

OPTIMASI VARIASI DOSIS DAN WAKTU REAKSI DALAM METODE OKSIDASI FENTON UNTUK PENGOLAHAN AIR LIMBAH INDUSTRI FARMASI

Tesis
untuk memenuhi sebagian persyaratan
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**MAGISTER TEKNIK LINGKUNGAN
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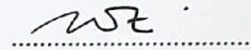
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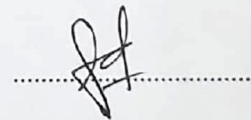
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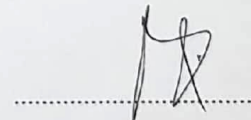
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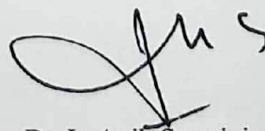
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ABSTRAK

Industri farmasi menghasilkan air limbah dengan kandungan mikropolutan kompleks yang sulit diuraikan secara biologis, sehingga berpotensi mencemari lingkungan. Instalasi pengolahan konvensional terbukti kurang efektif, khususnya terhadap senyawa resisten dengan rasio BOD/COD rendah. Penelitian ini bertujuan mengoptimasi variasi dosis H_2O_2 , dosis FeSO_4 , serta waktu reaksi pada metode oksidasi Fenton untuk meningkatkan efisiensi pengolahan air limbah farmasi. Optimasi dilakukan menggunakan *Response Surface Methodology* (RSM) metode *Central Composite Design* (CCD), serta analisis statistik dan lingkungan untuk mengevaluasi pengaruh faktor dan interaksi antar variabel. Parameter yang diuji meliputi BOD, COD, TSS, total-N, fenol, dan pH, dengan acuan baku mutu sesuai regulasi nasional. Hasil penelitian menunjukkan dosis optimal H_2O_2 sebesar 303,231 mmol/L, rasio $\text{H}_2\text{O}_2/\text{FeSO}_4$ sebesar 3:1, dan waktu reaksi optimal 40,123 menit. Optimasi oksidasi Fenton terbukti meningkatkan biodegradabilitas dan menurunkan parameter polutan lainnya. Selain itu, lumpur besi ($\text{Fe}(\text{OH})_3$) hasil samping dapat diaktivasi dan dimanfaatkan sebagai substitusi reagen FeSO_4 , mendukung konsep pemanfaatan sirkular (*circular use*) dan ekonomi sirkular (*circular economy*). Analisis hidrodinamika, kinetika reaksi, serta pembahasan kimia mendalam memperkuat pemahaman mekanisme proses. Dari sisi ekonomi lingkungan, nilai OPEX dan BCR menunjukkan bahwa skema oksidasi Fenton layak diterapkan. Keseluruhan temuan menegaskan bahwa optimasi oksidasi Fenton berbasis statistik dengan pendekatan analisis lingkungan merupakan solusi efektif dan efisien untuk pengolahan air limbah farmasi, sekaligus berkontribusi pada pengembangan teknologi ramah lingkungan di sektor industri.

Kata Kunci: *Advanced Oxidation Process* (AOP), Oksidasi Fenton, *Response Surface Methodology* (RSM), Optimasi Analisis Lingkungan, Ekonomi Sirkular

ABSTRACT

The pharmaceutical industry generates wastewater containing complex micropollutants that are difficult to degrade biologically, posing a potential risk of environmental contamination. Conventional treatment plants have proven ineffective, particularly against resistant compounds characterized by low BOD/COD ratios. This study aimed to optimize H₂O₂ dosage, FeSO₄ dosage, and reaction time within the Fenton oxidation process to enhance pharmaceutical wastewater treatment efficiency. Optimization was conducted using Response Surface Methodology (RSM) with a Central Composite Design (CCD), alongside statistical and environmental analyses to evaluate factor effects and variable interactions. Tested parameters included BOD, COD, TSS, total-N, phenol, and pH, benchmarked against national regulatory standards. Results indicated optimal conditions of 303.231 mmol/L for H₂O₂ dosage, a 3:1 H₂O₂/FeSO₄ ratio, and a reaction time of 40.123 minutes. Fenton oxidation optimization was shown to improve biodegradability and reduce other pollutant parameters. Furthermore, the iron sludge (Fe(OH)₃) byproduct could be activated and utilized as a substitute for FeSO₄ reagent, supporting concepts of circular use and the circular economy. Analyses of hydrodynamics, reaction kinetics, and chemical mechanisms deepened the understanding of the process. From an environmental-economic perspective, OPEX and BCR values demonstrated the feasibility of implementing the Fenton oxidation scheme. Overall, the findings confirm that statistically optimized Fenton oxidation, combined with an environmental analysis approach, offers an effective and efficient solution for pharmaceutical wastewater treatment while contributing to the development of eco-friendly technologies in the industrial sector.

Keywords: *Advanced Oxidation Process (AOP), Fenton Oxidation, Response Surface Methodology (RSM), Environmental Analysis Optimization, Circular Economy*

BAB I

PENDAHULUAN

1.1. Latar Belakang

Secara global, produksi atau pabrikasi produk farmasi memainkan peran penting di bidang kesehatan serta mendukung kesejahteraan masyarakat, terutama melalui penyediaan kebutuhan akan produk farmasi. Adanya potensi yang menjanjikan mendukung produksi atau pabrikasi produk farmasi di Indonesia kian berkembang, pernyataan ini didukung dengan adanya peningkatan kebutuhan akan produk farmasi serta dukungan dari pemerintah yang menjadikan sektor perangkat medis dan farmasi sebagai bagian dari sektor prioritas (Kementerian Investasi dan Hilirisasi, 2021). Menurut data dari Kementerian Kesehatan hingga tahun 2021, terdapat 241 industri farmasi, 17 industri bahan baku farmasi, 132 industri farmasi tradisional, dan 18 industri ekstraksi produk alami (Kementerian Investasi dan Hilirisasi, 2021). Dalam beberapa tahun terakhir, penerapan operasi ramah lingkungan dengan prioritas berupa kesadaran lingkungan dan operasi berkelanjutan telah menjadi fokus utama industri farmasi. Fokus pada penerapan operasional dengan pendekatan pengolahan untuk menangani air limbah industri farmasi menjadi salah satu fokus utama disamping pengurangan penggunaan air selama proses produksi (Sim et al., 2024). Air limbah industri farmasi memiliki kandungan senyawa kimia beracun yang dapat mencemari lingkungan serta mengancam kesehatan makhluk hidup disekitar area air yang tercemar. Beberapa bukti nyata dari pencemaran air limbah industri farmasi yang terdapat pada studi terdahulu antara lain ikan yang tercemar diklofenak disekitar instalasi pengolahan air limbah suatu industri farmasi, zat antibiotik yang memberi dampak buruk bagi bakteri dalam pengolahan lumpur aktif dan nitrifikasi, tercemarnya biomassa alga dan struktur komunitasnya, serta dampak terhadap rantai makanan yang ditimbulkan oleh berkurangnya bakteri akibat pencemaran air limbah industri farmasi (Kavianpour et al., 2024).

Kandungan polutan dalam air limbah industri farmasi merupakan mikropolutan atau *emerging pollutants* (S. R. Qasim & Zhu, 2017). Instalasi

pengolahan air limbah konvensional tidak dirancang dan tidak sepenuhnya mampu menghilangkan mikropolutan dalam air limbah industri farmasi, studi menunjukkan bahwa efisiensi remediasi untuk zat farmasi berupa karbamazepin, atenolol, asam asetilsalisilat, diklofenak, asam mefenamat, propranolol, atenolol, asam klofibrat, dan linkomisin hanya memiliki kisaran efisiensi remediasi sebesar 10% (Patel et al., 2019; Pratiwi et al., 2025). Hal tersebut mengakibatkan pelepasan atau pembuangan air limbah industri farmasi yang tidak terolah secara sempurna ke badan air berpotensi menimbulkan dampak negatif bagi lingkungan, permasalahan ini berpotensi diperparah lebih lagi pada saat cuaca hujan lebat dan/atau terdapat limpasan gabungan saluran pembuangan (Munro et al., 2015; Yun et al., 2023). Air limbah industri farmasi memiliki karakteristik fisik, kimia, dan biologis. Karakteristik dari air limbah industri farmasi memiliki kelarutan, kemampuan adsorpsi, volatilitas, biodegradabilitas, polaritas, dan stabilitas zat farmasi yang sangat bervariasi, serta keberadaannya yang dapat aktif pada konsentrasi yang sangat rendah (ng/L - µg/L) (Patel et al., 2019; Pratiwi et al., 2025). Kadar kebutuhan oksigen kimiawi atau *chemical oxygen demand* (COD) yang tinggi serta kadar kebutuhan oksigen biologis atau *biochemical oxygen demand* (BOD) yang rendah menimbulkan tantangan bagi metode pengolahan air limbah industri farmasi secara biologis. Rendahnya rasio BOD/COD (akibat kadar COD yang tinggi dan kadar BOD yang rendah) ini disebabkan oleh keberadaan zat-zat resisten dalam air limbah industri farmasi yang menghambat pematangan mikroorganisme, kandungan senyawa organik kompleks yang sukar terurai oleh mikroorganisme, serta toksisitas senyawa yang menghambat aktivitas mikroorganisme sehingga proses penguraian menjadi kurang efektif (Pratiwi et al., 2025; Zaman et al., 2024).

Mengacu pada dasar yang telah diuraikan, timbul suatu urgensi pengolahan air limbah industri farmasi yang tepat dengan mempertimbangkan karakteristik serta konsentrasi yang bervariasi untuk meminimalisir pencemaran lingkungan di sekitar industri farmasi, utamanya dalam sektor perairan. Kemajuan teknologi pada beberapa tahun terakhir menunjukkan bahwa *Advanced Oxidation Process* (AOP) efektif dalam mendegradasi senyawa kompleks dan resisten. Selain itu, teknologi ini juga mampu mengurai polutan penghambat, seperti polutan dengan tingkat

konsentrasi yang sangat rendah dan bersifat toksik (Iqbal et al., 2024; Thakur et al., 2023; Zaman et al., 2024). Salah satu contoh penerapan *Advanced Oxidation Process* (AOP) dalam pengolahan air limbah industri farmasi adalah integrasi teknologi kimia murni dengan proses oksidasi Fenton, yang melibatkan reaksi antara Fe^{2+} dan H_2O_2 (Mousset et al., 2021; Thakur et al., 2023). Proses oksidasi Fenton akan menghasilkan radikal hidroksil ($\bullet\text{OH}$) dari reaksi katalis Fe^{2+} dalam bentuk FeSO_4 dan oksidator H_2O_2 yang akan bereaksi memecah kandungan senyawa organik kompleks dan berpotensi untuk mineralisasi air serta kadar karbondioksida (CO_2) dalam air (Huilin et al., 2025; Mahtab et al., 2022). Dalam proses oksidasi Fenton, penggunaan FeSO_4 dan H_2O_2 tidak terlepas dari waktu reaksi yang dibutuhkan selama proses reaksi berjalan, ketiga faktor atau variabel ini memiliki *range* atau rentang yang sangat luas. Berdasarkan kajian literatur, penelitian, dan studi terdahulu menunjukkan bahwa variasi dosis FeSO_4 , dosis H_2O_2 , dan waktu reaksi dalam metode oksidasi Fenton untuk pengolahan air limbah industri farmasi masih sangat beragam (Ayoub, 2022; Durai et al., 2020; Huilin et al., 2025; Nasruddin et al., 2020; Rekhate & J. K, 2019; Sarkale et al., 2025; Wagdy et al., 2022), namun belum terdapat titik temu mengenai kombinasi optimal yang mampu memberikan efisiensi penyisihan yang tinggi dengan biaya yang minimal untuk studi kasus pengolahan air limbah industri farmasi. Adapun salah satu cara untuk mendapatkan kombinasi yang optimal ialah menggunakan penerapan optimasi *Response Surface Methodology* (RSM), namun penggunaan metode ini masih sangat terbatas dalam konteks pengolahan air limbah industri farmasi, padahal metode ini dapat memberikan pendekatan sistematis untuk menentukan kombinasi yang optimal (Huilin et al., 2025). Oleh karena itu, diperlukan adanya studi yang berfokus pada optimasi dosis serta waktu reaksi menggunakan metode *Response Surface Methodology* (RSM) guna meningkatkan efisiensi dan efektifitas pengolahan air limbah industri farmasi.

Apabila mengkaji dari studi peneliti terdahulu, berbagai penelitian melaporkan dosis optimal FeSO_4 dan H_2O_2 yang bervariasi, serta waktu reaksi, tergantung pada jenis air limbah dan pengaturan eksperimen yang dilakukan (Huilin et al., 2025; Öztürk et al., 2025; H. Xu et al., 2015). Studi lain juga menunjukkan

adanya dosis FeSO_4 dan H_2O_2 yang optimal, serta waktu reaksi, yang sangat bervariasi di berbagai penelitian, menunjukkan kurangnya standardisasi atau konsensus untuk pengolahan air limbah farmasi sesuai kondisi nyata di lapangan (Huilin et al., 2025; Lalwani et al., 2021). Meskipun oksidasi Fenton telah diterapkan pada berbagai jenis air limbah (misalnya, tekstil, *pulp* dan kertas, serta lindi tempat pembuangan sampah), hanya sedikit penelitian yang secara khusus membahas air limbah farmasi yang representatif. Banyak penelitian menggunakan air limbah simulasi atau yang telah diolah sebelumnya (telah melalui proses *pre-treatment*), yang mungkin tidak sepenuhnya mewakili kompleksitas limbah farmasi (C. Li et al., 2021; Sharma et al., 2017; Yong et al., 2026). Apabila dilihat dari sudut pandang penerapan optimasi *Response Surface Methodology* (RSM), nampak pada beberapa studi bahwa model dan parameternya bervariasi, dimana beberapa penelitian menggunakan model kuadratik, sementara yang lain menggunakan *Central Composite Design* (CCD). Inkonsistensi ini mempersulit perbandingan langsung dan generalisasi (Lalwani et al., 2021; Sharma et al., 2017; H. Xu et al., 2015). Studi oleh Limonti et al. (2026) juga menyatakan bahwa pembentukan dan pengelolaan lumpur tetap menjadi tantangan signifikan dalam proses oksidasi Fenton, khususnya untuk air limbah farmasi. Dari beberapa celah penelitian terdahulu yang telah dibahas ini, penelitian yang akan dilakukan akan mempertimbangkan aspek representasi air limbah industri farmasi yang nyata, dengan pelaporan dosis serta waktu reaksi yang transparan untuk meningkatkan aspek reproduksibilitas. Penelitian ini juga akan mempertimbangkan aspek lingkungan, dimana lumpur yang dihasilkan akan dianalisis untuk meminimalisir dampaknya terhadap lingkungan. Aplikasi optimasi *Response Surface Methodology* (RSM) metode *Central Composite Design* (CCD) yang akan digunakan akan dilaporkan dengan jelas, dengan mempertimbangkan aspek transparansi dan reproduksibilitas untuk meminimalisir inkonsistensi pada celah penelitian sebelumnya. Pengembangan optimasi dasar oksidasi Fenton ini juga didukung oleh teori dalam buku pedoman oleh Tchobanoglous et al. (2014) yang menyatakan bahwa peningkatan kinerja instalasi pengolahan dapat dilakukan melalui optimasi proses dan/atau perubahan operasional, dimana dari teori yang disampaikan,

penelitian ini mendukung aspek penerapan metode model komputer (*computer models*) dan dapat dijadikan salah satu contoh pedoman pengujian skala percontohan (*pilot scale testing*). Dengan diterapkannya metode oksidasi Fenton dengan optimasi *Response Surface Methodology* (RSM) untuk dosis FeSO_4 , dosis H_2O_2 , serta waktu reaksi diharapkan penelitian ini dapat memberi referensi variasi yang optimal untuk penerapan atau aplikasi metode oksidasi Fenton dalam mengolah air limbah industri farmasi yang efektif dan efisien. Pertimbangan efisiensi dan efektifitas penyisihan polutan, pemenuhan baku mutu, dan mengkaji dari sudut pandang aspek lingkungan akan menjadi pertimbangan mendasar dalam optimasi *Response Surface Methodology* (RSM) untuk variasi dosis FeSO_4 , dosis H_2O_2 , dan waktu reaksi pada penelitian ini.

1.2. Identifikasi Masalah

Berdasarkan permasalahan yang melatarbelakangi penelitian ini, dapat diidentifikasi masalah yang dijabarkan sebagai berikut.

1. Produksi atau pabrikasi produk farmasi yang menghasilkan produk samping berupa air limbah. Air limbah industri farmasi memiliki berpotensi mencemari lingkungan apabila tidak diolah dengan tepat.
2. Karakteristik dan konsentrasi air limbah industri farmasi yang berbeda dengan air limbah pada umumnya, sehingga membutuhkan metode pengolahan yang lebih spesifik.
3. Tidak terbatasnya variasi dosis FeSO_4 dan H_2O_2 , serta waktu reaksi sehingga dibutuhkan adanya optimasi dosis dan waktu reaksi untuk meningkatkan efisiensi dan efektivitas proses pengolahan air limbah industri farmasi menggunakan metode oksidasi Fenton.
4. Hasil pengolahan air limbah industri farmasi yang mempertimbangkan efisiensi dan efektifitas penyisihan polutan serta pemenuhan baku mutu sesuai regulasi yang berlaku.
5. Analisis aspek lingkungan yang masih minim, dengan produk sampingan pengolahan Fenton yaitu lumpur besi yang berpotensi mencemari lingkungan.

1.3. Rumusan Masalah

Berdasarkan identifikasi masalah dari penelitian ini, dapat dirumuskan permasalahan yang dijabarkan sebagai berikut.

1. Apa metode pengolahan air limbah industri farmasi yang tepat untuk meminimalisir potensi pencemaran lingkungan di sekitar industri farmasi?
2. Bagaimana metode oksidasi Fenton dapat mengolah air limbah industri farmasi dengan mempertimbangkan karakteristik dan konsentrasi air limbah yang representatif?
3. Apa metode optimasi dan bagaimana optimasi dosis FeSO_4 , dosis H_2O_2 , serta waktu reaksi untuk meningkatkan efisiensi dan efektifitas proses pengolahan air limbah industri farmasi menggunakan metode oksidasi Fenton?
4. Bagaimana hasil pengolahan air limbah industri farmasi menggunakan metode oksidasi Fenton setelah dioptimasi apabila ditinjau dari penyisihan polutan serta pemenuhan baku mutu yang berlaku?
5. Bagaimana analisis dari aspek lingkungan untuk memaksimalkan proses oksidasi Fenton yang dilakukan dan meminimalisir potensi dampak atau pencemaran lingkungan yang ada?

1.4. Rumusan Tujuan

Berdasarkan perumusan masalah dari penelitian ini, dapat dirumuskan tujuan yang dijabarkan sebagai berikut.

1. Mengetahui dan menerapkan metode pengolahan air limbah industri farmasi yang tepat untuk meminimalisir potensi pencemaran lingkungan di sekitar industri farmasi.
2. Mengidentifikasi dan menganalisis metode oksidasi Fenton yang diterapkan dalam mengolah air limbah industri farmasi dengan mempertimbangkan karakteristik dan konsentrasi air limbah yang representatif.
3. Mengetahui dan menerapkan metode optimasi variasi dosis FeSO_4 , dosis H_2O_2 , dan waktu reaksi dalam metode oksidasi Fenton; mengidentifikasi dan menganalisis optimasi dosis FeSO_4 , dosis H_2O_2 , serta waktu reaksi

untuk meningkatkan efisiensi dan efektifitas proses pengolahan air limbah industri farmasi menggunakan metode oksidasi Fenton.

