research underscores the urgent necessity to tackle emerging contaminants—ranging from pharmaceuticals and endocrine-disrupting chemicals to microplastics—in petrochemical wastewater (Tran, Reinhard, and Gin, 2021; Luo et al. , 2020). The persistence and toxicity of these substances create additional hurdles for traditional treatment technologies.

Consequently, selecting the right treatment technology should consider not only the effectiveness of pollutant removal but also adherence to current regulatory requirements, environmental sustainability, and operational expenses. In this regard, it is crucial to evaluate and compare the performance of Fenton and ozonation processes, particularly for the petrochemical industry's environmental management efforts.

Objectives

The aim of the research is to determine which is the most efficient method for the oxidation of wastewater from the petrochemical industry in the application of the Fenton and Ozonation processes Lima, 2023.

The specific objectives are the following:

- Identify the physicochemical parameters that characterize wastewater from the petrochemical industry.
- Identify the efficiency in the application of the Fenton process for the oxidation of wastewater from the petrochemical industry.
- Identify the efficiency in the application of the ozonation process for the oxidation of wastewater from the petrochemical industry
- Compare the results obtained from the Fenton oxidation and Ozonation processes to determine which of the two methods is the most efficient in terms of pollutant removal and economic viability

Methods

Type and Design of Research

Applied research is a type of research that focuses on an objective, its resolution, and subsequent application to help with the optimization of knowledge to interested professionals (Castro et al., 2023). Given this, the present study used the applied type of research, since it sought to apply the best oxidation process by solving the study problem, which sought to determine that by solving the problem of which is the most efficient method for the oxidation of wastewater from the petrochemical industry in the application of the Fenton and Ozonization processes Lima, 2023.

Research design consisted of a type of quasi-experimental design that allows the results obtained from experimental studies to be reinforced (Barnighausen et al., 2017).

That is why the type of research design is quasi-experimental, since the independent variable was intentionally manipulated, i.e., the Fenton and Ozonation processes in terms of doses, to determine the efficiency of Oxidation of wastewater from the petrochemical industry.

Variables are defined conceptually and operationally where they are classified by dimensions, indicators, and scale. The independent variable is the Fenton process and Ozonation, while the dependent variable is Oxidation efficiency of petrochemical industry wastewater.

The sample is a subset or representative portion of the population, also known as the universe, and refers to the entire collection of subjects, elements, or cases that are being explored. They contain characteristics that allow them to contribute to the information being studied (Alan and Cortez, 2017). Given this, the population in this research work refers to wastewater from the petrochemical industry that is analyzed, the inclusion criteria was wastewater from the petrochemical industry only, the exclusion criteria was the domestic and municipal wastewater, among others not belonging to the petrochemical industry. The sample consists of 65 liters of the collected wastewater sample volume.

The sampling is probabilistic since the individuals to be selected for the sample are completely random.

The data collection technique used is observation and among the instruments used for the collection of information are the research form and the laboratory data collection form. These instruments are used to detail the information presented as initial and final data.

Results

Now, according to the general objective to determine the most efficient method for the reduction of the concentration of parameters in wastewater from the textile industry, two methods are proposed: FENTON and OZONIZATION, as follows.

SAMPLE	**T (ºC)**	**pH**	**DBO (mg/L)**	**DQO (mg/L)**	**SST (mg/l)**	**Oils and fats (mg/L)**
M-1	21.2	7.2	840	1340	140	225
VMA	*<35ºC*	*6-9*	*500*	*1000*	500	100

Table 1

Characterization of wastewater from the petrochemical industry.

Table 1 shows that the values of sample 1 present values that exceed the VMA in BOD and COD.

Treatment #1 FENTON process: This first treatment was performed using a sample volume of 2000 ml, with a dose of oxidizing agent Hydrogen Peroxide (H2O2) of 100 mg/L, as well as the dose of catalyst Iron Oxide (Fe+2) of 50 mg/L, and finally the pH adjusted at 5.

CONTAMINATE	**Biochemical Oxygen Demand (BOD)**				
Time (min)	20	40	60	80	100
Initial Concentration (mg/l)	840 mg/L				
Initial Run	834	821	795	781	805
	Repetitions				
1	846	825	770	745	790
2	826	816	755	675	789
3	810	802	715	625	793
4	799	780	655	598	765
AVERAGE	**823**	**808.8**	**738**	**684.8**	**788.4**

Table 2

Treatment #1 BOD

As shown in Table 2, with an initial concentration of 840 mg/L of BOD, this had a reduction of up to 684.8 mg/L, in a time of 80 minutes.