4. Mengidentifikasi dan menganalisis hasil pengolahan air limbah industri farmasi menggunakan metode oksidasi Fenton setelah dioptimasi apabila ditinjau dari penyisihan polutan serta pemenuhan baku mutu yang berlaku.
5. Menganalisis dari aspek lingkungan untuk memaksimalkan proses oksidasi Fenton yang dilakukan dan meminimalisir potensi dampak atau pencemaran lingkungan yang ada.

1.5. Pembatasan Masalah

Pembatasan masalah memiliki tujuan agar poin bahasan dalam penelitian menjadi jelas, terstruktur, serta tidak melebar. Berdasarkan perumusan tujuan dari penelitian ini, terdapat pembatasan masalah yang dijabarkan sebagai berikut.

1. Ruang lingkup penelitian ini adalah pengolahan air limbah industri farmasi dari salah satu perusahaan atau industri farmasi yang berlokasi di Kota Semarang, Jawa Tengah, Indonesia dengan penerapan *Advanced Oxidation Process* (AOP) metode oksidasi Fenton.
2. Pengambilan sampel air limbah industri farmasi dilakukan pada salah satu perusahaan atau industri farmasi yang berlokasi di Kota Semarang, Jawa Tengah, Indonesia.
3. Metode oksidasi Fenton yang diterapkan menggunakan FeSO_4 sebagai katalis dan H_2O_2 sebagai oksidator dengan variasi dosis dan waktu reaksi yang akan diidentifikasi dan dianalisis berdasarkan literatur untuk mencari variasi optimal.
4. Identifikasi dan analisis variasi dosis FeSO_4 , dosis H_2O_2 , serta waktu reaksi menerapkan optimasi *Response Surface Methodology* (RSM) metode *Central Composite Design* (CCD) menggunakan *software* Design Expert Version 13, akan dilakukan analisis varians (ANOVA atau *analysis of variance*) dengan *software* yang sama.
5. Analisis data akan dilakukan menggunakan *software* Design Expert Version 13, Microsoft Excel, Microsoft Word, dan Google Spreadsheet.

6. Parameter air limbah industri farmasi yang akan diidentifikasi dan dianalisis meliputi parameter *biochemical oxygen demand* (BOD), *chemical oxygen demand* (COD), *total suspended solid* (TSS), total nitrogen, fenol, dan pH. Parameter dipilih berdasarkan baku mutu air limbah bagi usaha dan/atau kegiatan industri farmasi yang berlaku.
7. Prototipe reaktor skala laboratorium berupa alat *jar test* dengan media atau wadah berupa *beaker glass* Herma berkapasitas 1.000 mL atau 1 L akan digunakan dalam penelitian ini dengan tujuan sebagai media pengujian dan melaksanakan eksperimen metode oksidasi Fenton.
8. Pengujian laboratorium akan dilaksanakan pada Laboratorium Teknik Lingkungan, Fakultas Teknik, Universitas Diponegoro, Semarang.
9. Baku mutu yang digunakan sebagai pembanding dan acuan keberhasilan pengolahan air limbah industri farmasi adalah Peraturan Menteri Lingkungan Hidup Nomor 5 Tahun 2014 tentang Baku Mutu Air Limbah, Lampiran XXXIX tentang Baku Mutu Air Limbah Bagi Usaha dan/atau Kegiatan Industri Farmasi; dan Peraturan Pemerintah Republik Indonesia Nomor 22 Tahun 2021 tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup, Lampiran VI tentang Baku Mutu Air Nasional.
10. Analisis yang dilakukan akan menerapkan analisis statistik, analisis kimia dan fisika, serta analisis lingkungan untuk membahas hasil optimasi oksidasi Fenton lebih lanjut. Dasar analisis yang akan diterapkan dilakukan berdasarkan hasil pengujian dan dalam skala laboratorium untuk memberi gambaran pada studi skala nyata kedepannya.

1.6. Keaslian Penelitian

Advanced Oxidation Process (AOP) dengan penerapan metode oksidasi Fenton telah banyak digunakan untuk mengolah air limbah, terutama dengan karakteristik yang kompleks sehingga tidak memungkinkan diolah pada instalasi pengolahan air limbah konvensional. Penelitian ini dikembangkan dengan menerapkan optimasi *Response Surface Methodology* (RSM) metode *Central Composite Design* (CCD) dengan pertimbangan aspek lingkungan. Tesis ini

berjudul “Optimasi Variasi Dosis dan Waktu Reaksi dalam Metode Oksidasi Fenton untuk Pengolahan Air Limbah Industri Farmasi” dan merupakan karya penulis sendiri, segala referensi, kutipan, rujukan, serta literatur yang digunakan telah tercantum dalam daftar pustaka sebagai bentuk pemberian kredit bagi penulis asli karya terkait.

1.7. Rumusan Manfaat

Penelitian ini diharapkan dapat memberi manfaat baik bagi pihak internal maupun eksternal. Pihak internal yang terkait dengan penelitian secara langsung meliputi penulis sendiri, sedangkan pihak eksternal meliputi pembaca, perkembangan ilmu pengetahuan, masyarakat, pemerintah, serta bangsa dan negara secara luas.

1. Bagi Penulis

Dengan adanya penelitian ini, penulis dapat memperoleh wawasan terkait pengolahan air limbah industri farmasi menggunakan metode optimasi oksidasi Fenton serta dapat mengaplikasikan ilmu yang telah diperoleh di dunia perkuliahan secara langsung. Penelitian ini juga dibuat untuk memenuhi tahap penyelesaian tesis sebagai syarat kelulusan gelar magister.

2. Bagi Pembaca

Menjadi referensi mengenai karakteristik dan konsentrasi air limbah industri farmasi, optimasi *Response Surface Methodology* (RSM) metode *Central Composite Design* (CCD), pengolahan metode oksidasi Fenton dengan variasi dosis dan waktu reaksi yang dioptimasi, serta aplikasi analisis mendalam dengan pertimbangan sudut pandang aspek lingkungan.

3. Bagi Perkembangan Ilmu Pengetahuan

Penelitian ini digunakan untuk memberikan referensi dalam pengolahan air limbah, serta memberikan referensi studi kasus salah satu penerapan metode optimasi di bidang lingkungan terkhusus pada pengolahan air limbah industri farmasi dengan metode oksidasi Fenton yang dioptimasi menggunakan *Response Surface Methodology* (RSM) metode

Central Composite Design (CCD) dengan analisis lebih lanjut yang mempertimbangkan aspek lingkungan.

4. Bagi Masyarakat

Manfaat penelitian bagi masyarakat ialah dapat menjadi salah satu opsi pengolahan air limbah yang lebih spesifik, terutama bagi industri pabrikan produk farmasi guna meminimalisir dampak lingkungan di sekitar lokasi industri dan dampak terhadap masyarakat secara langsung maupun tidak langsung.

5. Bagi Pemerintah

Penelitian dapat diterapkan sebagai referensi dalam mengambil kebijakan pada hal pengendalian pencemaran air limbah industri farmasi, utamanya menggunakan variasi dosis dan waktu reaksi metode oksidasi Fenton yang dioptimasi, serta menjadi referensi untuk memajukan industri farmasi nasional dengan meningkatkan daya saing di bidang pengelolaan dan pengendalian lingkungan.

6. Bagi Bangsa dan Negara Secara Luas

Penelitian ini bermanfaat bagi bangsa dan negara secara luas dengan mendukung pelestarian lingkungan melalui pengolahan limbah industri farmasi dengan penerapan metode oksidasi Fenton. Diharapkan penelitian ini dapat mendukung keberlanjutan sumber daya air dan mendorong inovasi pengelolaan limbah yang sejalan dengan kebijakan lingkungan dan daya saing industri nasional.

DAFTAR PUSTAKA

- A. R. Gokul, & M. Pachamuthu. (2024). *A GRAPHICAL STUDY ON THE MISSING DATA OF CENTRAL COMPOSITE DESIGN WITHIN A SPHERICAL REGION*. <https://doi.org/10.24412/1932-2321-2024-480-228-239>
- Aanchal, Akhtar, N., Kanika, Goyal, D., & Goyal, A. (2016). Response surface methodology for optimization of microbial cellulase production. *Romanian Biotechnological Letters*, 21(5), 11832–11841.
- Abd Alateef, Z. A. A., Alemam Jyad, F. A., Faroon, M. A., & Ahmed Hamdan, A. N. (2024). Initial turbidity, pH, dosage of alum and paddles type optimization of efficiency removal by using response surface methods (RSM). *International Journal of Applied Science and Engineering*, 21(1), 1–9. [https://doi.org/10.6703/IJASE.202403_21\(1\).010](https://doi.org/10.6703/IJASE.202403_21(1).010)
- Abdelfattah, I., Abuarab, M. E., Mostafa, E., El-Awady, M. H., Aboelghait, K. M., & El-Shamy, A. M. (2023). Integrated system for recycling and treatment of hazardous pharmaceutical wastewater. *International Journal of Environmental Science and Technology*, 20(4), 4101–4110. <https://doi.org/10.1007/s13762-022-04269-7>
- Abedinzadeh, N., Shariat, M., Monavari, S. M., & Pendashteh, A. (2018). Evaluation of color and COD removal by Fenton from biologically (SBR) pre-treated pulp and paper wastewater. *Process Safety and Environmental Protection*, 116, 82–91. <https://doi.org/10.1016/j.psep.2018.01.015>
- Adnan, F., Meicahayanti, I., & Singgih, M. (2023). Foto Fenton UVC dengan Menggunakan H₂O₂/FeSO₄ dalam Mendegradasi Variasi pH dan Konsentrasi Asam Humat. *Jurnal Rekayasa Tropis, Teknologi, dan Inovasi (RETROTEKIN)*, 1(1), 1–7.
- Affam, A. C., Ezechi, E. H., & Chaudhuri, M. (2020). Classical Fenton and Sequencing Batch Reactor Treatment of Pesticide Wastewater: In A. C. Affam & E.

H. Ezechi (Eds.), *Advances in Environmental Engineering and Green Technologies* (pp. 373–403). IGI Global. <https://doi.org/10.4018/978-1-7998-0369-0.ch016>

Afolabi, O. A., Adekalu, K. O., & Okunade, D. A. (2022). Electro-Fenton treatment process for brewery wastewater: Effects of oxidant concentration and reaction time on BOD and COD removal efficiency. *Journal of Engineering and Applied Science*, 69(1), 42. <https://doi.org/10.1186/s44147-022-00089-1>

Ahile, U. J., Wuana, R. A., Itodo, A. U., Sha'Ato, R., Malvestiti, J. A., & Dantas, R. F. (2021). Stability and efficiency of Fe³⁺ EDDS complex for the treatment of secondary effluent in the photo-Fenton process. *Desalination and Water Treatment*, 222, 366–374. <https://doi.org/10.5004/dwt.2021.27081>

Ahmed, N., Vione, D., Rivoira, L., Carena, L., Castiglioni, M., & Bruzzoniti, M. C. (2021). A Review on the Degradation of Pollutants by Fenton-Like Systems Based on Zero-Valent Iron and Persulfate: Effects of Reduction Potentials, pH, and Anions Occurring in Waste Waters. *Molecules*, 26(15), 4584. <https://doi.org/10.3390/molecules26154584>

Ahn, H. (2015). Central Composite Design for the Experiments with Replicate Runs at Factorial and Axial Points. In M. Gen, K. J. Kim, X. Huang, & Y. Hiroshi (Eds.), *Industrial Engineering, Management Science and Applications 2015* (Vol. 349, pp. 969–979). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-47200-2_101

Ai, S., Yang, S., Sun, X., Wang, F., Zhang, Y., Zhang, H., & Bian, D. (2024). Experimental study on the treatment of high COD metal degreasing cleaning wastewater by coagulation and two-stage Fenton oxidation. *Water Science & Technology*, 90(9), 2572–2584. <https://doi.org/10.2166/wst.2024.350>

Akbari, M., Nasiri, M., Arabian, D., & Sadeghi, R. (2025). Removal of COD from spent caustic wastewater of the Merox Unit—Bandar Abbas Oil Refinery using a combined Sono-electrocoagulation treatment system. *Desalination and Water Treatment*, 322, 101162. <https://doi.org/10.1016/j.dwt.2025.101162>

Alam, Mohd. G., Danish, M., Alanazi, A. M., Ahmad, T., & Khalil H.P.S., A. (2023). Response surface methodology approach of phenol removal study using high-quality activated carbon derived from H₃PO₄ activation of Acacia mangium wood. *Diamond and Related Materials*, 132, 109632. <https://doi.org/10.1016/j.diamond.2022.109632>

Alkian, I., Hadiyanto, Hafni, A. K., Dalanta, F., Azzahra, G., Ilsahtam, M. I., Zhihao, Y., Zou, Y., Goei, R., Tok, A. I. Y., & Sutanto, H. (2023). Developing a robust treatment of antibiotics removal using Bi₂O₃/Cdots synthesized via microwave-assisted precipitation optimized by central composite design. *Materials Chemistry and Physics*, 310, 128456. <https://doi.org/10.1016/j.matchemphys.2023.128456>

American Water Chemicals. (n.d.). Advanced Oxidation Process. *Membranechemicals.Com*. Retrieved <https://www.membranechemicals.com/water-treatment/advanced-oxidation-plants/>

An, Z., Han, D., Sun, J., Mei, Q., Wei, B., Li, M., Qiu, Z., Bo, X., Wang, X., Xie, J., Zhan, J., & He, M. (2021). Full insights into the roles of pH on hydroxylation of aromatic acids/bases and toxicity evaluation. *Water Research*, 190, 116689. <https://doi.org/10.1016/j.watres.2020.116689>

Andersson, A. (2021). Publisher Correction: Mechanisms for log normal concentration distributions in the environment. *Scientific Reports*, 11(1), 18075. <https://doi.org/10.1038/s41598-021-97822-2>

Andrade, C. (2022). The Practical Importance of Half-Life in Psychopharmacology. *The Journal of Clinical Psychiatry*, 83(4). <https://doi.org/10.4088/JCP.22f14584>

Anil Kumar, K., Shrivastava, S., Tabassum, A., Roy, S., Raikwar, R., Katore, I., Ashok Kumar, S., & Sharma, S. (2023). Optimization for Removal of COD and BOD through RSM-CCD by Activated Sludge Treatment Process for Pharmaceutical Wastewater. *Journal of Environmental Nanotechnology*, 12(4), 68–86. <https://doi.org/10.13074/jent.2023.12.234486>

Anjana Anand, A. S., Adish Kumar, S., Rajesh Banu, J., & Ginni, G. (2016). The performance of fluidized bed solar photo Fenton oxidation in the removal of COD from hospital wastewaters. *Desalination and Water Treatment*, 57(18), 8236–8242. <https://doi.org/10.1080/19443994.2015.1021843>

Anwer, M., Shaikh, M. A. N., Khan, S. U., Mirkhalafi, S., Mahtab, M. S., Farooqi, I. H., Ayub, S., & Dehghani, M. H. (2025). Response surface modelling of Fenton pre-treatment of slaughterhouse sludge for enhanced anaerobic digestion. *Scientific Reports*, 15(1), 31584. <https://doi.org/10.1038/s41598-025-02731-3>

Ao, X., Eloranta, J., Huang, C.-H., Santoro, D., Sun, W., Lu, Z., & Li, C. (2021). Peracetic acid-based advanced oxidation processes for decontamination and disinfection of water: A review. *Water Research*, 188, 116479. <https://doi.org/10.1016/j.watres.2020.116479>

Apaydin, Ö., Kurt, U., & İlhan, F. (2023). Investigation of the synergistic effect of the Fenton process on the paint industry wastewater treatment and optimization of independent process parameters. *Desalination and Water Treatment*, 308, 68–79. <https://doi.org/10.5004/dwt.2023.29926>

Arinobu, N., Maki, R., Ogawa, T., Fujii, T., & Kusano, Y. (2025). Preparation of Lepidocrocite and Maghemite by the Addition of Calcite to Iron(II) Chloride Solutions. *Journal of the Japan Society of Powder and Powder Metallurgy*, 72(Supplement), S1505–S1508. <https://doi.org/10.2497/jjspm.16P-T10-07>

Asadi, N., & Zilouei, H. (2017). Optimization of organosolv pretreatment of rice straw for enhanced biohydrogen production using *Enterobacter aerogenes*. *Bioresource Technology*, 227, 335–344. <https://doi.org/10.1016/j.biortech.2016.12.073>

Asghar, A., Ramzan, N., Jamal, B. U., Maqsood, M., Sajjadi, B., & Chen, W. (2020). Low frequency ultrasonic-assisted Fenton oxidation of textile wastewater: Process optimization and electrical energy evaluation. *Water and Environment Journal*, 34(4), 523–535. <https://doi.org/10.1111/wej.12482>

Ayoub, M. (2022). Fenton process for the treatment of wastewater effluent from the edible oil industry. *Water Science and Technology*, 86(6), 1388–1401. <https://doi.org/10.2166/wst.2022.283>

Azizi, S., Valipour, A., Jamshidi, S., & Sithebe, T. (2015). Performance evaluation of the electrolysis process for waste sludge stabilization in decentralization practices. *Desalination and Water Treatment*, 54(3), 616–623. <https://doi.org/10.1080/19443994.2014.886293>

Azorín-Nieto, J., Furetta, C., Ortiz-Martínez, E., & Azorin-Vega, C. (2022). Calculation of the half life for the thermoluminescent signal of Beryllium oxide. *Applied Radiation and Isotopes*, 186, 110291. <https://doi.org/10.1016/j.apradiso.2022.110291>

Badan Standardisasi Nasional. (2004). Air dan air limbah – Bagian 21: Cara uji kadar fenol secara spektrofotometri. In *SNI 06-6989.21-2004*. Badan Standardisasi Nasional.

Badan Standardisasi Nasional. (2009). Air dan air limbah – Bagian 72: Cara uji kebutuhan oksigen biokimia (Biochemical Oxygen Demand/BOD). In *SNI 6989.72:2009*. Badan Standardisasi Nasional.

Badan Standardisasi Nasional. (2019a). Air dan air limbah – Bagian 2: Cara uji kebutuhan oksigen kimiawi (Chemical Oxygen Demand/COD) dengan reflus tertutup secara spektrofotometri. In *SNI 6989.2:2019*. Badan Standardisasi Nasional.

Badan Standardisasi Nasional. (2019b). Air dan air limbah – Bagian 3: Cara uji padatan tersuspensi total (Total Suspended Solids/TSS) secara gravimetri. In *SNI 6989.3:2019*. Badan Standardisasi Nasional.

Badan Standardisasi Nasional. (2019c). Air dan air limbah – Bagian 11: Cara uji derajat keasaman (pH) dengan menggunakan pH meter. In *SNI 6989.11:2019*. Badan Standardisasi Nasional.