	Sum of squares	gl	Root mean square	F	Sig.
Between groups	900.8	4	225	8.092	0.000
Within groups	556.6	20	28		
Total	1,457.4	24			

Table 3

ANOVA test to compare the efficiencies according to time.

Since Sig=0.000 is less than 0.05, it is concluded that the efficiency is different in at least one of the different time levels.

Time	N	Subset for alpha = 0.05	
		1	2
20 minutes	5	2.0	
40 minutes	5	3.7	
100 minutes	5	6.1	
60 minutes	5	12.1	12.1
80 minutes	5		18.5
Sig.		0.053	0.350

Table 4

Tukey's test to compare concentration according to time.

The means for the groups in the homogeneous subsets are displayed. a. Uses harmonic mean sample size = 5,000.

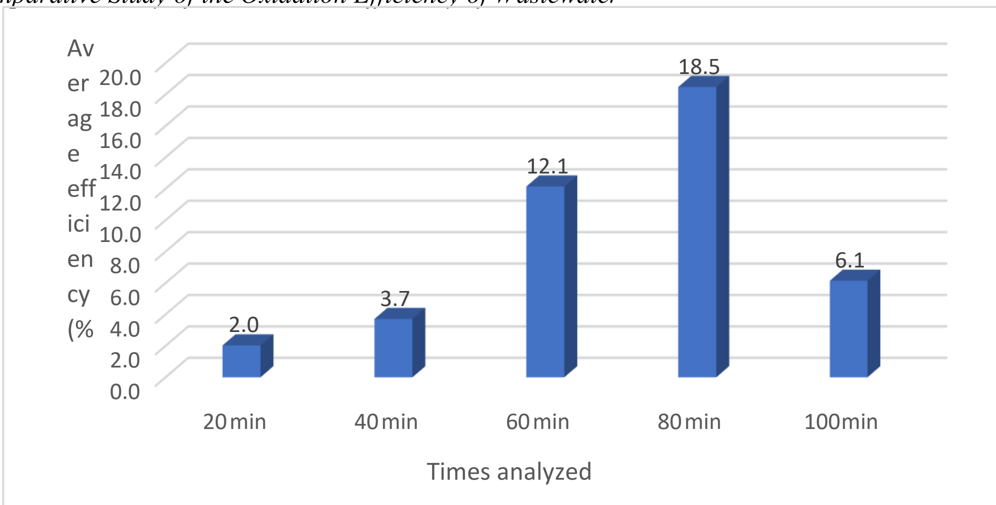

Fig. 1. Efficiency of Averaging Concerning Time.

CONTAMINATE	**Chemical Oxygen Demand (COD)**				
Time (min)	20	40	60	80	100
Initial Concentration (mg/l)	1340 mg/L				
Initial Run	1331	1315	1298	1245	1281
	Repetitions				
1	1319	1302	1289	1227	1275
2	1299	1278	1247	1213	1250
3	1282	1243	1220	1191	1219
4	1241	1228	1199	1173	1185
AVERAGE	**1294.4**	**1273.2**	**1250.6**	**1209.8**	**1242**

Table 5

Treatment #1 COD

Table 5 shows that with an initial concentration of 1340 mg/L of COD, it had a reduction of up to 1209.8 mg/L, in a time of 80 minutes.

	Sum of squares	gl	Root mean square	F	Sig.

Between groups	114.4	4	29	3.728	0.020
Within groups	153.5	20	8		
Total	268.0	24	-	-	-

Table 6

ANOVA test to compare the efficiencies according to time.

Since Sig=0.020 is less than 0.05, it is concluded that the efficiency is different in at least one of the different time levels.

Time	N	Subset for alpha = 0.05	
		1	2
20 minutes	5	3.4	-
40 minutes	5	5.0	5.0
60 minutes	5	6.7	6.7
100 minutes	5	7.3	7.3
80 minutes	5		9.7
Sig.	-	0.209	0.089

Table 7

Tukey's test to compare concentration according to time.

The means for the groups in the homogeneous subsets are displayed a. Uses harmonic mean sample size = 5,000.