Bahadur, N., Bhargava, N., Sarkar, S. K., & Dhawan, V. (2023). Breakthrough in Treatment of Sewage Using TADOX®, By-Passing Biological Treatment with removal of Micropollutants to enable high end Water Reuse. *Journal of The Institution of Engineers (India): Series A*, 104(3), 541–550. <https://doi.org/10.1007/s40030-023-00738-5>

Bain, K., Rodriguez, J.-M. G., & Towns, M. H. (2019). Investigating Student Understanding of Rate Constants: When is a Constant “Constant”? *Journal of Chemical Education*, 96(8), 1571–1577. <https://doi.org/10.1021/acs.jchemed.9b00005>

Baird, J. K., & Lang, J. R. (2017). Theory of First Order Chemical Kinetics at the Critical Point of Solution. *The Journal of Physical Chemistry A*, 121(42), 8048–8052. <https://doi.org/10.1021/acs.jpca.7b07635>

Balai Pengujian Standar Instrumen Tanah dan Pupuk. (2023). *Petunjuk teknis analisis kimia tanah, tanaman, air, dan pupuk* (3rd ed.). Kementerian Pertanian Republik Indonesia.

Barr, L., Conrad, J. K., McGregor, C., Perron, R., Yakabuskie, P. A., & Stuart, C. R. (2024). Kinetics of the reaction of ferrous ions with hydroxyl radicals in the temperature range 25–300 °C. *Physical Chemistry Chemical Physics*, 26(5), 4278–4283. <https://doi.org/10.1039/D3CP03819J>

Bartrum, E. A., & Karp, B. I. (2018). Writing a Protocol. In *Principles and Practice of Clinical Research* (pp. 219–229). Elsevier. <https://doi.org/10.1016/B978-0-12-849905-4.00016-2>

Baschieri, A., Jin, Z., & Amorati, R. (2023). Hydroperoxyl radical (HOO[•]) as a reducing agent: Unexpected synergy with antioxidants. A review. *Free Radical Research*, 57(2), 115–129. <https://doi.org/10.1080/10715762.2023.2212121>

Baştürk, E., & Alver, A. (2019). Modeling azo dye removal by sono-fenton processes using response surface methodology and artificial neural network

approaches. *Journal of Environmental Management*, 248, 109300. <https://doi.org/10.1016/j.jenvman.2019.109300>

Bayar, S., Massara, T. M., Boncukcuoglu, R., Komesli, O. T., Malamis, S., & Katsou, E. (2018). Advanced treatment of industrial wastewater from pistachio processing by Fenton process. *Desalination and Water Treatment*, 112, 106–111. <https://doi.org/10.5004/dwt.2018.22197>

Bazin, M. (2018). *Physiological Models in Microbiology* (M. J. Bazin & J. I. Prosser, Eds.; 1st ed.). CRC Press. <https://doi.org/10.1201/9781351075657>

Beg, S., & Rahman, Z. (2021). Central Composite Designs and Their Applications in Pharmaceutical Product Development. In S. Beg (Ed.), *Design of Experiments for Pharmaceutical Product Development* (pp. 63–76). Springer Singapore. https://doi.org/10.1007/978-981-33-4717-5_6

Bello, M. M., Abdul Raman, A. A., & Asghar, A. (2019). A review on approaches for addressing the limitations of Fenton oxidation for recalcitrant wastewater treatment. *Process Safety and Environmental Protection*, 126, 119–140. <https://doi.org/10.1016/j.psep.2019.03.028>

BenchChem Technical Support Team. (2026). *Technical Support Center: Fenton's Reaction* [Troubleshooting & Optimization]. BenchChem. https://pdf.benchchem.com/1209/Technical_Support_Center_Fenton_s_Reaction.pdf

Benítez, F. J., Melín, V., Perez-Gonzalez, G., Henríquez, A., Zarate, X., Schott, E., & Contreras, D. (2023). The ferryl generation by fenton reaction driven by catechol. *Chemosphere*, 335, 139155. <https://doi.org/10.1016/j.chemosphere.2023.139155>

Bernard, J. (2022). Can We “Show” the Correctness of Reasoning? On the Role of Diagrammatic Spatialization in Logical Justification. In L. Boi & C. Lobo (Eds.), *When Form Becomes Substance* (pp. 27–64). Springer International Publishing. https://doi.org/10.1007/978-3-030-83125-7_2

Bessioud, S., Affoune, A. M., & Chelaghmia, M. L. (2023). Investigation and optimisation of turbidity and organic matter removal from surface water by electrocoagulation using response surface methodology. *International Journal of Environmental Technology and Management*, 26(3/4/5), 360. <https://doi.org/10.1504/IJETM.2023.130801>

Bezerra, M. A., Santelli, R. E., Oliveira, E. P., Villar, L. S., & Escalera, L. A. (2008). Response surface methodology (RSM) as a tool for optimization in analytical chemistry. *Talanta*, 76(5), 965–977. <https://doi.org/10.1016/j.talanta.2008.05.019>

Bianco, B., De Michelis, I., & Vegliò, F. (2011). Fenton treatment of complex industrial wastewater: Optimization of process conditions by surface response method. *Journal of Hazardous Materials*, 186(2–3), 1733–1738. <https://doi.org/10.1016/j.jhazmat.2010.12.054>

Biglarijoo, N., Mirbagheri, S. A., Ehteshami, M., & Ghaznavi, S. M. (2016). Optimization of Fenton process using response surface methodology and analytic hierarchy process for landfill leachate treatment. *Process Safety and Environmental Protection*, 104, 150–160. <https://doi.org/10.1016/j.psep.2016.08.019>

Biglarijoo, N., & Shams, A. (2024). Multivariate modeling of the Fenton process for enhanced COD removal and low sludge generation in landfill leachate treatment. *Journal of Applied Research in Water and Wastewater*, 11(2). <https://doi.org/10.22126/arww.2025.11294.1346>

BiglariJoo, N., Shams, A., & Hadipour, V. (2025). Modeling Fenton Treatment for Landfill Leachate with the Focus on Initial COD and Sludge Generation. *Numerical Methods in Civil Engineering*, 9(3), 39–46. <https://doi.org/10.61186/NMCE.2411.1079>

BinAhmed, S., Ayoub, G., Al-Hindi, M., & Azizi, F. (2015). The effect of fast mixing conditions on the coagulation–flocculation process of highly turbid suspensions using liquid bittern coagulant. *Desalination and Water Treatment*, 53(12), 3388–3396. <https://doi.org/10.1080/19443994.2014.933043>

- Birima, A. H. (2021). The Effect of the Operational Parameters on Turbidity Removal Using Peanut Cake as Primary Coagulant. *International Journal of Design & Nature and Ecodynamics*, 16(2), 161–165. <https://doi.org/10.18280/ijдне.160205>
- Bolobajev, J., Trapido, M., & Goi, A. (2016). Interaction of tannic acid with ferric iron to assist 2,4,6-trichlorophenol catalytic decomposition and reuse of ferric sludge as a source of iron catalyst in Fenton-based treatment. *Applied Catalysis B: Environmental*, 187, 75–82. <https://doi.org/10.1016/j.apcatb.2016.01.015>
- Borba, F. H., Pellenz, L., Bueno, F., Inticher, J. J., Braun, L., Espinoza-Quiñones, F. R., Trigueros, D. E. G., De Pauli, A. R., & Módenes, A. N. (2018). Pollutant removal and biodegradation assessment of tannery effluent treated by conventional Fenton oxidation process. *Journal of Environmental Chemical Engineering*, 6(6), 7070–7079. <https://doi.org/10.1016/j.jece.2018.11.005>
- Borcher, J. E., Salo, V.-T., Golin Almeida, T., & Kjaergaard, H. G. (2026). Hydrogen Shift Reactions in Nonhydrocarbon Peroxy Radicals. *The Journal of Physical Chemistry A*, 130(6), 1375–1383. <https://doi.org/10.1021/acs.jpca.5c06832>
- Boublia, A., Lebouachera, S. E. I., Haddaoui, N., Guezzout, Z., Ghriga, M. A., Hasanzadeh, M., Benguerba, Y., & Drouiche, N. (2023). State-of-the-art review on recent advances in polymer engineering: Modeling and optimization through response surface methodology approach. *Polymer Bulletin*, 80(6), 5999–6031. <https://doi.org/10.1007/s00289-022-04398-6>
- Bowles, J. F. W. (2021). Hydroxides. In *Encyclopedia of Geology* (pp. 442–451). Elsevier. <https://doi.org/10.1016/B978-0-08-102908-4.00162-4>
- Bradley, N. (2007). *The response surface methodology* [Indiana University South Bend]. <https://scholarworks.iu.edu/iuswrrest/api/core/bitstreams/75342ee7-2d28-4629-9b96-d5d6b240b987/content>
- Bruun, N. H., Uldall Torp, N. M., & Andersen, S. L. (2025). Establishing reference interval bounds for censored and contaminated data. *The Stata Journal: Promoting*

Communications on Statistics and Stata, 25(1), 151–168.
<https://doi.org/10.1177/1536867X251322968>

Buzrul, S. (2026). The Michaelis–Menten Equation and Its Linear Transformations Revisited. *Chemistry & Biodiversity*, 23(2), e03211.
<https://doi.org/10.1002/cbdv.202503211>

Cai, Q. Q., Lee, B. C. Y., Ong, S. L., & Hu, J. Y. (2021). Fluidized-bed Fenton technologies for recalcitrant industrial wastewater treatment—Recent advances, challenges and perspective. *Water Research*, 190, 116692.
<https://doi.org/10.1016/j.watres.2020.116692>

Canadian Society for Civil Engineering (Ed.). (2016). *Sustainable municipalities: Annual Conference of the Canadian Society for Civil Engineering 2014: Halifax, Canada, 28-31 May 2014 = Municipalités durables*. Curran Associates, Inc. Canadian Society for Civil Engineering.

Çankaya, S., & Pekey, B. (2024). Evaluating the environmental and economic performance of biological and advanced biological wastewater treatment plants by life cycle assessment and life cycle costing. *Environmental Monitoring and Assessment*, 196(4), 373. <https://doi.org/10.1007/s10661-024-12519-z>

Carvalho-Silva, V. H., Vaz, E. C., Coutinho, N. D., Kobayashi, H., Kobayashi, Y., Kasai, T., Palazzetti, F., Lombardi, A., & Aquilanti, V. (2019). The Increase of the Reactivity of Molecular Hydrogen with Hydroxyl Radical from the Gas Phase versus an Aqueous Environment: Quantum Chemistry and Transition State-Theory Calculations. In S. Misra, O. Gervasi, B. Murgante, E. Stankova, V. Korkhov, C. Torre, A. M. A. C. Rocha, D. Taniar, B. O. Apduhan, & E. Tarantino (Eds.), *Computational Science and Its Applications – ICCSA 2019* (Vol. 11624, pp. 450–459). Springer International Publishing. https://doi.org/10.1007/978-3-030-24311-1_33

Cascajares, M., Alcayde, A., Salmerón-Manzano, E., & Manzano-Agugliaro, F. (2021). The Bibliometric Literature on Scopus and WoS: The Medicine and Environmental Sciences Categories as Case of Study. *International Journal of*

Environmental Research and Public Health, 18(11), 5851.
<https://doi.org/10.3390/ijerph18115851>

Chakraborty, B., & Ghosh, P. (2021). Factorial Designs. In K. Kim, F. Bretz, Y. K. K. Cheung, & L. V. Hampson, *Handbook of Statistical Methods for Randomized Controlled Trials* (1st ed., pp. 163–190). Chapman and Hall/CRC.
<https://doi.org/10.1201/9781315119694-9>

Changotra, R., Rajput, H., & Dhir, A. (2019). Treatment of real pharmaceutical wastewater using combined approach of Fenton applications and aerobic biological treatment. *Journal of Photochemistry and Photobiology A: Chemistry*, 376, 175–184. <https://doi.org/10.1016/j.jphotochem.2019.02.029>

Chen, H., Liu, J., Pei, Y., Zhao, P., Zhang, Y., Yan, L., Zhang, T., Li, W., Wu, C., & Hussain, M. (2018). Study on the synergistic effect of UV/Fenton oxidation and mass transfer enhancement with addition of activated carbon in the bubble column reactor. *Chemical Engineering Journal*, 336, 82–91.
<https://doi.org/10.1016/j.cej.2017.10.185>

Chen, H.-Y., & Chen, C. (2025). Importance of Using Modern Regression Analysis for Response Surface Models in Science and Technology. *Applied Sciences*, 15(13), 7206. <https://doi.org/10.3390/app15137206>

Chen, L., Li, X., Zhang, J., Fang, J., Huang, Y., Wang, P., & Ma, J. (2015). Production of Hydroxyl Radical via the Activation of Hydrogen Peroxide by Hydroxylamine. *Environmental Science & Technology*, 49(17), 10373–10379.
<https://doi.org/10.1021/acs.est.5b00483>

Chen, L., Yan, B., & Lu, H. (2022). An experimental study on the pretreatment of lignite upgrading wastewater using the Fenton oxidation method. *Chemical Papers*, 76(1), 393–399. <https://doi.org/10.1007/s11696-021-01871-w>

Chen, M., Li, M., Zhou, Y., Ma, Y., Wen, N., Gu, Q., Xie, J., Zhang, Y., & He, M. (2025). Theoretical study on the degradation of hydroxybenzophenones by hydroxyl radical in water: Microscopic reaction mechanism, kinetics, toxicity.

Computational and Theoretical Chemistry, 1254, 115507.
<https://doi.org/10.1016/j.comptc.2025.115507>

Chen, Q., Zhao, B., Zhang, Y., Zhu, F., Wang, H., Wang, J., & Fu, X. (2023). The function of “Cambi® thermal hydrolysis + anaerobic digestion” on heavy metal behavior and risks in a full-scale sludge treatment plant based on four seasons investigation. *Journal of Hazardous Materials*, 445, 130579.
<https://doi.org/10.1016/j.jhazmat.2022.130579>

Chen, W., Gu, Z., Wen, P., & Li, Q. (2019). Degradation of refractory organic contaminants in membrane concentrates from landfill leachate by a combined coagulation-ozonation process. *Chemosphere*, 217, 411–422.
<https://doi.org/10.1016/j.chemosphere.2018.11.002>

Chen, Y., Cheng, Y., Guan, X., Liu, Y., Nie, J., & Li, C. (2019). A Rapid Fenton treatment of bio-treated dyeing and finishing wastewater at second-scale intervals: Kinetics by stopped-flow technique and application in a full-scale plant. *Scientific Reports*, 9(1), 9689. <https://doi.org/10.1038/s41598-019-45948-9>

Cheng, W., Jiang, L., Quan, X., Cheng, C., Huang, X., Cheng, Z., & Yang, L. (2019). Ozonation process intensification of p-nitrophenol by in situ separation of hydroxyl radical scavengers and microbubbles. *Water Science and Technology*, 80(1), 25–36. <https://doi.org/10.2166/wst.2019.227>

Cheng, Y., Chen, Y., Lu, J., Nie, J., & Liu, Y. (2018). Fenton treatment of bio-treated fermentation-based pharmaceutical wastewater: Removal and conversion of organic pollutants as well as estimation of operational costs. *Environmental Science and Pollution Research*, 25(12), 12083–12095. <https://doi.org/10.1007/s11356-018-1400-0>

Choe, Y. J., Byun, J. Y., Kim, S. H., & Kim, J. (2018). Fe₃S₄/Fe₇S₈-promoted degradation of phenol via heterogeneous, catalytic H₂O₂ scission mediated by S-modified surface Fe²⁺ species. *Applied Catalysis B: Environmental*, 233, 272–280.
<https://doi.org/10.1016/j.apcatb.2018.03.110>

- Chung, R., & Hein, J. E. (2017). The More, The Better: Simultaneous In Situ Reaction Monitoring Provides Rapid Mechanistic and Kinetic Insight. *Topics in Catalysis*, 60(8), 594–608. <https://doi.org/10.1007/s11244-017-0737-9>
- Çifçi, D. İ. (2025). Optimization of the Treatment of Chemical Industry Wastewater by Coagulation and Fenton Oxidation. *CLEAN – Soil, Air, Water*, 53(11), e70060. <https://doi.org/10.1002/clen.70060>
- Clark-Carter, D. (2005). Standard Deviation. In B. S. Everitt & D. C. Howell (Eds.), *Encyclopedia of Statistics in Behavioral Science* (1st ed.). Wiley. <https://doi.org/10.1002/0470013192.bsa637>
- Clausi, M., Savino, S., Cangialosi, F., Eramo, G., Fornaro, A., Quatraro, L., Pinto, D., & D'Accolti, L. (2023). Pollutants abatement in aqueous solutions with geopolymer catalysts: A photo fenton case. *Chemosphere*, 344, 140333. <https://doi.org/10.1016/j.chemosphere.2023.140333>
- Colicchia, C., Creazza, A., Noè, C., & Strozzi, F. (2019). Information sharing in supply chains: A review of risks and opportunities using the systematic literature network analysis (SLNA). *Supply Chain Management: An International Journal*, 24(1), 5–21. <https://doi.org/10.1108/SCM-01-2018-0003>
- Collivignarelli, M., Pedrazzani, R., Sorlini, S., Abbà, A., & Bertanza, G. (2017). H₂O₂ Based Oxidation Processes for the Treatment of Real High Strength Aqueous Wastes. *Sustainability*, 9(2), 244. <https://doi.org/10.3390/su9020244>
- Contreras-Bustos, R., Cárdenas-Mijangos, J., Dector-Espinoza, A., Rodríguez-García, A., Montoya-Herrera, L., Jiménez-Becerril, J., & Centro de Investigación y Desarrollo Tecnológico en Electroquímica S. C. (2019). Treatment of wastewater from the petrochemical industry with chemical Fenton process. *Revista Mexicana de Ingeniería Química*, 19(2), 523–532. <https://doi.org/10.24275/rmiq/IA637>
- Cook, B. G., Wong, V. C., Fleming, J. I., & Solari, E. J. (2025). Preregistration of Randomized Controlled Trials. *Research on Social Work Practice*, 35(3), 277–286. <https://doi.org/10.1177/10497315221121117>

- Cortés, L. A., Simpson, J. R., & Parker, P. A. (2022). A class of response surface split-plot designs. *Quality Engineering*, 34(3), 359–369. <https://doi.org/10.1080/08982112.2022.2052730>
- Cunha-Filho, F. J. V., Do Nascimento Silva, D., Do Nascimento, C. A. O., Chiavone-Filho, O., & Mota-Lima, A. (2022). Stoichiometric excesses of H₂O₂ as dosimetry strategy: Proof of concept for UVC-H₂O₂, dark-Fenton, and UVC-Fenton. *Environmental Science and Pollution Research*, 30(6), 14860–14872. <https://doi.org/10.1007/s11356-022-22968-z>
- Dai, M., Niu, Q., Wu, S., Lin, Y., Biswas, J. K., & Yang, C. (2024). Hydroxyl radicals in ozone-based advanced oxidation of organic contaminants: A review. *Environmental Chemistry Letters*, 22(6), 3059–3106. <https://doi.org/10.1007/s10311-024-01772-w>
- Daouda, M. M. A., Hounkpè, S. P., Djihouessi, M. B., Akowanou, A. V. O., Aïna, M. P., & Drogui, P. (2021). Physicochemical assessment of urban wastewater of Cotonou (Benin). *Water Science and Technology*, 83(6), 1499–1510. <https://doi.org/10.2166/wst.2021.073>
- Davies, E. (2026). Laying the groundwork and designing for trust: Why research protocols matter. *Advances in Simulation*, 11(1), 34. <https://doi.org/10.1186/s41077-026-00430-1>
- Davison, R. C. R., & Smith, P. M. (2018). Quantitative data analyses. In S. R. Bird (Ed.), *Research Methods in Physical Activity and Health* (1st ed., pp. 168–183). Routledge. <https://doi.org/10.4324/9781315158501-17>
- Ding, R., Wang, Y., Chen, X., Gao, Y., & Yang, M. (2019). Extended Fenton's process: Toward improving biodegradability of drilling wastewater. *Water Science and Technology*, 79(9), 1790–1797. <https://doi.org/10.2166/wst.2019.179>
- Ding, S., Zhao, Z., Tian, Q., Li, D., & Ren, H. (2021). Effect of Iron-Carbon Micro-Electrolysis-Fenton on the Dewatering Performance of Sludge. *Environmental*