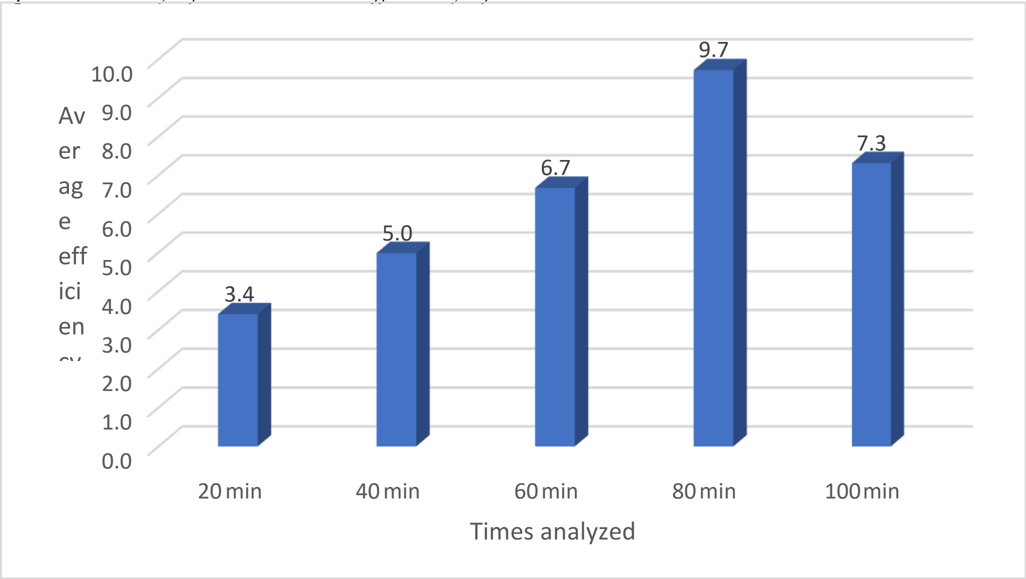

Fig.

Eficiencia del promedio respecto al tiempo

According to figure 3, efficiency was significantly higher at 40, 60, 80 and 100 minutes.

CONTAMINATE		**Oils and Fats (O**		**&F)**	
Time (min)	20	40	60	80	100
Initial Concentration (mg/l)			225 mg/L		
Initial Run	223	219	222	218	220
	Repetitions				
1	219	215	223	210	213
2	213	211	217	206	209
3	207	208	212	199	204
4	201	200	209	185	199
AVERAGE	**212.6**	**210.6**	**216.6**	**203.6**	**209**

Table 8

Treatment #1 OyF

Finally, for treatment 1 Fenton process, the Oils parameter with an initial concentration of 225 mg/L obtained a concentration reduction of up to 203.6 mg/L, in a time of 80 minutes.

	Sum of squares	gl	Root mean square	F	Sig.
Between groups	90.4	4	23	1.469	0.249
Within groups	307.5	20	15		
Total	397.9	24	-	-	-

Table 9

ANOVA test to compare the efficiencies according to time.

Since Sig=0.249 is greater than 0.05, it is concluded that the efficiency is the same for the different time levels.

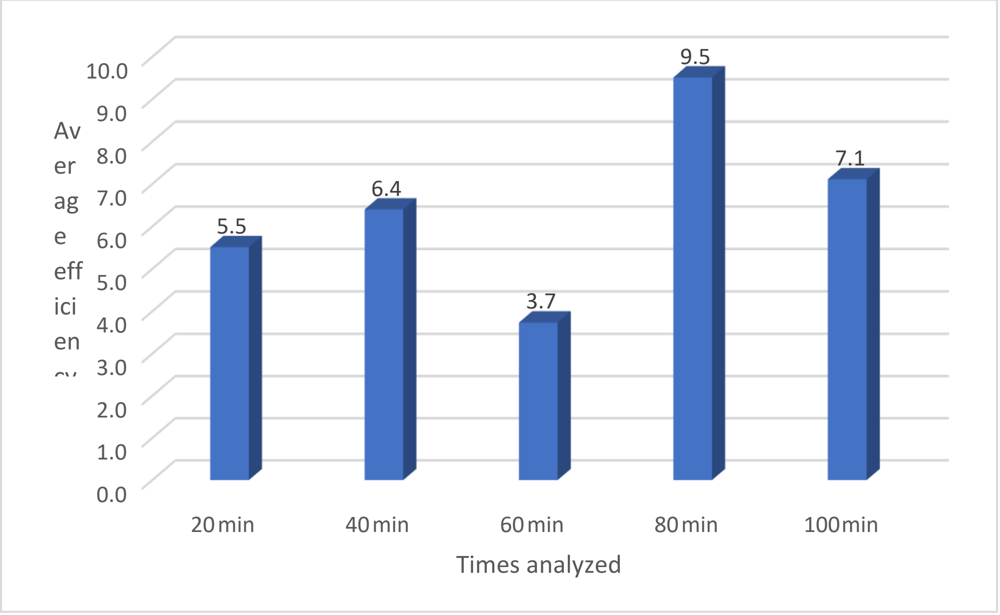

Fig. 4. Efficiency of Averaging for Time.