Science and Pollution Research, 28(34), 47126–47135.
<https://doi.org/10.1007/s11356-021-13514-4>

Dobrosz-Gómez, I., Quintero-Arias, J.-D., & Gómez-García, M.-Á. (2024). Fenton advanced oxidation process for the treatment of industrial textile wastewater highly polluted with acid-black 194 dye. *Case Studies in Chemical and Environmental Engineering*, 9, 100672. <https://doi.org/10.1016/j.cscee.2024.100672>

Domergue, L., Cimetière, N., Giraudet, S., & Hauchard, D. (2023). Determination of hydrogen peroxide by differential pulse polarography in advanced oxidation processes for water treatment. *Journal of Water Process Engineering*, 53, 103707. <https://doi.org/10.1016/j.jwpe.2023.103707>

Domingo-Félez, C., Jensen, M. M., Bang, A., & Smets, B. F. (2024). Variability and Uncertainty Analysis of N₂O Emissions from WWTP to Improve the Accuracy of Emission Factors and the Design of Monitoring Strategies. *ACS ES&T Water*, 4(6), 2542–2552. <https://doi.org/10.1021/acsestwater.4c00048>

Domingues, E., Fernandes, E., Gomes, J., Castro-Silva, S., & Martins, R. C. (2021). Olive oil extraction industry wastewater treatment by coagulation and Fenton's process. *Journal of Water Process Engineering*, 39, 101818. <https://doi.org/10.1016/j.jwpe.2020.101818>

Domínguez-Talamantes, D. G., Vargas-Hernández, D., Hernández-Oloño, J. T., Rodríguez-Castellón, E., Arellano-Cortaza, M., Castillo, S. J., & Tánori-Córdova, J. C. (2024). Enhanced photocatalytic activity of FeSO₄ in a ZnO photocatalyst with H₂O₂ for dye degradation. *Optik*, 304, 171753. <https://doi.org/10.1016/j.ijleo.2024.171753>

Du, H., Zhu, B., Luan, G., Gu, S., Jin, X., Zhang, G., & Yin, S. (2026). A testing methodology for tensile and creep properties of heat-resistant steel based on the internal pressure bulge test. *International Journal of Pressure Vessels and Piping*, 223, 105902. <https://doi.org/10.1016/j.ijpvp.2026.105902>

- Dubey, A., Prasad, R. S., Kumar Singh, J., & Nayyar, A. (2022). Optimization of diesel engine performance and emissions with biodiesel-diesel blends and EGR using response surface methodology (RSM). *Cleaner Engineering and Technology*, 8, 100509. <https://doi.org/10.1016/j.clet.2022.100509>
- Duoandicoechea, U., Bilbao-García, E., & Villota, N. (2025). Kinetic Modeling of Sulfamethoxazole Degradation by Photo-Fenton: Tracking Color Development and Iron Complex Formation for Enhanced Bioremediation. *Applied Sciences*, 15(8), 4531. <https://doi.org/10.3390/app15084531>
- Durai, N. J., Gopalakrishna, G. V. T., Padmanaban, V. C., & Selvaraju, N. (2020). Oxidative removal of stabilized landfill leachate by Fenton's process: Process modeling, optimization & analysis of degraded products. *RSC Advances*, 10(7), 3916–3925. <https://doi.org/10.1039/C9RA09415F>
- Elsawah, A. M., & Qin, H. (2017). Optimum mechanism for breaking the confounding effects of mixed-level designs. *Computational Statistics*, 32(2), 781–802. <https://doi.org/10.1007/s00180-016-0651-9>
- Fan, X., McLaughlin, J. B., Melman, A., & Mededovic Thagard, S. (2017). Quantum Chemical Approach for Determining Degradation Pathways of Phenol by Electrical Discharge Plasmas. *Plasma Chemistry and Plasma Processing*, 37(1), 5–28. <https://doi.org/10.1007/s11090-016-9758-6>
- Fan, X., Su, W., & Huang, Y. (2019). Thermal Hazard Evaluation of Hydrogen Peroxide Solution. *2019 9th International Conference on Fire Science and Fire Protection Engineering (ICFSFPE)*, 1–5. <https://doi.org/10.1109/ICFSFPE48751.2019.9055798>
- Fang, K.-T., Liu, M.-Q., Qin, H., & Zhou, Y.-D. (2018). Connections Between Uniformity and Other Design Criteria. In K.-T. Fang, M.-Q. Liu, H. Qin, & Y.-D. Zhou, *Theory and Application of Uniform Experimental Designs* (Vol. 221, pp. 209–241). Springer Singapore. https://doi.org/10.1007/978-981-13-2041-5_6

Farrukh, A., & Sajjad, A. (2023). A Critical Review of Literature Review Methodologies. In S. Rana, J. Singh, & S. Kathuria (Eds.), *Review of Management Literature* (pp. 103–123). Emerald Publishing Limited. <https://doi.org/10.1108/S2754-586520230000002006>

Feng, X., Hong, W., Tan, X., Zhang, Z., Liang, S., & Zhuang, H. (2024). Treatment Design and Operational Efficacy of the “Pre-Acidification + Anaerobic + Two-Stage AO + Improved Fenton” Treatment for Biopharmaceutical Wastewater. In D. Han & M. J. K. Bashir (Eds.), *Environmental Governance, Ecological Remediation and Sustainable Development* (pp. 563–570). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-52901-6_55

Ferrentino, R., Merzari, F., & Andreottola, G. (2020). Optimisation of $\text{Fe}^{2+}/\text{H}_2\text{O}_2$ ratio in Fenton process to increase dewaterability and solubilisation of sludge. *Environmental Technology*, 41(22), 2946–2954. <https://doi.org/10.1080/09593330.2019.1589583>

Firdaus, F., Azhar, N. H. A., Idris, M. S. F., & M. Yusoff, S. F. (2017). Pengoptimuman Tindak Balas Penghidrogenan Getah Asli Cecair melalui Kaedah Rangsangan Permukaan. *Sains Malaysiana*, 46(12), 2469–2475. <https://doi.org/10.17576/jsm-2017-4612-24>

Fischbacher, A., Von Sonntag, C., & Schmidt, T. C. (2017). Hydroxyl radical yields in the Fenton process under various pH, ligand concentrations and hydrogen peroxide/Fe(II) ratios. *Chemosphere*, 182, 738–744. <https://doi.org/10.1016/j.chemosphere.2017.05.039>

Fitria, N., Qadafi, M., Kusuma, R. P., Prayogo, W., & Fitria, L. (2023). Effect of Storage Time and Temperature on Drinking Water Characteristics. *Journal of Community Based Environmental Engineering and Management*, 7(7), 67–74. <https://doi.org/10.23969/jcbeem.v7i2.7854>

Frey, J., Wallington, T. J., Hartshorn, R., Quack, M., Heus, P., & Emmerson, S. (2023). The units of rate constants in chemical kinetics. *Accreditation and Quality Assurance*, 28(3), 115–119. <https://doi.org/10.1007/s00769-022-01515-w>

- Fu, B.-G., Cheng, L., Zhou, X., & Yu, Y.-Y. (2023). Single-atom catalysts-based Fenton-like processes for water contaminant management: A review. *Surfaces and Interfaces*, 43, 103553. <https://doi.org/10.1016/j.surfin.2023.103553>
- G, A., & Kori, B. B. (2026). Case Study: Pharmaceutical Wastewater Characterization and Treatment. *Water, Air, & Soil Pollution*, 237(7), 448. <https://doi.org/10.1007/s11270-026-09114-y>
- Gamaralalage, D., Sawai, O., & Nunoura, T. (2019). Reusing the generated sludge as Fe source in Fenton process for treating crepe rubber wastewater. *Journal of Material Cycles and Waste Management*, 21(2), 248–257. <https://doi.org/10.1007/s10163-018-0784-8>
- Gandhi, T. P., Sai, M. G. C. P., Allabakshi, S. M., Gangwar, R. K., & Maliyekkal, S. M. (2025). Transforming antibiotic treatment in pharmaceutical wastewater: Unleashing the nexus between UV photons and nonthermal atmospheric pressure air plasma. *Journal of Environmental Chemical Engineering*, 13(5), 119160. <https://doi.org/10.1016/j.jece.2025.119160>
- Ganiyu, S. O., Zhou, M., & Martínez-Huitle, C. A. (2018). Heterogeneous electro-Fenton and photoelectro-Fenton processes: A critical review of fundamental principles and application for water/wastewater treatment. *Applied Catalysis B: Environmental*, 235, 103–129. <https://doi.org/10.1016/j.apcatb.2018.04.044>
- Gao, Z., Zhang, D., & Jun, Y.-S. (2021). Does *Tert* -Butyl Alcohol Really Terminate the Oxidative Activity of $\cdot\text{OH}$ in Inorganic Redox Chemistry? *Environmental Science & Technology*, 55(15), 10442–10450. <https://doi.org/10.1021/acs.est.1c01578>
- Garrett, G. E., & Taylor, M. S. (2017). A Nonlinear Ordinary Differential Equation for Generating Graphical Rate Equations from Concentration Versus Time Data. *Topics in Catalysis*, 60(8), 554–563. <https://doi.org/10.1007/s11244-017-0739-7>

- Gassie, L. W., & Englehardt, J. D. (2017). Advanced oxidation and disinfection processes for onsite net-zero greywater reuse: A review. *Water Research*, 125, 384–399. <https://doi.org/10.1016/j.watres.2017.08.062>
- Gauvreau, K. (2005). Standard Deviation. In P. Armitage & T. Colton (Eds.), *Encyclopedia of Biostatistics* (1st ed.). Wiley. <https://doi.org/10.1002/0470011815.b2a15151>
- Geed, S. R., & Ghime, D. (2021). Treatment of Emerging Water Pollutants by Fenton and Modified Fenton Processes. In M. P. Shah, *Removal of Refractory Pollutants from Wastewater Treatment Plants* (1st ed., pp. 299–310). CRC Press. <https://doi.org/10.1201/9781003204442-16>
- Gheraout, D., Elboughdiri, N., & Ghareba, S. (2020). Fenton Technology for Wastewater Treatment: Dares and Trends. *OALib*, 07(01), 1–26. <https://doi.org/10.4236/oalib.1106045>
- Giannakis, S., Lin, K.-Y. A., & Ghanbari, F. (2021). A review of the recent advances on the treatment of industrial wastewaters by Sulfate Radical-based Advanced Oxidation Processes (SR-AOPs). *Chemical Engineering Journal*, 406, 127083. <https://doi.org/10.1016/j.cej.2020.127083>
- GilPavas, E., Dobrosz-Gómez, I., & Gómez-García, M.-Á. (2019). Optimization and toxicity assessment of a combined electrocoagulation, H₂O₂/Fe²⁺/UV and activated carbon adsorption for textile wastewater treatment. *Science of The Total Environment*, 651, 551–560. <https://doi.org/10.1016/j.scitotenv.2018.09.125>
- Gim, H.-G., Park, E., Ha, J., Lee, J., Kim, Y.-T., & Choi, J. (2024). Bifunctional phosphorus-doped NiMo oxide/Ni-Fe hydroxide composite for overall water electrolysis: Optimized performance with exceptional stability. *Materials Today Energy*, 41, 101526. <https://doi.org/10.1016/j.mtener.2024.101526>
- Giménez, B. N., Conte, L. O., Duarte, S. A., & Schenone, A. V. (2024). Improvement of ferrioxalate assisted Fenton and photo-Fenton processes for paracetamol degradation by hydrogen peroxide dosage. *Environmental Science and*

Pollution Research, 31(9), 13489–13500. <https://doi.org/10.1007/s11356-024-32056-z>

Giménez, B. N., Schenone, A. V., & Conte, L. O. (2024). Exploring the role of hydrogen peroxide dosage strategies in the photo-Fenton process: Scaling from lab-scale to pilot plant solar reactor. *Chemical Engineering Journal Advances*, 19, 100627. <https://doi.org/10.1016/j.cej.2024.100627>

Giwa, A.-R. A., Bello, I. A., Olabintan, A. B., Bello, O. S., & Saleh, T. A. (2020). Kinetic and thermodynamic studies of fenton oxidative decolorization of methylene blue. *Heliyon*, 6(8), e04454. <https://doi.org/10.1016/j.heliyon.2020.e04454>

Gladich, I., Chen, S., Yang, H., Boucly, A., Winter, B., Van Bokhoven, J. A., Ammann, M., & Artiglia, L. (2022). Liquid–Gas Interface of Iron Aqueous Solutions and Fenton Reagents. *The Journal of Physical Chemistry Letters*, 13(13), 2994–3001. <https://doi.org/10.1021/acs.jpcclett.2c00380>

Gligorovski, S., Strekowski, R., Barbati, S., & Vione, D. (2018). Addition and Correction to Environmental Implications of Hydroxyl Radicals ($\cdot\text{OH}$). *Chemical Reviews*, 118(4), 2296–2296. <https://doi.org/10.1021/acs.chemrev.7b00742>

Gómez, C. A., Gómez-García, M.-Á., & Dobrosz-Gómez, I. (2023). Analysis of the Capacity of the Fenton Process for the Treatment of Polluted Wastewater from the Leather Dyeing Industry. *The Scientific World Journal*, 2023, 1–21. <https://doi.org/10.1155/2023/4724606>

Graf, S., Kranz, J., Schmidt, S., Bellut, L., & Uhlig, A. (2021). Formen der Evidenzsynthese. *Der Urologe*, 60(4), 434–443. <https://doi.org/10.1007/s00120-021-01476-x>

Grosser, A., Neczaj, E., Krzemińska, D., & Ratman-Kłosińska, I. (2025). Hybrid System of Fenton Process and Sequencing Batch Reactor for Coking Wastewater Treatment. *Water*, 17(5), 751. <https://doi.org/10.3390/w17050751>

Guo, S., Yuan, N., Zhang, G., & Yu, J. C. (2017). Graphene modified iron sludge derived from homogeneous Fenton process as an efficient heterogeneous Fenton

catalyst for degradation of organic pollutants. *Microporous and Mesoporous Materials*, 238, 62–68. <https://doi.org/10.1016/j.micromeso.2016.02.033>

Guo, Y., & Amorati, R. (2022). The Underrecognized Role of the Hydroperoxyl (HOO•) Radical in Chain Propagation of Lipids and its Implication in Antioxidant Activity. In C. Bravo-Diaz (Ed.), *Lipid Oxidation in Food and Biological Systems* (pp. 115–132). Springer International Publishing. https://doi.org/10.1007/978-3-030-87222-9_5

Guo, Y., Shi, W., Zhang, B., Li, W., & Lens, P. N. L. (2021). Effect of voltage intensity on the nutrient removal performance and microbial community in the iron electrolysis-integrated aerobic granular sludge system. *Environmental Pollution*, 274, 116604. <https://doi.org/10.1016/j.envpol.2021.116604>

Guo, Z., Ma, L., Dai, Q., Liu, Y., Zhang, D., & Ao, R. (2023). Behavior of heavy metals in municipal sludge during dewatering: The role of conditioners and extracellular polymeric substances. *Journal of Environmental Management*, 342, 118287. <https://doi.org/10.1016/j.jenvman.2023.118287>

Hall, C. L., Brown, S., James, M., Martin, J. L., Brown, N., Selby, K., Clarke, J., Williams, L., Sayal, K., Hollis, C., & Groom, M. J. (2019). Consensus workshops on the development of an ADHD medication management protocol using QbTest: Developing a clinical trial protocol with multidisciplinary stakeholders. *BMC Medical Research Methodology*, 19(1), 126. <https://doi.org/10.1186/s12874-019-0772-2>

Han, Y., Zhou, M., Xiao, Y., Zhou, X., Geng, J., Wang, T., Wan, S., & Hou, H. (2017). Roles of Fe(III) and Fe(VI) in enhancing dewaterability of sewage sludge based on floc size grading. *Desalination and Water Treatment*, 84, 324–331. <https://doi.org/10.5004/dwt.2017.21205>

Hao, L., Li, L., Yu, S., & Liu, J. (2022). Humic acid-coated hydrated ferric oxides-polymer nanocomposites for heavy metal removal in water. *Science of The Total Environment*, 834, 155427. <https://doi.org/10.1016/j.scitotenv.2022.155427>

Haq, R. U., Singh, H., & Choudhary, M. P. (2025). Experimental study on optimization of chemical oxygen demand reduction through advanced oxidation process for refinery-based oily sludge in Barmer Rajasthan, India. *EQA - International Journal of Environmental Quality*, 67(EQA-International Journal of Environmental Quality, Vol. 67 (2025)), 36–44. <https://doi.org/10.6092/ISSN.2281-4485/20955>

Hardyanti, N., Zaman, B., Pramesti, I. A., William, G. S., & Purwono, P. (2024). Integrated Ozone-Fenton Treatment – A Breakthrough in Pharmaceutical Wastewater Purification. *Ecological Engineering & Environmental Technology*, 25(11), 228–240. <https://doi.org/10.12912/27197050/192607>

Hasan, G., Salo, V.-T., Golin Almeida, T., Valiev, R. R., & Kurtén, T. (2023). Computational Investigation of Substituent Effects on the Alcohol + Carbonyl Channel of Peroxy Radical Self- and Cross-Reactions. *The Journal of Physical Chemistry A*, 127(7), 1686–1696. <https://doi.org/10.1021/acs.jpca.2c08927>

Hasan, G., Salo, V.-T., Valiev, R. R., Kubečka, J., & Kurtén, T. (2020). Comparing Reaction Routes for³ (RO[•]OR') Intermediates Formed in Peroxy Radical Self- and Cross-Reactions. *The Journal of Physical Chemistry A*, 124(40), 8305–8320. <https://doi.org/10.1021/acs.jpca.0c05960>

Haselsteiner, R., Pamuk, R., & Ersoy, B. (2017). Aspects concerning the shear strength of rockfill material in rockfill dam engineering. *geotechnik*, 40(3), 193–203. <https://doi.org/10.1002/gete.201600099>

He, J., Yang, X., Men, B., & Wang, D. (2016). Interfacial mechanisms of heterogeneous Fenton reactions catalyzed by iron-based materials: A review. *Journal of Environmental Sciences*, 39, 97–109. <https://doi.org/10.1016/j.jes.2015.12.003>

He, W., Pan, Y., & Bo, C. (2025). Iterative Learning Predictive Control Method Based on Reinforcement Learning for Rubber Mixing Batch Process. *IEEE Transactions on Automation Science and Engineering*, 22, 19266–19278. <https://doi.org/10.1109/TASE.2025.3591540>

He, X., Li, Y., Chen, J., & Cai, Z. (2015). Research on electrolysis factors of galvanizing slag's soluble anode effect on current efficiency. In A. Sheng (Ed.), *Energy, Environment and Green Building Materials* (pp. 311–313). CRC Press. <https://doi.org/10.1201/b18511-65>

Heikal, G. E. S., Ali Bayoumi, M. N., & Etgany, M. (2024). Box-Behnken Design Wastewater Treatment Optimization for Fenton Technology Reuse in Irrigation. *Engineering Research Journal (Shoubra)*, 53(4), 179–185. <https://doi.org/10.21608/erjsh.2024.288002.1305>

Hernández-Sancho, F., Lamizana-Diallo, B., & Ingram, W. (2017). Valuing environmental and health impacts from no action in wastewater management. In T. Ancev, M. A. S. Azad, & F. Hernández-Sancho (Eds.), *New Directions in Productivity Measurement and Efficiency Analysis*. Edward Elgar Publishing. <https://doi.org/10.4337/9781786432421.00014>

Heydari, M., Karimyan, K., Darvishmotevalli, M., Karami, A., Vasseghian, Y., Azizi, N., Ghayebzadeh, M., & Moradi, M. (2018). Data for efficiency comparison of raw pumice and manganese-modified pumice for removal phenol from aqueous environments—Application of response surface methodology. *Data in Brief*, 20, 1942–1954. <https://doi.org/10.1016/j.dib.2018.09.027>

Heynderickx, P. M. (2018). Acquisition of nonlinear kinetics from linear relations: Application on homogeneous transesterification reactions. *Chemical Engineering Journal*, 342, 41–51. <https://doi.org/10.1016/j.cej.2018.01.027>

Hu, W., Qu, Y., Xiong, J., Li, L., Wang, X., Wang, X., Liu, W., & Wu, Y. (2024). Wastewater from natural gas Cansolv desulfurization process: Comprehensive characterization and effective removal of organic compounds. *Science of The Total Environment*, 911, 168681. <https://doi.org/10.1016/j.scitotenv.2023.168681>

Hua, T.-W., Huang, G.-X., Qian, C., Zeng, H.-W., Jiang, J., & Yu, H.-Q. (2025). Data-Driven Recursive Kinetic Modeling for Fenton Reaction. *Environmental Science & Technology*, 59(45), 24473–24480. <https://doi.org/10.1021/acs.est.5c06048>

- Huang, C., Chen, Q., Li, S., & Wang, J. (2023). The Detection Methods of Hydroxyl Radical: A Review. *E3S Web of Conferences*, 375, 03009. <https://doi.org/10.1051/e3sconf/202337503009>
- Huang, T., Zhu, J., Ge, S., Guo, T., Jiang, C., & Xie, L. (2020). Synthesis of novel CdSe QDs/BiFeO₃ composite catalysts and its application for the photo-Fenton catalytic degradation of phenol. *Journal of Environmental Chemical Engineering*, 8(5), 104384. <https://doi.org/10.1016/j.jece.2020.104384>
- Hübner, U., Spahr, S., Lutze, H., Wieland, A., Rüting, S., Gernjak, W., & Wenk, J. (2024). Advanced oxidation processes for water and wastewater treatment – Guidance for systematic future research. *Heliyon*, 10(9), e30402. <https://doi.org/10.1016/j.heliyon.2024.e30402>
- Huilin, W., Saishengtai, G., Cheng, H., & Qin, Q. (2025). Enhancing Fenton Oxidation for Pharmaceutical Wastewater: Optimization and Mechanism Analysis. *International Journal of Agricultural and Environmental Information Systems*, 16(1), 1–18. <https://doi.org/10.4018/IJAEIS.386837>
- Hung, D. P., Oanh, L. T. K., Chi, V. T. D., Thinh, L. N. Q., Nguyen, D. T., Tuan, N. Q., & Han, H. T. N. (2021). Applicability Assessment of Electrocoagulation in Real Dyeing Wastewater Treatment. *Nature Environment and Pollution Technology*, 20(2). <https://doi.org/10.46488/NEPT.2021.v20i02.015>
- Hur, B., Kang, D., Lee, S., Moon, J. H., Lee, G., & Kim, S. (2019). Venn-diaNet: Venn diagram based network propagation analysis framework for comparing multiple biological experiments. *BMC Bioinformatics*, 20(S23), 667. <https://doi.org/10.1186/s12859-019-3302-7>
- Illés, E., Mizrahi, A., Marks, V., & Meyerstein, D. (2019). Carbonate-radical-anions, and not hydroxyl radicals, are the products of the Fenton reaction in neutral solutions containing bicarbonate. *Free Radical Biology and Medicine*, 131, 1–6. <https://doi.org/10.1016/j.freeradbiomed.2018.11.015>

Iqbal, J., Shah, N. S., Ali Khan, J., Naushad, Mu., Boczkaj, G., Jamil, F., Khan, S., Li, L., Murtaza, B., & Han, C. (2024). Pharmaceuticals wastewater treatment via different advanced oxidation processes: Reaction mechanism, operational factors, toxicities, and cost evaluation – A review. *Separation and Purification Technology*, 347, 127458. <https://doi.org/10.1016/j.seppur.2024.127458>

Jasińska, M. (2015). Test Reactions to Study Efficiency of Mixing. *Chemical and Process Engineering*, 36(2), 171–208. <https://doi.org/10.1515/cpe-2015-0013>

Jenkin, M. E., Valorso, R., Aumont, B., Rickard, A. R., & Wallington, T. J. (2018). Estimation of rate coefficients and branching ratios for gas-phase reactions of OH with aliphatic organic compounds for use in automated mechanism construction. *Atmospheric Chemistry and Physics*, 18(13), 9297–9328. <https://doi.org/10.5194/acp-18-9297-2018>

Jeon, B.-C., Nam, S.-Y., & Kim, Y.-K. (2014). Treatment of Pharmaceutical Wastewaters by Hydrogen Peroxide and Zerovalent Iron. *Environmental Engineering Research*, 19(1), 9–14. <https://doi.org/10.4491/eer.2014.19.1.009>

Jiang, R., Li, G., Li, B., Guo, Y., & Yang, X. (2025a). Effect of turbulence induced shear on continuous synthesis of imidazolium ionic liquid 1-butyl-3-methylimidazolium bromide ([BMIM]Br) in a high shear rate Taylor-Couette flow reactor. *Chemical Engineering Journal*, 525, 170636. <https://doi.org/10.1016/j.cej.2025.170636>

Jiang, R., Li, G., Li, B., Guo, Y., & Yang, X. (2025b). Effect of turbulence induced shear on micro-mixing in a vertically aligned high-shear rate Taylor-Couette flow reactor. *Chemical Engineering Science*, 317, 122047. <https://doi.org/10.1016/j.ces.2025.122047>

Johnson, M. S., Mueller, J. N., Daniels, C., Najm, H. N., & Zádor, J. (2024). Diffusion-Limited Kinetics in Reactive Systems. *The Journal of Physical Chemistry A*, 128(18), 3685–3702. <https://doi.org/10.1021/acs.jpca.4c00727>

- Jones, B., & Montgomery, D. C. (2017). Partial replication of small two-level factorial designs. *Quality Engineering*, 29(2), 190–195. <https://doi.org/10.1080/08982112.2016.1254797>
- Juel, Md. A. I., Chowdhury, Z. U. Md., & Ahmed, T. (2016). *Heavy metal speciation and toxicity characteristics of tannery sludge*. 060009. <https://doi.org/10.1063/1.4958450>
- Juwar, V. A., Rathod, A. P., & Kodape, S. M. (2025). Optimization and kinetic study of Fenton treated industrial wastewater using response surface method. *Indian Journal of Chemical Technology*. <https://doi.org/10.56042/ijct.v32i4.10218>
- Kalyanaraman, C., Sri Bala Kameswari, K., Srinivasan, S. V., Thirumaran, K., & Raghava Rao, J. (2015). Effect of pre-treatment on dye degradation in aerobic reactor. *Desalination and Water Treatment*, 56(6), 1547–1557. <https://doi.org/10.1080/19443994.2014.954149>
- Kamaruzaman, N. A., Jaafar, M. H., Mohideen, M., & Fatinathan, S. (2023). Effects of Treated and Untreated Sludge Applications on Human Health, the Environment and Other Ecological Factors. In M. Mohd Zaini Makhtar, H. Shukor, & A. Z. Yaser (Eds.), *Microbial Fuel Cell (MFC) Applications for Sludge Valorization* (pp. 23–42). Springer Nature Singapore. https://doi.org/10.1007/978-981-99-1083-0_2
- Kamath, D., Mezyk, S. P., & Minakata, D. (2018). Elucidating the Elementary Reaction Pathways and Kinetics of Hydroxyl Radical-Induced Acetone Degradation in Aqueous Phase Advanced Oxidation Processes. *Environmental Science & Technology*, 52(14), 7763–7774. <https://doi.org/10.1021/acs.est.8b00582>
- Kar, K., Cope, R., & Lueske, J. (2025). Hydrodynamics. In K. Kar, R. Cope, & J. Lueske, *Mixing Process Technology* (1st ed., pp. 43–50). CRC Press. <https://doi.org/10.1201/9781003606390-5>
- Karmoker, J. R., Hasan, I., Ahmed, N., Saifuddin, M., & Reza, M. S. (2019). Development and Optimization of Acyclovir Loaded Mucoadhesive Microspheres

by Box – Behnken Design. *Dhaka University Journal of Pharmaceutical Sciences*, 18(1), 1–12. <https://doi.org/10.3329/dujps.v18i1.41421>

Kastanek, F., Spacilova, M., Krystynik, P., Dlaskova, M., & Solcova, O. (2023). Fenton Reaction–Unique but Still Mysterious. *Processes*, 11(2), 432. <https://doi.org/10.3390/pr11020432>

Kavianpour, B., Piadeh, F., Gheibi, M., Ardakanian, A., Behzadian, K., & Campos, L. C. (2024). Applications of artificial intelligence for chemical analysis and monitoring of pharmaceutical and personal care products in water and wastewater: A review. *Chemosphere*, 368, 143692. <https://doi.org/10.1016/j.chemosphere.2024.143692>

Kechagias, J. D., & Vidakis, N. (2022). Parametric optimization of material extrusion 3D printing process: An assessment of Box-Behnken vs. full-factorial experimental approach. *The International Journal of Advanced Manufacturing Technology*, 121(5–6), 3163–3172. <https://doi.org/10.1007/s00170-022-09532-2>

Kementerian Investasi dan Hilirisasi. (2021). Potensi Menjanjikan di Industri Farmasi dan Kesehatan Indonesia. *OSS Indonesia*. <https://oss.go.id/id/berita/potensi-menjanjikan-di-industri-farmasi-dan-kesehatan-indonesia>

Kementerian Kesehatan Republik Indonesia. (2018). *Peraturan Menteri Kesehatan Republik Indonesia Nomor 26 Tahun 2018 tentang Pelayanan Perizinan Berusaha Terintegrasi Secara Elektronik Sektor Kesehatan*. Jakarta: Kementerian Kesehatan.

Kementerian Lingkungan Hidup Republik Indonesia. (2014). *Peraturan Menteri Lingkungan Hidup Republik Indonesia Nomor 5 Tahun 2014 tentang Baku Mutu Air Limbah*.

Khalidi-Idrissi, A., Madinzi, A., Anouzla, A., Pala, A., Mouhir, L., Kadmi, Y., & Souabi, S. (2023). Recent advances in the biological treatment of wastewater rich in emerging pollutants produced by pharmaceutical industrial discharges.

International Journal of Environmental Science and Technology, 20(10), 11719–11740. <https://doi.org/10.1007/s13762-023-04867-z>

Khan, N. A., Khan, A. H., Tiwari, P., Zubair, M., & Naushad, Mu. (2021). New insights into the integrated application of Fenton-based oxidation processes for the treatment of pharmaceutical wastewater. *Journal of Water Process Engineering*, 44, 102440. <https://doi.org/10.1016/j.jwpe.2021.102440>

Khodadadi, T., Solgi, E., Mortazavi, S., & Nourmoradi, H. (2020). Comparison of advanced oxidation methods of Fenton, UV/Fenton, and O₃/Fenton in treatment of municipal wastewater. *Desalination and Water Treatment*, 206, 108–115. <https://doi.org/10.5004/dwt.2020.26373>

Khursheed, A., & Sabumon, P. C. (2024). Removal of pharmaceutical contaminants from wastewater using activated sludge process. In *Development in Wastewater Treatment Research and Processes* (pp. 117–136). Elsevier. <https://doi.org/10.1016/B978-0-323-99278-7.00019-5>

Kim, H.-G., Ko, Y.-J., Lee, S., Hong, S. W., Lee, W.-S., & Choi, J.-W. (2018). Degradation of Organic Compounds in Actual Wastewater by Electro-Fenton Process and Evaluation of Energy Consumption. *Water, Air, & Soil Pollution*, 229(10), 335. <https://doi.org/10.1007/s11270-018-3987-7>

Kim, S. Y. (2022). Why do journals publish research protocols? *Science Editing*, 9(2), 146–148. <https://doi.org/10.6087/kcse.280>

Köntös, Z. (2026). Kinetics of uncatalyzed hydrogen peroxide decomposition: Determination of rate constants, Arrhenius parameters. *Journal of Chemical Research*, 50(3), 17475198261446754. <https://doi.org/10.1177/17475198261446754>

Krishnan, P. (2021). When and how to use factorial design in nursing research. *Nurse Researcher*, 29(1), 26–31. <https://doi.org/10.7748/nr.2020.e1757>

Kumaran, P., Natarajan, S., Sudesh Kumar, M. P., Mohamed, R., & Nithish, S. (2023). Optimization of Diesel Engine Performance and Emissions Characteristics

with Tomato Seed Blends and EGR Using Response Surface Methodology. *International Journal of Automotive Science and Technology*, 7(3), 223–233. <https://doi.org/10.30939/ijastech..1326036>

Kuznietsov, P., Biedunkova, O., Pryshchepa, A., & Yaroschuk, O. (2026). Processes Optimisation of Coagulation, Flocculation, and Liming for Power Plant Water Treatment. In H. Altenbach, X.-W. Gao, S. Syngellakis, A. H.-D. Cheng, P. Lampart, & A. Tkachuk (Eds.), *Advances in Mechanical and Power Engineering III* (pp. 65–74). Springer Nature Switzerland. https://doi.org/10.1007/978-3-032-16381-3_7

Laguta, A. N., Eltsov, S. V., & Mchedlov-Petrosyan, N. O. (2021). Nitrophenol Violet as a New Tool for Studying of Kinetics of Reactions in Solutions. *Journal of Chemical Education*, 98(9), 2964–2972. <https://doi.org/10.1021/acs.jchemed.9b00115>

Lalwani, J., Thatikonda, S., & Challapalli, S. (2021). Varying Efficacies of Fenton's Oxidation Treatment on Pharmaceutical Industry Effluents of Contrasting Viscosity Profiles. *CLEAN – Soil, Air, Water*, 49(3), 2000335. <https://doi.org/10.1002/clen.202000335>

Lamichhane, P., Acharya, T. R., Jaiswal, A., Admasu, K. A., Kaushik, N., Kaushik, N. K., & Choi, E. H. (2024). Investigating the impact of plasma plume length of atmospheric pressure plasma jet on ampicillin degradation efficiency and toxicity. *Journal of Environmental Chemical Engineering*, 12(5), 113445. <https://doi.org/10.1016/j.jece.2024.113445>

Lane, K. L., & Kettler, R. J. (2019). Literature Review, Questions, and Hypotheses. In R. J. Kettler, *Research Methodologies of School Psychology* (1st ed., pp. 24–41). Routledge. <https://doi.org/10.4324/9781315724072-2>

Laws, T. R., & Maishman, T. C. (2022). Considerations in the design of animal infection pilot studies. *Frontiers in Cellular and Infection Microbiology*, 12, 948464. <https://doi.org/10.3389/fcimb.2022.948464>

- Lente, G. (2015). Kinetics of irreversible consecutive processes with first order second steps: Analytical solutions. *Journal of Mathematical Chemistry*, 53(4), 1172–1183. <https://doi.org/10.1007/s10910-015-0477-7>
- Li, A., Fang, X., Sun, J., Liu, Q., Lian, Y., Li, S., An, Y., Wang, Y., & Gao, A. (2021). Analyzing the kinetics of degradation of Acid Red B dye through Fenton oxidation with online monitoring system. *Desalination and Water Treatment*, 216, 412–422. <https://doi.org/10.5004/dwt.2021.26863>
- Li, C., Mei, Y., Qi, G., Xu, W., Zhou, Y., & Shen, Y. (2021). Degradation characteristics of four major pollutants in chemical pharmaceutical wastewater by Fenton process. *Journal of Environmental Chemical Engineering*, 9(1), 104564. <https://doi.org/10.1016/j.jece.2020.104564>
- Li, J., Luo, G., Gao, J., Yuan, S., Du, J., & Wang, Z. (2015). Quantitative evaluation of potential ecological risk of heavy metals in sewage sludge from three wastewater treatment plants in the main urban area of Wuxi, China. *Chemistry and Ecology*, 31(3), 235–251. <https://doi.org/10.1080/02757540.2014.961439>
- Li, T., Zhang, X., Zhou, Y., Du, X., Fang, D., Liang, J., Li, J., & Zhou, L. (2023). Schwertmannite-based heterogeneous Fenton for enhancing sludge dewaterability over a wide pH range. *Journal of Hazardous Materials*, 459, 132240. <https://doi.org/10.1016/j.jhazmat.2023.132240>
- Li, Y., & Cheng, H. (2021). Chemical kinetic modeling of organic pollutant degradation in Fenton and solar photo-Fenton processes. *Journal of the Taiwan Institute of Chemical Engineers*, 123, 175–184. <https://doi.org/10.1016/j.jtice.2021.05.011>
- Liang, D. H., Hu, Y., Cheng, J., & Chen, Y. (2020). Simultaneous sulfamethoxazole biodegradation and nitrogen conversion in low C/N ratio pharmaceutical wastewater by *Achromobacter* sp. JL9. *Science of The Total Environment*, 703, 135586. <https://doi.org/10.1016/j.scitotenv.2019.135586>

Liang, J., Zhang, L., Yan, W., & Zhou, Y. (2020). Mechanistic insights into a novel nitrilotriacetic acid-Fe⁰ and CaO₂ process for efficient anaerobic digestion sludge dewatering at near-neutral pH. *Water Research*, 184, 116149. <https://doi.org/10.1016/j.watres.2020.116149>

Liao, Y., & Wang, B. (2026). Collaborative degradation of tetracycline hydrochloride using nickel ferrite catalyst and peroxymonosulfate in electrochemical fluidized-bed reactor. *Journal of Water Process Engineering*, 81, 109422. <https://doi.org/10.1016/j.jwpe.2025.109422>

Lien, H.-L., Yu, C.-H., Kamali, S., & Sahu, R. S. (2019). Bimetallic Fe/Al system: An all-in-one solid-phase Fenton reagent for generation of hydroxyl radicals under toxic conditions. *Science of The Total Environment*, 673, 480–488. <https://doi.org/10.1016/j.scitotenv.2019.04.116>