According to Figure 4, efficiency was significantly higher at 100 and 80 minutes.

Discussion

The analysis of physicochemical parameters in wastewater from the petrochemical industry involved measuring several key indicators: Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), temperature, oil and grease content, total suspended solids (TSS), and pH. A 15-liter sample was taken from the sedimentation tank of a petrochemical plant and then thoroughly examined in the laboratory to assess its pollutant load and compliance with the Maximum Allowable Values (MAV). The findings revealed that multiple parameters exceeded regulatory limits, underscoring the immediate need for effective treatment strategies. In a similar vein, Santos et al. (2020) highlighted the importance of initial wastewater characterization in selecting suitable treatment methods for petrochemical effluents.

The Fenton process was found to exhibit relatively high oxidation efficiencies. When compared to the ozonation process, the Fenton method demonstrated superior reductions in BOD, COD, and oil and grease concentrations. This finding aligns with the research of Dehboudeh et al. (2020), which indicated that the Fenton process is particularly effective in degrading stubborn organic pollutants in industrial wastewater.

Under neutral pH conditions (approximately 7), the Fenton process achieved removal efficiencies of 41%, 28%, and 57% for BOD, COD, and oil and grease, respectively. In contrast, at acidic pH levels (around 5), the efficiency dropped significantly, with removal rates ranging only from 4% to 23% for the same parameters. These results highlight the crucial role of pH in enhancing Fenton process performance, in line with observations from Gamarra-Güere et al. (2014) and Gong et al. (2022), who noted that near-neutral pH conditions optimize the generation of hydroxyl radicals, thereby improving pollutant degradation.

The reduction in COD concentrations was particularly noteworthy. As detailed in Table 5, an initial COD level of 1340 mg/L was lowered to 1209. 8 mg/L after 80 minutes of treatment, showcasing a significant improvement. Gong et al. (2022) reported similar findings, where prolonged reaction times and optimal oxidant dosages led to enhanced COD removal.

Treatment efficiency was observed to increase with extended reaction times, reaching maximum reductions at 80 and 100 minutes. This time dependency reflects the kinetics of hydroxyl radicals interacting with organic contaminants and corresponds with studies that stress the necessity for adequate contact time in Advanced Oxidation Processes (AOPs) (Oturan and Aaron, 2017).

Regarding the removal of oil and grease, the Fenton process reduced the concentration from 225 mg/L to 203. 6 mg/L after 80 minutes. While the ANOVA test indicated that the differences across time points were not statistically significant ($p > 0.05$), a clear downward trend was evident, suggesting the potential of Fenton oxidation for treating hydrophobic pollutants.

Conversely, the ozonation process showed relatively lower overall effectiveness, achieving removal percentages for BOD, COD, and oil and grease of only 22%, 12%, and 28%, respectively. Interestingly, the ozonation process proved more effective under acidic conditions ($pH \approx 4$), supporting the findings of Hu et al. (2020) and Rekhate and Srivastava (2020), who noted that acidic environments facilitate ozone decomposition into highly reactive hydroxyl radicals, thereby improving contaminant removal.

Despite its comparatively lower efficiency, ozonation remains a valuable complementary technique because it generates less sludge than the Fenton process. Nevertheless, an economic analysis indicated that ozonation incurs higher operational costs, primarily due to the energy-intensive nature of ozone production and the requirement for longer treatment durations (Ibarra et al. , 2018).

From an economic standpoint, the Fenton process has proven to be more effective. As highlighted in the comparative analysis presented in Table 23, the Fenton process not only surpassed traditional methods in pollutant removal but also significantly lowered treatment costs. This finding is reinforced by Shi et al. (2022), who demonstrated that Fenton-based treatments can cut operational expenses by over 60% compared to conventional approaches, all while generating minimal residual waste.

However, it is important to note that the Fenton process requires meticulous pH management and additional post-treatment measures to handle iron sludge effectively. Regulatory bodies, such as the United States Environmental Protection Agency (EPA) and the European Commission, mandate that the concentrations of residual iron and the generation of secondary waste must be minimized prior to the discharge of effluent (European Commission, 2020; EPA, 2021). Therefore, implementing appropriate sludge management strategies is essential for ensuring compliance with these regulations.

In conclusion, while both treatment methods offer promise for enhancing wastewater quality, the Fenton process distinguishes itself as the most advantageous technology for treating petrochemical wastewater, particularly when factoring in pollutant removal efficiency, operational cost, and adherence to regulatory standards in the conditions examined in this study.

Conclusions

The physicochemical parameters that characterize the wastewater from the petrochemical industry were identified, obtaining that the characterization values such as pH, BOD, COD, and O&F exceed the Maximum Allowable Values (MAV).

The application of the Fenton process for the oxidation of wastewater from the petrochemical industry presented an intermediate efficiency, with percentages higher than 40%, 28%, and 57% for BOD, COD, and O&F.

The application of the Ozonation process presented a low efficiency and lower than the Fenton process, for the oxidation of wastewater from the petrochemical industry, presenting higher percentages of removal of BOD, COD, and O&F in 22%, 12%, and 28%.

In the comparison of the results obtained from the oxidation processes of Fenton and Ozonization, to determine which of the two methods is the most efficient in terms of pollutant removal and economic viability, it was found that the Fenton process presents higher efficiency in its removal averages of BOD, COD and AGO, and in economic terms the Fenton process is more economically viable.

To obtain good removal efficiency in the Fenton and Ozonization processes, it is recommended to consider the pH value, which is ideal for Fenton with a neutral pH and Ozonization with an acid pH.

In addition, it is recommended to use long times in both the Fenton and Ozonation processes, since in longer periods the removal rate increases.

For the Fenton oxidation process to occur, it is recommended that the oxidant be added to the sample gradually at pH intervals of 3 to 5 throughout the oxidation process, as this may increase the removal efficiency.

To increase the efficiency of the ozonation process, it is recommended to apply treatments with different ozonation processes; for example, implementing catalytic ozonation with microbubbles, since studies have mentioned the elimination of organic compounds 1.8 times higher than in the ozonation process.

Acknowledgement

The authors would like to express their gratitude to all the participants and the authorities of the Universidad Cesar Vallejo, who made it possible for this project to take place.

Author Contributions Statement

The author designed the study, collected data, curated, and analyzed the dataset, and wrote the manuscript. Ho also read, reviewed and approved the final version of the manuscript.

Funding

No financial support was received for this study.

Conflicts of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data Availability

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

References

Alan, D., & Cortez, L. (2017). Procesos y fundamentos de la investigación científica. Universidad Técnica de Machala.

Andreides, D., Varga, Z., Pokarma, D., & Zabranska, J. (2021). Performance evaluation of sulfide-based autotrophic denitrification for petrochemical industry wastewater. Journal of Water Process Engineering, 40, 101834. https://doi.org/10.1016/j.jwpe.2020.101834

Bahri, M., Mahdavi, A., Mirzael, A., Mansouri, A., & Haghighat, F. (2018). Integrated oxidation process and biological treatment for highly concentrated petrochemical effluents: A review. Chemical Engineering and Processing-Process Intensification, 125, 183–196. https://doi.org/10.1016/j.cep.2018.02.002

Bärnighausen, T., Tugwell, P., Røttingen, J., Shemilt, I., Rockers, P., Geldsetzer, P., Lavis, J., Grimshaw, J., Daniels, K., Brown, A., Borm, J., Tanner, J., Rashidiano, A., Barreto, M., Vollmer, S., & Atun, R. (2017). Quasi-experimental study designs series—paper 4: uses and value. Journal of Clinical Epidemiology, 89, 21–29. https://doi.org/10.1016/j.jclinepi.2017.03.012

Bernal, M., Quispe, G., Medina, C., Villasante, A., & Rengifo, J. (2021). Estudio experimental de la degradación del plaguicida metomilo en aguas superficiales aplicando procesos avanzados de oxidación. Revista de la Sociedad Química del Perú, 87(3), 242–260. http://dx.doi.org/10.37761/rsqp.v87i3.351