Lima, E. C., Sher, F., Guleria, A., Saeb, M. R., Anastopoulos, I., Tran, H. N., & Hosseini-Bandegharai, A. (2021). Is one performing the treatment data of adsorption kinetics correctly? *Journal of Environmental Chemical Engineering*, 9(2), 104813. <https://doi.org/10.1016/j.jece.2020.104813>

Limonti, C., Andreoli, T., Curcio, G. M., Aucancela Rivera, E. G., Agostino, G., Zenobi, F., & Siciliano, A. (2026). Development of Fenton Process with Sludge Reuse for the Treatment of Wastewater from a Pharmaceutical Industry Producing Anticancer Active Ingredients. *Earth Systems and Environment*, 10(2), 1221–1236. <https://doi.org/10.1007/s41748-025-00668-1>

Lin, Y.-J., Hossain, N., & Chen, C.-C. (2021). Modeling dissociation of ionic liquids with electrolyte NRTL model. *Journal of Molecular Liquids*, 329, 115524. <https://doi.org/10.1016/j.molliq.2021.115524>

Liu, X., Liu, Y., Zhu, X., Yang, H., & Liao, B. (2025). Activation of persulfate by Fe-Mn bimetallic system for the remediation of aged landfill leachate. *Journal of Environmental Chemical Engineering*, 13(6), 120428. <https://doi.org/10.1016/j.jece.2025.120428>

Liu, X., Wang, C., Ji, M., & Zhou, Y. (2016). Pretreatment of ultra-high concentration pharmaceutical wastewater by a combined Fenton And Electrolytic oxidation technologies: COD reduction, biodegradability improvement, and biotoxicity removal. *Environmental Progress & Sustainable Energy*, 35(3), 772–778. <https://doi.org/10.1002/ep.12318>

Liu, Y., Cheng, Z., Liu, S., Tan, Y., Yuan, T., Yu, X., & Shen, Z. (2020). Quantitative structure activity relationship (QSAR) modelling of the degradability rate constant of volatile organic compounds (VOCs) by OH radicals in atmosphere. *Science of The Total Environment*, 729, 138871. <https://doi.org/10.1016/j.scitotenv.2020.138871>

Liu, Y., Zhao, Y., & Wang, J. (2021). Fenton/Fenton-like processes with in-situ production of hydrogen peroxide/hydroxyl radical for degradation of emerging contaminants: Advances and prospects. *Journal of Hazardous Materials*, 404, 124191. <https://doi.org/10.1016/j.jhazmat.2020.124191>

Lucena, L. G., De Carvalho, N. A., Segundo, I. D. B., Melo, M. M. M., Cahino, A. M., & Rocha, E. M. R. (2021). A Systematic Review on Fenton Optimization for Leachate Treatment Via Response Surface Methodology from 2005 to 2015. *The Journal of Solid Waste Technology and Management*, 47(3), 409–416. <https://doi.org/10.5276/JSWTM/2021.409>

Lucena, L. G., Rocha, E. M. R., De Almeida Porto, C., De Carvalho, N. A., & Da Silva, F. L. H. (2019). Multi-response optimisation of the solar photo-Fenton process for landfill leachate post-treatment. *Desalination and Water Treatment*, 151, 106–116. <https://doi.org/10.5004/dwt.2019.23754>

Lucena, L. G., Rocha, E. M. R., Silva, F. L. H. D., & Cahino, A. M. (2018). Otimização multivariada do processo foto-Fenton solar na remoção da demanda química de oxigênio em lixiviados de aterros sanitários. *Engenharia Sanitaria e Ambiental*, 23(3), 499–507. <https://doi.org/10.1590/s1413-41522018153783>

Lye, H. L., Mohammed, B. S., Liew, M. S., Wahab, M. M. A., & Al-Fakih, A. (2020). Bond behaviour of CFRP-strengthened ECC using Response Surface

Methodology (RSM). *Case Studies in Construction Materials*, 12, e00327. <https://doi.org/10.1016/j.cscm.2019.e00327>

Lyngsie, G., Krumina, L., Tunlid, A., & Persson, P. (2018). Generation of hydroxyl radicals from reactions between a dimethoxyhydroquinone and iron oxide nanoparticles. *Scientific Reports*, 8(1), 10834. <https://doi.org/10.1038/s41598-018-29075-5>

Ma, C., Wang, J., Liu, X., Duan, X., Qi, J., Li, S., Li, N., Li, Y., Fan, X., & Peng, W. (2025). Enhanced Fe(III)/Fe(II) Cycle by Lattice Sulfur for Continuous Fenton Reactions. *Environmental Science & Technology*, 59(17), 8812–8821. <https://doi.org/10.1021/acs.est.4c12824>

Madane, K., Leonard, P., Mulligan, S., & Clifford, E. (2025). Effect of Wastewater Treatment Biological Reactor Geometry on Required Mixing Intensity. *41st IAHR World Congress*, 1857–1865. https://doi.org/10.64697/978-90-835589-7-4_41WC-P2102-cd

Madjene, F., Belkaid, S., & Rahmouni, F. (2026). Optimization of the coagulation/flocculation process by D-optimal experimental design for the treatment of cheese manufacturing wastewater. *Instrumentation Science & Technology*, 54(4), 545–560. <https://doi.org/10.1080/10739149.2025.2593649>

Mahapatra, S. S., & Vishwanathan, A. S. (2026). Improving the Efficiency and Turnover of a Domestic Wastewater Treatment Plant Using Coagulation–Flocculation. *Water and Environment Journal*, 40(1), 153–166. <https://doi.org/10.1111/wej.70020>

Mahtab, M. S., Basheer, F., & Farooqi, I. H. (2026). Chelate-Assisted Fenton Process at Circumneutral pH for Efficient Landfill Leachate Treatment: Process Intensification and Optimization. *Journal of Hazardous, Toxic, and Radioactive Waste*, 30(3), 04026010. <https://doi.org/10.1061/JHTRBP.HZENG-1603>

- Mahtab, M. S., Farooqi, I. H., & Khursheed, A. (2021). Sustainable approaches to the Fenton process for wastewater treatment: A review. *Materials Today: Proceedings*, 47, 1480–1484. <https://doi.org/10.1016/j.matpr.2021.04.215>
- Mahtab, M. S., Farooqi, I. H., & Khursheed, A. (2022). Optimization of Fenton process for concurrent COD removal and lower sludge production: Process intensification and impact of reagents dosing mode. *Journal of Environmental Management*, 315, 115207. <https://doi.org/10.1016/j.jenvman.2022.115207>
- Mahtab, M. S., Farooqi, I. H., Khursheed, A., Siddiqui, M. I., & Zhang, L. (2024). Perspectives on sustainable process control optimization through reusability of non-regenerated Fenton sludge in landfill leachate treatment. *Journal of Water Process Engineering*, 60, 105205. <https://doi.org/10.1016/j.jwpe.2024.105205>
- Mahtab, M. S., Islam, D. T., & Farooqi, I. H. (2021). Optimization of the process variables for landfill leachate treatment using Fenton based advanced oxidation technique. *Engineering Science and Technology, an International Journal*, 24(2), 428–435. <https://doi.org/10.1016/j.jestch.2020.08.013>
- M’Arimi, M. M., Mecha, C. A., Kiprop, A. K., & Ramkat, R. (2020). Recent trends in applications of advanced oxidation processes (AOPs) in bioenergy production: Review. *Renewable and Sustainable Energy Reviews*, 121, 109669. <https://doi.org/10.1016/j.rser.2019.109669>
- Martinez-Luaces, V. (Ed.). (2023). *A closer look at chemical kinetics*. Nova Science Publishers.
- Matvieieva, N., Bessarabov, V., Khainakova, O., Duplij, V., Bohdanovych, T., Ratushnyak, Y., Kuzmina, G., Lisovyi, V., Zderko, N., & Kobylinska, N. (2023). Cichorium intybus L. “hairy” roots as a rich source of antioxidants and anti-inflammatory compounds. *Heliyon*, 9(3), e14516. <https://doi.org/10.1016/j.heliyon.2023.e14516>
- Maulidiany, N. D., Oktovidonna, S. A., Rastandi, J. D., Lokahita, B., & Abdillah, A. (2025). Model-Based Assessment of Heavy Metals Leaching Behavior in Wasted

Activated Sludge Utilization. *Jurnal Presipitasi: Media Komunikasi Dan Pengembangan Teknik Lingkungan*, 22(1), 143–156.
<https://doi.org/10.14710/presipitasi.v22i1.143-156>

Mielke, J., Innerbichler, F., Schiestl, M., Ballarini, N. M., & Jones, B. (2019). The Assessment of Quality Attributes for Biosimilars: A Statistical Perspective on Current Practice and a Proposal. *The AAPS Journal*, 21(1), 7.
<https://doi.org/10.1208/s12248-018-0275-9>

Miklos, D. B., Remy, C., Jekel, M., Linden, K. G., Drewes, J. E., & Hübner, U. (2018). Evaluation of advanced oxidation processes for water and wastewater treatment – A critical review. *Water Research*, 139, 118–131.
<https://doi.org/10.1016/j.watres.2018.03.042>

Mishra, P., & Ein-Mozaffari, F. (2017). Using computational fluid dynamics to analyze the performance of the Maxblend impeller in solid-liquid mixing operations. *International Journal of Multiphase Flow*, 91, 194–207.
<https://doi.org/10.1016/j.ijmultiphaseflow.2017.01.009>

Mishra, S. R. K., Yadav, E. S., & Indiran, T. (2023). *Validation of split range control algorithm on a laboratory scale batch reactor heating system*. 090001.
<https://doi.org/10.1063/5.0136021>

Mojaver, P., Hasanzadeh, R., Chitsaz, A., Azdast, T., & Mojaver, M. (2024). Tri-objective central composite design optimization of co-gasification of eucalyptus biomass and polypropylene waste. *Biomass Conversion and Biorefinery*, 14(4), 4829–4841. <https://doi.org/10.1007/s13399-022-02597-9>

Montgomery, D. C. (2017). *Design and analysis of experiments* (Ninth edition). John Wiley & Sons, Inc.

Mortenson, M. J., & Vidgen, R. (2016). A computational literature review of the technology acceptance model. *International Journal of Information Management*, 36(6), 1248–1259. <https://doi.org/10.1016/j.ijinfomgt.2016.07.007>

- Mousset, E., Loh, W. H., Lim, W. S., Jarry, L., Wang, Z., & Lefebvre, O. (2021). Cost comparison of advanced oxidation processes for wastewater treatment using accumulated oxygen-equivalent criteria. *Water Research*, 200, 117234. <https://doi.org/10.1016/j.watres.2021.117234>
- Munoz, J., Moya Fernandez, P. J., Alvarez, E., & Blanco-Encomienda, F. (2020). An alternative expression for the constant $c_4[n]$ with desirable properties. *Scientia Iranica*, 0(0), 0–0. <https://doi.org/10.24200/sci.2020.52702.2846>
- Muñoz-Palazon, B., Rosa-Masegosa, A., Vilchez-Vargas, R., Link, A., Gorrasi, S., Gonzalez-Lopez, J., & Gonzalez-Martinez, A. (2022). Biological removal processes in aerobic granular sludge for treating synthetic hospital wastewater: Effect of temperature. *Journal of Water Process Engineering*, 47, 102691. <https://doi.org/10.1016/j.jwpe.2022.102691>
- Munro, K., Miller, T. H., Martins, C. P. B., Edge, A. M., Cowan, D. A., & Barron, L. P. (2015). Artificial neural network modelling of pharmaceutical residue retention times in wastewater extracts using gradient liquid chromatography-high resolution mass spectrometry data. *Journal of Chromatography A*, 1396, 34–44. <https://doi.org/10.1016/j.chroma.2015.03.063>
- Muszyńska, J., Bąk, Ł., Górski, J., Górka, K., Sałata, A., & Gawdzik, J. (2021). Fenton Process Optimization with Landfill Leachate in Janczyce as an Example. *Polish Journal of Environmental Studies*, 30(4), 3769–3775. <https://doi.org/10.15244/pjoes/130909>
- Narukulla, S., Bogadi, S., Tallapaneni, V., Sanapalli, B. K. R., Sanju, S., Khan, A. A., Malik, A., Barai, H. R., Mondal, T. K., Karri, V. V. S. R., Alexiou, A., Pindiprolu, S. K. S. S., Kuppusamy, G., Subramanian, V., Rabiul Islam, Md., & Papadakis, M. (2024). Comparative study between the Full Factorial, Box–Behnken, and Central Composite Designs in the optimization of metronidazole immediate release tablet. *Microchemical Journal*, 207, 111875. <https://doi.org/10.1016/j.microc.2024.111875>

- Nasruddin, M. N., Fahmi, M. R., Lun, Y. W., Abidin, C. Z. A., & Noer, Z. (2020). *Influence of pH and FeSO₄ to H₂O₂ ratio in degradation of p-Cresol by Fenton's reagent*. 110023. <https://doi.org/10.1063/5.0003179>
- Neves, P. H. R., Gonçalves, V. P. D., Pereira, A. C., Simonassi, N. T., Vieira, C. M. F., & Lopes, F. P. D. (2026). Characterization and Reuse Potential of High-Density Polyethylene (HDPE) from Decommissioned Oil and Gas Industry Pipelines. In H. A. C. Lopera, F. P. D. Lopes, S. N. Monteiro, D. Salazar, & M. A. Meyers (Eds.), *Natural Fibers and Biocomposites 2026* (pp. 141–148). Springer Nature Switzerland. https://doi.org/10.1007/978-3-032-13577-3_14
- Ngonadi, L. O., Diab, L. S., Onyeagu, S. I., Eze, F. C., Obulezi, O. J., & Aldukeel, A. (2026). High-Dimensional Evaluation of Central Composite Designs Under Classical and Regularized Optimality Criteria. *Symmetry*, 18(5), 814. <https://doi.org/10.3390/sym18050814>
- Nguyen, T. L., & Stanton, J. F. (2023). *Ab initio* rate coefficients for the reaction of OH and H₂ O₂ under upper troposphere and lower stratosphere conditions. *Environmental Science: Atmospheres*, 3(11), 1678–1684. <https://doi.org/10.1039/D3EA00143A>
- Nie, S., Yu, W., Zhu, X., Liu, L., Li, M., Yin, M., Liu, H., Wang, K., Xiao, X., Chu, C., Zhu, X., & Chen, B. (2025). Dual Roles of Phenolic Groups in Pyrogenic Carbon as Mediators and Quenchers for Hydroxyl Radical Production. *Environmental Science & Technology*, 59(41), 21978–21987. <https://doi.org/10.1021/acs.est.5c05017>
- Nordness, O., & Brennecke, J. F. (2020). Ion Dissociation in Ionic Liquids and Ionic Liquid Solutions. *Chemical Reviews*, 120(23), 12873–12902. <https://doi.org/10.1021/acs.chemrev.0c00373>
- Norris, K. E., Leresche, F., Vialykh, E. A., Mezyk, S. P., & Rosario-Ortiz, F. L. (2025). Mechanisms of Hydroxylating Species Production by Dissolved Organic Matter Model Photosensitizers. *Environmental Science & Technology*, 59(41), 22122–22132. <https://doi.org/10.1021/acs.est.5c04743>

Ocampo-Gaspar, M., Cano-Guzmán, C. F., Payan-Martínez, L. F., González-Reyes, L., Hernández-Pérez, I., Garibay-Febles, V., Pérez-Orozco, J. P., Cabrera-Lara, L. I., Ramón-García, M. L., Galicia-Luis, L., & Suárez-Parra, R. (2018). Sizing the Fenton's catalyst. *Journal of Photochemistry and Photobiology A: Chemistry*, 353, 527–535. <https://doi.org/10.1016/j.jphotochem.2017.12.022>

Ochando-Pulido, J. M., Pimentel-Moral, S., Verardo, V., & Martinez-Ferez, A. (2017). A focus on advanced physico-chemical processes for olive mill wastewater treatment. *Separation and Purification Technology*, 179, 161–174. <https://doi.org/10.1016/j.seppur.2017.02.004>

Office of Surface Mining Reclamation and Enforcement. (n.d.). *Help Instruction File: Reaction Tank Module Overview* [Technical Report / Guidance Document]. U.S. Department of the Interior. Retrieved January 7, 2025, from https://www.osmre.gov/sites/default/files/inline-files/reactionTank_amdtreatHelp_final508_0.pdf

Orito, Y. (2025). Practical Methodology in Kinetic Modeling for Complex Reactions: Weighted Error Manipulation to Allow Effective Model Evaluation in a Borderline S_N Reaction. *ACS Omega*, 10(9), 9266–9274. <https://doi.org/10.1021/acsomega.4c09609>

Ortiz Ortega, E., Hosseini, H., Rosales López, M. J., Rodríguez Vera, A., & Hosseini, S. (2022). Characterization Techniques for Chemical and Structural Analyses. In E. Ortiz Ortega, H. Hosseini, I. B. Aguilar Meza, M. J. Rosales López, A. Rodríguez Vera, & S. Hosseini, *Material Characterization Techniques and Applications* (Vol. 19, pp. 93–152). Springer Singapore. https://doi.org/10.1007/978-981-16-9569-8_4

Oskui, F. N., Aghdasinia, H., & Sorkhabi, M. G. (2019). Modeling and optimization of chromium adsorption onto clay using response surface methodology, artificial neural network, and equilibrium isotherm models. *Environmental Progress & Sustainable Energy*, 38(6), e13260. <https://doi.org/10.1002/ep.13260>

Oturan, N., & Oturan, M. A. (2018). Electro-Fenton Process: Background, New Developments, and Applications. In *Electrochemical Water and Wastewater Treatment* (pp. 193–221). Elsevier. <https://doi.org/10.1016/B978-0-12-813160-2.00008-0>

Owan, V. J. (2022). A Data Mining Algorithm for Accessing Research Literature in Electronic Databases: Boolean Operators. In T. M. Masenya (Ed.), *Advances in Knowledge Acquisition, Transfer, and Management* (pp. 140–155). IGI Global. <https://doi.org/10.4018/978-1-6684-3364-5.ch009>

Oyama, K., Shimada, K., Ishibashi, J., Sasaki, K., Miki, H., & Okibe, N. (2020). Catalytic mechanism of activated carbon-assisted bioleaching of enargite concentrate. *Hydrometallurgy*, 196, 105417. <https://doi.org/10.1016/j.hydromet.2020.105417>

Öztürk, E., Ateş, A. E., Selçuk, H., & Ateş, S. (2025). Treatment of real pharmaceutical industry wastewater by photo-Fenton oxidation using the response surface methodology, evaluation of diclofenac degradation and toxicity. *Engineering Science and Technology, an International Journal*, 64, 102004. <https://doi.org/10.1016/j.jestch.2025.102004>

Patel, M., Kumar, R., Kishor, K., Mlsna, T., Pittman, C. U., & Mohan, D. (2019). Pharmaceuticals of Emerging Concern in Aquatic Systems: Chemistry, Occurrence, Effects, and Removal Methods. *Chemical Reviews*, 119(6), 3510–3673. <https://doi.org/10.1021/acs.chemrev.8b00299>

Pemerintah Republik Indonesia. (2014). *Undang-Undang Republik Indonesia Nomor 3 Tahun 2014 tentang Perindustrian*.

Pemerintah Republik Indonesia. (2021). *Peraturan Pemerintah Republik Indonesia Nomor 22 Tahun 2021 tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup*.

Pemerintah Republik Indonesia. (2023). *Undang-Undang Republik Indonesia Nomor 17 Tahun 2023 tentang Kesehatan*.