Biswas, T., Banerjee, S., Saha, A., Bhattacharya, A., Chanda, C., Mohan, L., Bhadury, P., & Ray, S. (2022). Bacterial consortium based petrochemical wastewater treatment: From strain isolation to industrial effluent treatment. Environmental Advances, 7, 100132. https://doi.org/10.1016/j.envadv.2021.100132

Boaventura, K., Peixoto, F., Fernandes, H., & Pessoa, F. (2022). Long-range investment assessment in a petrochemical industry: Cost and safety considerations. Computers & Chemical Engineering, 161, 107737. https://doi.org/10.1016/j.compchemeng.2022.107737

Borglum, S., & Soeder, D. (2019). 5-International shale plays. In The fossil fuel revolution: Shale gas and tight oil (pp. 137–171). https://doi.org/10.1016/B978-0-12-815397-0.00006-9

Cardoso, I., Cardoso, R., Da Silva, J., & Esteves, C. (2021). Advanced oxidation processes coupled with nanomaterials for water treatment. Nanomaterials, 11(8), 2045. https://doi.org/10.3390/nano11082045

Castro, J., Gómez, L., & Camargo, E. (2023). La investigación aplicada y el desarrollo experimental en el fortalecimiento de las competencias de la sociedad del siglo XXI. Tecnura, 27(75), 8. https://doi.org/10.14483/22487638.19171

Cheng, S., Ran, X., Ren, G., Wei, Z., Wang, Z., Rao, T., Li, R., & Ma, X. (2022). Comparison of Fenton and ozone oxidation for pretreatment of petrochemical wastewater: COD removal and biodegradability improvement mechanism. Separations, 9(7), 179. https://doi.org/10.3390/separations9070179

Clews, R. (2016). Chapter 11 - The Petrochemicals Industry. In Project finance for the international petroleum industry (pp. 187–203). https://doi.org/10.1016/B978-0-12-800158-5.00011-6

Dehboudeh, M., Dehghan, P., Azari, A., & Abbasi, M. (2020). Experimental investigation of petrochemical industrial wastewater treatment by a combination of integrated fixed-film activated sludge (IFAS) and electroFenton methods. Journal of Environmental Chemical Engineering, 8(6), 104537. https://doi.org/10.1016/j.jece.2020.104537

European Commission. (2020). Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32000L006

Fardin, S., Ghaedi, M., & Zalipour, Z. (2021). Chapter 4 - Advanced oxidation. In Interface science and technology volume 32 (pp. 225–324). https://doi.org/10.1016/B978-0-12-818806-4.00001-2

Gamarra, C., & La Rosa, A. (2014). Decoloración del anaranjado de metilo empleando el sistema fenton. Revista de la Sociedad Química del Perú, 80(1), 24–34.

Ghanbari, F., & Moradi, M. (2017). A review on application of Fenton and Fenton based processes for the removal of pharmaceutical pollutants. Journal of Environmental Management, 198, 447–466. https://doi.org/10.1016/j.jenvman.2017.04.073

Gong, C., Ren, X., Han, J., Wu, Y., Gou, Y., Zhang, Z., & He, P. (2022). Toxicity reduction of reverse osmosis concentrates from petrochemical wastewater by electrocoagulation and Fered-Fenton treatments. Chemosphere, 286, 131582. https://doi.org/10.1016/j.chemosphere.2021.131582

Gupta, S., & Pathak, B. (2020). Mycoremediation of polycyclic aromatic hydrocarbons. In Abatement of environmental pollutants (pp. 127–149). Elsevier. https://doi.org/10.1016/B978-0-12-818095-2.00006-0

Hajizadeh, Y., Teiri, H., Nazmara, S., & Parseh, I. (2018). Environmental and biological monitoring of exposures to VOCs in a petrochemical complex in Iran. Environmental Science and Pollution Research, 25, 6656–6667. https://doi.org/10.1007/s11356-017-1045-4

Hu, J., Fu, W., Ni, F., Zhang, Z., Yang, C., & Sang, J. (2020). An integrated process for the advanced treatment of hypersaline petrochemical wastewater: A pilot study. Water Research, 182, 116019. https://doi.org/10.1016/j.watres.2020.116019

Ibarra, G. (2018). Evaluación económica de tratamientos de aguas residuales industriales. Revista de Ingeniería Ambiental y Sostenibilidad, 5(1), 23–34.

Ibrahim, M., Banerjee, A., & El-Naas, M. (2022). Treatment of petroleum industry wastewater: Current practices and perspectives. In Petroleum industry wastewater (pp. 1–6). Elsevier. https://doi.org/10.1016/B978-0-323-85884-7.00015-1

Jain, M., Majumder, A., Kumar, A., & Sarathi, P. (2023). Application of a new baffled horizontal flow constructed wetland-filter unit (BHFCW-FU) for treatment and reuse of petrochemical industry wastewater. Journal of Environmental Management, 325, 116443. https://doi.org/10.1016/j.jenvman.2022.116443

Luo, Y., Guo, W., Hao, H., Duc, L., Ibney, F., Zhang, J., Liang, S., & Wang, X. (2020). A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. Science of The Total Environment, 473–474, 619–641. https://doi.org/10.1016/j.scitotenv.2013.12.065

Ma, F., Hao, B., Yu, X., Wang, R., & Ma, P. (2022). Aggregation-induced demulsification technology for the separation of highly emulsified oily wastewater produced in the petrochemical industry. Journal of Cleaner Production, 374, 134017. https://doi.org/10.1016/j.jclepro.2022.134017

Ministerio del Ambiente del Perú. (2017). Reglamento de estándares de calidad ambiental para agua y criterios de evaluación. https://www.gob.pe/minam

Nisar Khattak, M., Muhammad, N., & Robinson, D. (2021). Understanding the interplay between support agencies and small and medium-sized enterprises in a conflict environment from an institutional theory perspective. Asia-Pacific Journal of Business Administration, 13(2), 256-271.

Oturan, M., & Aaron, J. (2017). Advanced oxidation processes in water/wastewater treatment: Principles and applications. Critical Reviews in Environmental Science and Technology, 44(23), 2577–2641. https://doi.org/10.1080/10643389.2013.829765

Pignatello, J., Oliveros, E., & MacKay, A. (2006). Advanced oxidation processes for organic contaminant destruction based on the Fenton reaction and related chemistry. Critical Reviews in Environmental Science and Technology, 36(1), 1–84. https://doi.org/10.1080/10643380500326564

Rekhate, C., & Srivastava, J. (2020). Recent advances in ozone-based advanced oxidation processes for treatment of wastewater—A review. Chemical Engineering Journal Advances, 3, 100031. https://doi.org/10.1016/j.ceja.2020.100031

Rubio, A., Chica, E., & Peñuela, G. (2015). Petrochemical wastewater treatment by photo-Fenton process. Water, Air, & Soil Pollution, 226(62). https://doi.org/10.1007/s11270-015-2321-x

Santos, P., Scherer, C., Fisch, A., & Rodriguez, M. (2020). Petrochemical wastewater treatment: Water recovery using membrane distillation. Journal of Cleaner Production, 267, 121985. https://doi.org/10.1016/j.jclepro.2020.121985

Segovia, J., Hernandez, S., Cossío, E., & Sánchez, E. (2022). Tackling sustainability challenges in Latin America and Caribbean from the chemical engineering perspective: A literature review in the last 25 years. Chemical Engineering Research and Design. https://doi.org/10.1016/j.cherd.2022.10.012

Sevda, S., Kumar, V., Sharma, S., Bhattacharjee, U., Pandey, L., & Sreekrishnan, T. (2020). Oil and petrochemical industries wastewater treatment in bioelectrochemical systems. In Integrated microbial fuel cells for wastewater treatment (pp. 157–173). Butterworth-Heinemann.

Shi, L., Zhang, Y., Zeng, C., Lai, X., & Chen, S. (2022). Zero sludge discharge strategy for Fenton oxidation wastewater treatment technology: Biological regeneration and in-situ cyclic utilization—A feasibility study. Journal of Cleaner Production, 376, 134259. https://doi.org/10.1016/j.jclepro.2022.134259

Tian, X., Song, Y., Shen, Z., Zhou, Y., Wang, K., Jin, Z., Han, Z., & Liu, T. (2020). A comprehensive review on toxic petrochemical wastewater pretreatment and advanced treatment. Journal of Cleaner Production, 245, 118692. https://doi.org/10.1016/j.jclepro.2019.118692

Tran, N., Reinhard, M., & Gin, K. (2021). Occurrence and fate of emerging contaminants in municipal wastewater treatment plants: A review. Water Research, 133, 182–207. https://doi.org/10.1016/j.watres.2017.12.029

United States Environmental Protection Agency (EPA). (2021). National Pollutant Discharge Elimination System (NPDES) Program Overview. https://www.epa.gov/npdes.