- Pérez, J. F., Llanos, J., Sáez, C., López, C., Cañizares, P., & Rodrigo, M. A. (2017). Treatment of real effluents from the pharmaceutical industry: A comparison between Fenton oxidation and conductive-diamond electro-oxidation. *Journal of Environmental Management*, 195, 216–223. <https://doi.org/10.1016/j.jenvman.2016.08.009>
- Peruzzi, V., Torresan, S., Cortiula, F., Fanelli, M., Ermacora, P., Girometti, R., & Cereser, L. (2023). Unveiling the Potential of Venn Diagrams as a Helpful Tool for Clinical Reasoning: An Illustrative Case-based Discussion. *Current Problems in Diagnostic Radiology*, 52(6), 478–481. <https://doi.org/10.1067/j.cpradiol.2023.06.002>
- Picalho, A. C., Lucas, E. R. D. O., & Amorim, I. S. (2022). Lógica booleana aplicada na construção de expressões de busca. *AtoZ: Novas Práticas Em Informação e Conhecimento*, 11, 1. <https://doi.org/10.5380/atoz.v11i0.81838>
- Pineau, L., & Cordier, V. (2025). Water sample stability. *Environmental Technology & Innovation*, 38, 104080. <https://doi.org/10.1016/j.eti.2025.104080>
- Pohl, L., Winkler, P., Mikutta, R., Rücknagel, J., & Gerwin, W. (2025). Potential of Fe sludge addition to increase the water holding capacity of sandy soil substrates. *Journal of Environmental Management*, 393, 126870. <https://doi.org/10.1016/j.jenvman.2025.126870>
- Pollet, B. G., & Kalanur, S. S. (2024). Applications of Ferric Oxide in Water Splitting by Electrolysis: A Comprehensive Review. *Molecules*, 29(21), 4990. <https://doi.org/10.3390/molecules29214990>
- Popovic, A., Milicevic, S., Milosevic, V., Ivosevic, B., Carapic, J., Jovanovic, V., & Povrenovic, D. (2019). Fenton process in dispersed systems for industrial wastewater treatment. *Hemijaska Industrija*, 73(1), 47–62. <https://doi.org/10.2298/HEMIND181019005P>

- Pranckutė, R. (2021). Web of Science (WoS) and Scopus: The Titans of Bibliographic Information in Today's Academic World. *Publications*, 9(1), 12. <https://doi.org/10.3390/publications9010012>
- Pratiwi, W. Z., Hadiyanto, H., & Widayat, W. (2025). Ozone-based Advanced Oxidation Process for pharmaceutical contamination in wastewater: A review. *E3S Web of Conferences*, 605, 03058. <https://doi.org/10.1051/e3sconf/202560503058>
- Prowse, S. R., Brazzelli, M., Green, H. R., & Treweek, S. (2026). International Stakeholder Guidance for Improving Informativeness of Randomized Clinical Trials. *JAMA Network Open*, 9(6), e2619487. <https://doi.org/10.1001/jamanetworkopen.2026.19487>
- Puddoo, H., Nithyanandam, R., Taylor's University Malaysia, Nguyenhuynh, T., & Taylor's University Malaysia. (2017). Degradation of the Antibiotic Ceftriaxone by Fenton Oxidation Process and Compound Analysis. *Journal of Physical Science*, 28(3), 95–114. <https://doi.org/10.21315/jps2017.28.3.7>
- Qasim, M., Afridi, M. N., Suhail, S. A., Khan, U. P., Khan, I. A., & Kim, J.-O. (2025). Performance comparison of complete mix reactor and static mixer in ballasted flocculation. *Chemosphere*, 393, 144754. <https://doi.org/10.1016/j.chemosphere.2025.144754>
- Qasim, S. R., & Zhu, G. (2017). *Wastewater Treatment and Reuse, Theory and Design Examples, Volume 1: Principles and Basic Treatment* (Vol. 1) [Print / e-Book]. CRC Press.
- Qi, G., Jia, Y., Liu, W., Wei, Y., Du, B., Fang, W., Guo, Y., Guo, F., Wu, Y., Zou, Q., & Liu, J. (2020). Leaching behavior and potential ecological risk of heavy metals in Southwestern China soils applied with sewage sludge compost under acid precipitation based on lysimeter trials. *Chemosphere*, 249, 126212. <https://doi.org/10.1016/j.chemosphere.2020.126212>

- Qi, J., Jiang, G., Wan, Y., Liu, J., & Pi, F. (2023). Nanomaterials-modulated Fenton reactions: Strategies, chemodynamic therapy and future trends. *Chemical Engineering Journal*, 466, 142960. <https://doi.org/10.1016/j.cej.2023.142960>
- Qin, K., Wang, T., Li, W.-T., Lu, Z.-Y., Li, C.-Y., Kuan, W.-F., Su, J.-F., & Chen, C.-L. (2025). A potential closed-loop reutilization of iron sludge for wastewater treatment through the solid state reaction with spent coffee grounds. *Process Safety and Environmental Protection*, 198, 107200. <https://doi.org/10.1016/j.psep.2025.107200>
- Qin, W., Guo, K., Chen, C., & Fang, J. (2024). Differences in the Reaction Mechanisms of Chlorine Atom and Hydroxyl Radical with Organic Compounds: From Thermodynamics to Kinetics. *Environmental Science & Technology*, 58(40), 17886–17897. <https://doi.org/10.1021/acs.est.4c03872>
- Ragunath, S., Velmurugan, C., & Kannan, T. (2017). Optimization of tribological behavior of nano clay particle with sisal/jute/glass/epoxy polymer hybrid composites using RSM. *Polymers for Advanced Technologies*, 28(12), 1813–1822. <https://doi.org/10.1002/pat.4066>
- Raimondo, A., & Bisagni, C. (2024). A Numerical Assessment of the Influence of Local Stress Ratio in the Fatigue Analysis of Post-Buckled Composite Single-Stringer Specimen. *Journal of Composites Science*, 8(4), 143. <https://doi.org/10.3390/jcs8040143>
- Rais, D. R., & Setiawan, O. (2024). Pengolahan limbah cair industri sarung dengan metode fenton. *Jurnal Intergrasi Proses Dan Lingkungan*, 1(2), 55–61.
- Rajaniemi, K., Heponiemi, A., Hu, T., Bergna, D., Tuomikoski, S., & Lassi, U. (2023). Use of Fe and Al Containing Electrocoagulation Sludge as an Adsorbent and a Catalyst in Water Treatment. *Journal of Environmental Engineering*, 149(3), 04022097. <https://doi.org/10.1061/JOEEDU.EEENG-6973>

Ramli, S. B., Aziz, M. Y., Shafie, F. A., & Ishak, A. R. (2021). *Optimization of Fenton Oxidation Process for the Palm Oil Mill Effluent (POME) Treatment and Its Phytotoxicity Effect*.

Ramteke, L. P., & Gogate, P. R. (2016). Treatment of real industrial wastewater using the combined approach of advanced oxidation followed by aerobic oxidation. *Environmental Science and Pollution Research*, 23(10), 9712–9729. <https://doi.org/10.1007/s11356-016-6156-9>

Ravikumar, M., Velmurugan, K., John, A. J., & Selvarajan, E. (2024). Microalgae to remove pharmaceutical and personal care products (PPCPs) from wastewater. *Biocatalysis and Agricultural Biotechnology*, 62, 103415. <https://doi.org/10.1016/j.bcab.2024.103415>

Razavi, S., & Gupta, H. V. (2015). What do we mean by sensitivity analysis? The need for comprehensive characterization of “global” sensitivity in Earth and Environmental systems models. *Water Resources Research*, 51(5), 3070–3092. <https://doi.org/10.1002/2014WR016527>

Rebosura, M., Salehin, S., Pikaar, I., Sun, X., Keller, J., Sharma, K., & Yuan, Z. (2018). A comprehensive laboratory assessment of the effects of sewer-dosed iron salts on wastewater treatment processes. *Water Research*, 146, 109–117. <https://doi.org/10.1016/j.watres.2018.09.021>

Regti, A., Laamari, M. R., Stiriba, S.-E., & El Haddad, M. (2017). Use of response factorial design for process optimization of basic dye adsorption onto activated carbon derived from *Persea* species. *Microchemical Journal*, 130, 129–136. <https://doi.org/10.1016/j.microc.2016.08.012>

Rekhate, C., & J. K, S. (2019). Fenton Oxidation Process as Remedial Solution for Sewage Water. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.3366881>

Ribeiro, J. P., Marques, C. C., Neves, M. C., Gomes, H. G. M. F., Sarinho, L., Tarelho, L. A. C., & Nunes, M. I. (2025). Catalytic performance of thermochemically treated sludge generated in the Fenton process for AOX

degradation. *Journal of Industrial and Engineering Chemistry*, 144, 337–345.
<https://doi.org/10.1016/j.jiec.2024.09.028>

Ribeiro, J. P., Marques, C. C., Portugal, I., & Nunes, M. I. (2020). Fenton processes for AOX removal from a kraft pulp bleaching industrial wastewater: Optimisation of operating conditions and cost assessment. *Journal of Environmental Chemical Engineering*, 8(4), 104032. <https://doi.org/10.1016/j.jece.2020.104032>

Ribeiro, J. P., Sarinho, L., & Nunes, M. I. (2024). Application of life cycle assessment to Fenton processes in wastewater treatment – A review. *Journal of Water Process Engineering*, 57, 104692.
<https://doi.org/10.1016/j.jwpe.2023.104692>

Riswanto, F. D. O., Rohman, A., Pramono, S., & Martono, S. (2019). Application of response surface methodology as mathematical and statistical tools in natural product research. *Journal of Applied Pharmaceutical Science*, 9(10), 125–133.
<https://doi.org/10.7324/JAPS.2019.91018>

Rossi, G. B., Carneiro Da Cunha, J., & Urdan, A. T. (2023). Procedimentos metodológicos para a seleção de material para a Revisão Estruturada da Literatura. *ReMark - Revista Brasileira de Marketing*, 21(5), 1480–1526.
<https://doi.org/10.5585/remark.v21i5.23454>

Roudi, A. M., Salem, S., Abedini, M., Maslahati, A., & Imran, M. (2021). Response Surface Methodology (RSM)-Based Prediction and Optimization of the Fenton Process in Landfill Leachate Decolorization. *Processes*, 9(12), 2284.
<https://doi.org/10.3390/pr9122284>

Roy, S., Kr Saha, A., Panda, S., & Dey, G. (2023). Optimization of turmeric oil extraction in an annular supercritical fluid extractor by comparing BBD-RSM and FCCD-RSM approaches. *Materials Today: Proceedings*, 76, 47–55.
<https://doi.org/10.1016/j.matpr.2022.09.039>

- Rudolf, P., Maršálek, B., Maršálková, E., Krajcar, I., Pochylý, F., Fialová, S., & Balko, M. (2023). *Removal of biological and chemical contaminants using ozonization and UV photolysis*. 030017. <https://doi.org/10.1063/5.0122248>
- Rumky, J., Ncibi, M. C., Burgos-Castillo, R. C., Deb, A., & Sillanpää, M. (2018). Optimization of integrated ultrasonic-Fenton system for metal removal and dewatering of anaerobically digested sludge by Box-Behnken design. *Science of The Total Environment*, 645, 573–584. <https://doi.org/10.1016/j.scitotenv.2018.07.125>
- Russell, J., Berney, L., Stansfeld, S., Lanz, D., Kerry, S., Chandola, T., & Bhui, K. (2016). The role of qualitative research in adding value to a randomised controlled trial: Lessons from a pilot study of a guided e-learning intervention for managers to improve employee wellbeing and reduce sickness absence. *Trials*, 17(1), 396. <https://doi.org/10.1186/s13063-016-1497-8>
- Rys, P. (2026). The mixing-sensitive product distribution of chemical reactions. In A. Gyr & F. S. Rys, *Physical Processes and Chemical Reactions in Liquid Flows* (1st ed., pp. 17–37). CRC Press. <https://doi.org/10.1201/9781003761495-2>
- Sa'adah, F., Sutanto, H., Hadiyanto, H., Khumaeni, A., & Pratiwi, W. Z. (2025). Monitoring and antibiotic detection from a pharmaceutical wastewater treatment plant: A case study from an Indonesia pharmaceutical industry. *Journal of Ecological Engineering*, 26(10), 42–57. <https://doi.org/10.12911/22998993/205250>
- Saeed, M. O., Azizli, K., Isa, M. H., & Bashir, M. J. K. (2015). Application of CCD in RSM to obtain optimize treatment of POME using Fenton oxidation process. *Journal of Water Process Engineering*, 8, e7–e16. <https://doi.org/10.1016/j.jwpe.2014.11.001>
- Sahu, A., Silori, R., & Bilouhan, V. (2022). Qualitative and Comparative Assessment of Pharmaceutical Industry Effluents in Selaqui Region. In V. P. Singh, Z. Li, N. A. Siddiqui, & H. Patel (Eds.), *Sustainable Infrastructure Development*

(Vol. 199, pp. 135–145). Springer Singapore. https://doi.org/10.1007/978-981-16-6647-6_13

Saini, R., & Kumar, P. (2016). Optimization of chlorpyrifos degradation by Fenton oxidation using CCD and ANFIS computing technique. *Journal of Environmental Chemical Engineering*, 4(3), 2952–2963. <https://doi.org/10.1016/j.jece.2016.06.003>

Salgado, P., Melin, V., Albornoz, M., Mansilla, H., Vidal, G., & Contreras, D. (2018). Effects of pH and substituted 1,2-dihydroxybenzenes on the reaction pathway of Fenton-like systems. *Applied Catalysis B: Environmental*, 226, 93–102. <https://doi.org/10.1016/j.apcatb.2017.12.035>

Samy, M., Alalm, M. G., & Mossad, M. (2020). Utilization of iron sludge resulted from electro-coagulation in heterogeneous photo-Fenton process. *Water Practice and Technology*, 15(4), 1228–1237. <https://doi.org/10.2166/wpt.2020.093>

Sang, N. D. (2021). Estimate half-life of thermoluminescence signals according to the different models by using Python. *Journal of Taibah University for Science*, 15(1), 599–608. <https://doi.org/10.1080/16583655.2021.1996113>

Sanoja-Lopez, K. A., Balu, A. M., Carmona, H. D. P., Hájek, M., Luque, R., & Herrador, J. M. H. (2025). A Practical Guide to Heterogeneous Catalysis in Hydrocarbon Transformations. *Chemistry – An Asian Journal*, 20(20), e00635. <https://doi.org/10.1002/asia.202500635>

Sari, D. N., Amelia, D., Ramadhon, M. D., & Tiandho, Y. (2022). Utilization of iron scrap for palm oil mill effluent treatment by fenton and photo-fenton processes. *Jurnal Sains Natural*, 12(2), 73–77.

Sarkale, P., Chougale, S., Patil, P., Jadhav, A., & Pathade, G. (2025). Fenton Process for The Treatment of Wastewater Effluent from the Pharmaceutical Industry. *Journal of Neonatal Surgery*, 14(24s), 889–894.

Savaş, A., Uslu, S., & Şener, R. (2025). Optimization of performance and emission characteristics of a diesel engine fueled with MgCO₃ nanoparticle doped second

generation biodiesel from jojoba by using response surface methodology (RSM). *Fuel*, 381, 133658. <https://doi.org/10.1016/j.fuel.2024.133658>

Schuurmans, J. H. A., Zondag, S. D. A., Chaudhuri, A., Van Der Schaaf, J., & Noël, T. (2026). Stirring the Debate: How Mixing Influences Reproducibility and Efficiency in Synthetic Organic Chemistry. *ACS Central Science*, 12(1), 7–13. <https://doi.org/10.1021/acscentsci.5c01825>

Senguttuvan, K. R. M., Kuppusamy, S., & Sellappa, K. (2025). Comparative Study of Fenton and Photo-Fenton Processes for the Treatment of Distillery Wastewater: Pollutant Removal Efficiency and Kinetic Analysis. *Global NEST Journal*. <https://doi.org/10.30955/gnj.07452>

Shahid, M., Zhou, Y., Tang, R.-C., Chen, G., & Wani, W. A. (2017). Colourful and antioxidant silk with chlorogenic acid: Process development and optimization by central composite design. *Dyes and Pigments*, 138, 30–38. <https://doi.org/10.1016/j.dyepig.2016.11.012>

Shamshad, J., & Ur Rehman, R. (2025). Innovative approaches to sustainable wastewater treatment: A comprehensive exploration of conventional and emerging technologies. *Environmental Science: Advances*, 4(2), 189–222. <https://doi.org/10.1039/D4VA00136B>

Sharma, S., Kapoor, S., & Christian, R. A. (2017). Effect of Fenton process on treatment of simulated textile wastewater: Optimization using response surface methodology. *International Journal of Environmental Science and Technology*, 14(8), 1665–1678. <https://doi.org/10.1007/s13762-017-1253-y>

Shen, J.-H., Horng, J.-J., Wang, Y.-S., & Zeng, Y.-R. (2017). The use of reactive index of hydroxyl radicals to investigate the degradation of acid orange 7 by Fenton process. *Chemosphere*, 182, 364–372. <https://doi.org/10.1016/j.chemosphere.2017.05.043>

Sheng, A., & Wang, Y. (Eds.). (2015). *Manufacturing and engineering technology*. CRC Press/Balkema. <https://doi.org/10.1201/b17735>

- Shetty, R., & Verma, S. (2015). Fenton's Reagent for the Treatment of Pharmaceutical Industry Wastewater. *International Journal of Science and Research*, 4(7), 3093–3096.
- Sillanpää, M., Ncibi, M. C., & Matilainen, A. (2018). Advanced oxidation processes for the removal of natural organic matter from drinking water sources: A comprehensive review. *Journal of Environmental Management*, 208, 56–76. <https://doi.org/10.1016/j.jenvman.2017.12.009>
- Silva, T. F. C. V., Fonseca, A., Saraiva, I., Boaventura, R. A. R., & Vilar, V. J. P. (2016). Scale-up and cost analysis of a photo-Fenton system for sanitary landfill leachate treatment. *Chemical Engineering Journal*, 283, 76–88. <https://doi.org/10.1016/j.cej.2015.07.063>
- Sim, L. N., Jayaraman, P., Lau, Y. H., Chong, T. H., & Wang, R. (2024). Pharmaceutical wastewater treatment using direct contact membrane distillation. *Journal of Water Process Engineering*, 68, 106563. <https://doi.org/10.1016/j.jwpe.2024.106563>
- Singa, P. K., Isa, M. H., Ho, Y.-C., & Lim, J.-W. (2018). Treatment of hazardous waste landfill leachate using Fenton oxidation process. *E3S Web of Conferences*, 34, 02034. <https://doi.org/10.1051/e3sconf/20183402034>
- Singh, V. K., Singh, P., Karmakar, M., Leta, J., & Mayr, P. (2021). The journal coverage of Web of Science, Scopus and Dimensions: A comparative analysis. *Scientometrics*, 126(6), 5113–5142. <https://doi.org/10.1007/s11192-021-03948-5>
- Sivagami, K., Sakthivel, K. P., & Nambi, I. M. (2018). Advanced oxidation processes for the treatment of tannery wastewater. *Journal of Environmental Chemical Engineering*, 6(3), 3656–3663. <https://doi.org/10.1016/j.jece.2017.06.004>
- Sollin, M., Hosseiniinasab, S., Malenfant, J., El-Akhrass, M., Lopez De Arbina, A., Montulet, A., & Frenette, M. (2024). Oxidation of secondary hydroperoxides via α C–H abstraction to form ketones and hydroxyl radicals: Fluorene autoxidation as

a model system. *Canadian Journal of Chemistry*, 102(1), 1–6.
<https://doi.org/10.1139/cjc-2022-0089>

Song, H., Ou, X., Wang, M., Zhang, Y., & Lin, Z. (2022). Water reduction on the facets of Fe(OH)₂: An experimental and DFT study. *Environmental Science: Nano*, 9(9), 3407–3416. <https://doi.org/10.1039/D2EN00629D>

Song, W., Li, J., Wang, Z., Fu, C., Zhang, X., Feng, J., Xu, Z., & Song, Q. (2020). Degradation of bisphenol A by persulfate coupled with dithionite: Optimization using response surface methodology and pathway. *Science of The Total Environment*, 699, 134258. <https://doi.org/10.1016/j.scitotenv.2019.134258>

Srividya, R., Rao, A. V. R., Sameera, S., Bethi, B., Prasad, K., Rao, A., & Botla, G. (2026). Flow Regimes and Reynolds Number. In R. K. Arya, G. D. Verros, & J. P. Davim, *Fluid Mechanics* (1st ed., pp. 147–182). CRC Press.
<https://doi.org/10.1201/9781003739159-5>

Su, T., Wang, Z., Zhou, K., Chen, X., Cheng, Y., Zhang, G., Wu, D. W., & Sun, S.-P. (2021). Advanced treatment of secondary effluent organic matters (EfOM) from an industrial park wastewater treatment plant by Fenton oxidation combining with biological aerated filter. *Science of The Total Environment*, 784, 147204. <https://doi.org/10.1016/j.scitotenv.2021.147204>

Su, X., Li, X., Ma, L., & Fan, J. (2019). Formation and transformation of schwertmannite in the classic Fenton process. *Journal of Environmental Sciences*, 82, 145–154. <https://doi.org/10.1016/j.jes.2019.03.004>

Suhendra, S., Aisyah, S., Masri, D., Ali, Y., Andriyanti, S., & Saharja, K. (2024). Preliminary review delone success model with the E-business model among SMEs in medan area. 020052. <https://doi.org/10.1063/5.0203774>

Sun, J., Pikaar, I., Sharma, K. R., Keller, J., & Yuan, Z. (2015). Feasibility of sulfide control in sewers by reuse of iron rich drinking water treatment sludge. *Water Research*, 71, 150–159. <https://doi.org/10.1016/j.watres.2014.12.044>

- Suphirat, C., & Pradubsri, W. (2024). Comparison of the Three Types of Central Composite Designs Over Subsets of Reduced Models by Design Optimality Criteria. *Trends in Sciences*, 21(11), 8193. <https://doi.org/10.48048/tis.2024.8193>
- Suwannahong, K., Wongcharee, S., Kreanuarte, J., & Kreetachat, T. (2021). Pre-treatment of acetic acid from food processing wastewater using response surface methodology via Fenton oxidation process for sustainable water reuse. *Journal of Sustainable Development of Energy, Water and Environment Systems*, 9(4), 1–18. <https://doi.org/10.13044/j.sdewes.d8.0363>
- Suyantara, G. P. W., Hirajima, T., Miki, H., Sasaki, K., Yamane, M., Takida, E., Kuroiwa, S., & Imaizumi, Y. (2018). Selective flotation of chalcopyrite and molybdenite using H₂O₂ oxidation method with the addition of ferrous sulfate. *Minerals Engineering*, 122, 312–326. <https://doi.org/10.1016/j.mineng.2018.02.005>
- Süzen, Y., & Ozmetin, C. (2019). Removal of Reactive Black 5 dye using Fenton oxidation from aqueous solutions and optimization of response surface methodology. *Desalination and Water Treatment*, 172, 106–114. <https://doi.org/10.5004/dwt.2019.24943>
- Tahmasebi, A., Ghaffari, S.-B., & Sarrafzadeh, M.-H. (2024). Techno-economic comparison of two hydroxyl and sulfate radicals based advanced oxidation process for enhancing biodegradability of pulp and paper mill wastewater. *Chemical Engineering Science*, 293, 120095. <https://doi.org/10.1016/j.ces.2024.120095>
- Taira, K., McInnes, D., & Zhang, L. (2023). How many data points and how large an R-squared value is essential for Arrhenius plots? *Journal of Catalysis*, 419, 26–36. <https://doi.org/10.1016/j.jcat.2023.01.033>
- Takashina, T. A., Tavares, C. R. G., Mafra, M. R., Kolichski, M. B., & Igarashi-Mafra, L. (2019). Sourwater treatment by fenton process and its effect on phytotoxicity with *Lactuca sativa*. *Acta Scientiarum. Technology*, 41(1), 41288. <https://doi.org/10.4025/actascitechnol.v41i1.41288>

Tao, N., Hu, L., Fang, D., Tarabara, V., & Zhou, L. (2022). Supplementation of tea polyphenols in sludge Fenton oxidation improves sludge dewaterability and reduces chemicals consumption. *Water Research*, 218, 118512. <https://doi.org/10.1016/j.watres.2022.118512>

Tarapara, B., & Divecha, J. (2023). Practical efficient alpha: Encompassing all alphas of central composite design. *Communications in Statistics - Simulation and Computation*, 52(4), 1621–1629. <https://doi.org/10.1080/03610918.2021.1887234>

Tchobanoglous, G., Stensel, D. H., Tsuchihashi, R., Burton, F., Abu-Orf, M., Bowden, G., Pfrang, W., Metcalf & Eddy, Inc, & Albert Einstein College of Medicine (Eds.). (2014). *Wastewater engineering: Treatment and resource recovery* (Fifth Edition). McGraw-Hill Education.

Teresi, J. A., Yu, X., Stewart, A. L., & Hays, R. D. (2022). Guidelines for Designing and Evaluating Feasibility Pilot Studies. *Medical Care*, 60(1), 95–103. <https://doi.org/10.1097/MLR.0000000000001664>

Thakur, A. K., Kumar, R., Kumar, A., Shankar, R., Khan, N. A., Gupta, K. N., Ram, M., & Arya, R. K. (2023). Pharmaceutical waste-water treatment via advanced oxidation based integrated processes: An engineering and economic perspective. *Journal of Water Process Engineering*, 54, 103977. <https://doi.org/10.1016/j.jwpe.2023.103977>

Thwaini, H. H., & Salman, R. H. (2023). Modification of Electro-Fenton Process with Granular Activated Carbon for Phenol Degradation – Optimization by Response Surface Methodology. *Journal of Ecological Engineering*, 24(9), 92–104. <https://doi.org/10.12911/22998993/168411>

Tong, M., Liu, F., Dong, Q., Ma, Z., & Liu, W. (2020). Magnetic Fe₃O₄-deposited flower-like MoS₂ nanocomposites for the Fenton-like Escherichia coli disinfection and diclofenac degradation. *Journal of Hazardous Materials*, 385, 121604. <https://doi.org/10.1016/j.jhazmat.2019.121604>

Trabelsi, A. B. G., Alkallas, F. H., Mansour, S. A., Al Naim, A. F., Alshoaibi, A., Rekik, N., Nour, M. M., & Tony, M. A. (2025). Iron Sludge-Derived Photo-Fenton Reaction for Laundry Wastewater Effluent Oxidation and Process Optimization into Industrial Ecology Symbiosis. *Catalysts*, 15(7), 669. <https://doi.org/10.3390/catal15070669>

Tsuneda, T. (2020). Fenton reaction mechanism generating no OH radicals in Nafion membrane decomposition. *Scientific Reports*, 10(1), 18144. <https://doi.org/10.1038/s41598-020-74646-0>

Turner, B. D., Henley, B. J., Sleep, S. B., & Sloan, S. W. (2015). Kinetic model selection and the Hill model in geochemistry. *International Journal of Environmental Science and Technology*, 12(8), 2545–2558. <https://doi.org/10.1007/s13762-014-0662-4>

Ugbe, T. A., Akpan, P., Ofonodo, R., & Bassey, E. (2023). On Evaluation of Three Basic Properties of Central Composite Design. *Asian Journal of Probability and Statistics*, 23(1), 1–15. <https://doi.org/10.9734/ajpas/2023/v23i1493>

Underhill, R., Lewis, R. J., Freakley, S. J., Douthwaite, M., Miedziak, P. J., Akdim, O., Edwards, J. K., & Hutchings, G. J. (2018). Oxidative Degradation of Phenol using in situ Generated Hydrogen Peroxide Combined with Fenton's Process: Supported palladium-iron catalysts for the removal of model contaminants from wastewater. *Johnson Matthey Technology Review*, 62(4), 417–425. <https://doi.org/10.1595/205651318X15302623075041>

Valderrama-Rios, C., Garcia-Perez, M., Chejne-Janna, F., & Valdés, C. (2025). Fundamentals of kinetic analysis on pyrolysis and gasification reactions. In *Thermochemical Conversion of Lignocellulosic Materials* (pp. 349–407). Elsevier. <https://doi.org/10.1016/B978-0-323-95551-5.00008-3>

Valdiviezo-Gonzales Lorgio, Justiniano Valeria D., Berlanga Kiara N., Molina Julio M., Cabello Torres Rita J., & Garcia Avila Fernando. (2023). Modeling of Chemical Oxygen Demand and Total Suspended Solids Removal Using the Fenton Process.

Chemical Engineering Transactions, 102, 313–318.
<https://doi.org/10.3303/CET23102053>

Varank, G., Yazici Guvenc, S., Gurbuz, G., & Onkal Engin, G. (2016). Statistical optimization of process parameters for tannery wastewater treatment by electrocoagulation and electro-Fenton techniques. *Desalination and Water Treatment*, 57(53), 25460–25473. <https://doi.org/10.1080/19443994.2016.1157042>

Varshney, V., Trivedi, N., Singh, B. K., Rajpoot, A. K., & Singh, V. K. (2025). Challenges in Pharmaceutical and Industrial Wastewater Treatment: In A. S. Grewal, G. Deswal, & A. L. Srivastav (Eds.), *Advances in Environmental Engineering and Green Technologies* (pp. 33–80). IGI Global. <https://doi.org/10.4018/979-8-3693-8487-9.ch002>

Veza, I., Spraggon, M., Fattah, I. M. R., & Idris, M. (2023). Response surface methodology (RSM) for optimizing engine performance and emissions fueled with biofuel: Review of RSM for sustainability energy transition. *Results in Engineering*, 18, 101213. <https://doi.org/10.1016/j.rineng.2023.101213>

Viebig, J., Poddig, T., & Varmaz, A. (Eds.). (2012). Understanding Regressions. In *Equity Valuation* (1st ed., pp. 275–279). Wiley. <https://doi.org/10.1002/9781119208754.ch27>

Villiermaux, E. (2019). Mixing Versus Stirring. *Annual Review of Fluid Mechanics*, 51(1), 245–273. <https://doi.org/10.1146/annurev-fluid-010518-040306>

Vodyanitskii, Yu. N., & Shoba, S. A. (2016). Ferrihydrite in soils. *Eurasian Soil Science*, 49(7), 796–806. <https://doi.org/10.1134/S1064229316070127>

Vogelsang, J., Zachert, H., Huber, G., & Triantafyllidis, Th. (2015). Effects of Soil Deposition on the Initial Stress State in Model Tests: Experimental Results and FE Simulation. In Th. Triantafyllidis (Ed.), *Holistic Simulation of Geotechnical Installation Processes* (Vol. 77, pp. 1–20). Springer International Publishing. https://doi.org/10.1007/978-3-319-18170-7_1

Von Sperling, M. (2007). *Basic Principles of Wastewater Treatment*. IWA Publishing.

Wagdy, A., El-Hazek, A., & Hassanain, A. (2022). Assessment of a Fenton Reaction in treating Greywater for reuse in Irrigation. *Engineering Research Journal - Faculty of Engineering (Shoubra)*, 51(4), 141–148. <https://doi.org/10.21608/erjsh.2022.151400.1062>

Wang, B., Zhao, P., Zhang, X., Zhang, Y., & Liu, Y. (2024). Three-dimensional electro-Fenton system with iron-carbon packing as a particle electrode for nitrobenzene wastewater treatment. *Frontiers of Environmental Science & Engineering*, 18(11), 138. <https://doi.org/10.1007/s11783-024-1898-y>

Wang, G., Tang, K., Jiang, Y., Andersen, H. R., & Zhang, Y. (2020). Regeneration of Fe(II) from Fenton-derived ferric sludge using a novel biocathode. *Bioresource Technology*, 318, 124195. <https://doi.org/10.1016/j.biortech.2020.124195>

Wang, H., Chen, X., Chen, B., Yang, M., & Zhang, B. (2025). Switchable biomaterials for wastewater treatment: From material innovations to technological advancements. *Chemical Engineering Journal*, 509, 160928. <https://doi.org/10.1016/j.cej.2025.160928>

Wang, H., Wang, J., George, U. K., Hussain, S. M., Zhu, C., Ma, Y., & Fu, T. (2026). Synthesis of glyoxylic acid and reaction kinetics of glyoxal by Fenton oxidation in a capillary microreactor. *Chemical Engineering Science*, 327, 123628. <https://doi.org/10.1016/j.ces.2026.123628>

Wang, J., & Tang, J. (2021). Fe-based Fenton-like catalysts for water treatment: Catalytic mechanisms and applications. *Journal of Molecular Liquids*, 332, 115755. <https://doi.org/10.1016/j.molliq.2021.115755>

Wang, J., Zhao, C., Qian, F., Su, J., & Gao, H. (2025). Fate of Dissolved Organic Matter and Cooperation Behavior of Coagulation: Fenton Combined with MBR Treatment for Pharmaceutical Tail Water. *Molecules*, 30(12), 2520. <https://doi.org/10.3390/molecules30122520>

Wang, K. M., Shu, J., Wang, S. J., Hong, T. Y., Xu, X. P., & Wang, H. Y. (2020). Efficient electrochemical generation of ferrate(VI) by iron coil anode imposed with square alternating current and treatment of antibiotics. *Journal of Hazardous Materials*, 384, 121458. <https://doi.org/10.1016/j.jhazmat.2019.121458>

Wang, K., Wang, Z., & Qin, S. (2020). Application of advanced oxidation process combining anaerobic granular sludge on refractory industrial wastewater treatment. *IOP Conference Series: Earth and Environmental Science*, 474(5), 052095. <https://doi.org/10.1088/1755-1315/474/5/052095>

Wang, L., He, X., Liang, L., Wang, Y., Yan, B., Chen, G., Li, N., & Hou, L. (2025). Removal of COD from Secondary Effluent Using Fenton Iron Sludge-Based Biochar/Fe(VI)/H₂O₂ Process. *Applied Sciences*, 15(11), 5945. <https://doi.org/10.3390/app15115945>

Wang, L., Liang, L., Xu, J., Wang, Y., Yan, B., Chen, G., Li, N., & Hou, L. (2025). Pilot-Scale Fenton-like System for Wastewater Treatment Using Iron Mud Carbon Catalyst. *Applied Sciences*, 15(15), 8210. <https://doi.org/10.3390/app15158210>

Wang, L., Wang, M., Tian, Y., Qi, Y., & Gao, Y. (2022). Experimental and simulation study on mixing time and suspension quality of liquid-solid flow field in stirred reactor with draft tube. *International Journal of Chemical Reactor Engineering*, 20(4), 445–463. <https://doi.org/10.1515/ijcre-2021-0151>

Wang, L., Yang, Q., Wang, D., Li, X., Zeng, G., Li, Z., Deng, Y., Liu, J., & Yi, K. (2016). Advanced landfill leachate treatment using iron-carbon microelectrolysis-Fenton process: Process optimization and column experiments. *Journal of Hazardous Materials*, 318, 460–467. <https://doi.org/10.1016/j.jhazmat.2016.07.033>

Wang, M., Sun, Y., Yu, Q., Zhao, Z., Li, Y., & Zhang, Y. (2023). Sustainable disposal of Fenton sludge and enhanced organics degradation based on dissimilatory iron reduction in the hydrolytic acidification process. *Journal of Hazardous Materials*, 459, 132258. <https://doi.org/10.1016/j.jhazmat.2023.132258>

- Wang, M., Zhao, Z., & Zhang, Y. (2019). Disposal of Fenton sludge with anaerobic digestion and the roles of humic acids involved in Fenton sludge. *Water Research*, 163, 114900. <https://doi.org/10.1016/j.watres.2019.114900>
- Wang, X., Chen, N., Liu, X., Shi, Y., Ling, C., & Zhang, L. (2021). Ascorbate guided conversion of hydrogen peroxide to hydroxyl radical on goethite. *Applied Catalysis B: Environmental*, 282, 119558. <https://doi.org/10.1016/j.apcatb.2020.119558>
- Wang, X., Song, B., Xie, Y., Liu, X., Cheng, J., Chen, T., & Zhang, A. (2026). Influence of Fenton iron sludge on anaerobic digestion and extracellular polymeric substances of anaerobic granular sludge. *Water, Air, & Soil Pollution*, 237(5), 297. <https://doi.org/10.1007/s11270-025-08984-y>
- Wang, Z., Nie, F., Zhang, C., Wang, R., & Li, X. (2024). Worst-Case Discriminative Feature Learning via Max-Min Ratio Analysis. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 46(1), 641–658. <https://doi.org/10.1109/TPAMI.2023.3323453>
- Wanyama, S. B., McQuaid, R. W., & Kittler, M. (2022). Where you search determines what you find: The effects of bibliographic databases on systematic reviews. *International Journal of Social Research Methodology*, 25(3), 409–422. <https://doi.org/10.1080/13645579.2021.1892378>
- Wei, Y., Dai, J., Mackey, H. R., & Chen, G.-H. (2017). The feasibility study of autotrophic denitrification with iron sludge produced for sulfide control. *Water Research*, 122, 226–233. <https://doi.org/10.1016/j.watres.2017.05.073>
- Willden, C., & Jensen, W. A. (2020). Optimal designs with axial values. *Journal of Quality Technology*, 52(3), 235–248. <https://doi.org/10.1080/00224065.2019.1571346>
- Wojnárovits, L., Homlok, R., Kovács, K., Tegze, A., & Takács, E. (2024). Oxidation and mineralization rates of harmful organic chemicals in hydroxyl radical induced

reactions. *Ecotoxicology and Environmental Safety*, 281, 116669. <https://doi.org/10.1016/j.ecoenv.2024.116669>

Wong, B. (2019). An Irreversible Thermodynamic Perspective on Chemical Reaction Kinetics in Ceramic Processing under Resonant Microwave-Fields. *Contributed Papers from MS&T19*, 174–181. https://doi.org/10.7449/2019/MST_2019_174_181

Wu, H., Luo, X., & Mu, S. (2026). The Fe sites in non-precious metal nanocatalysts toward efficient water oxidation. *Nanoscale Horizons*, 10.1039.D6NH00223D. <https://doi.org/10.1039/D6NH00223D>

Wu, P., Li, J., Li, S., & Tao, F.-M. (2012). Theoretical study of mechanism and kinetics for the addition of hydroxyl radical to phenol. *Science China Chemistry*, 55(2), 270–276. <https://doi.org/10.1007/s11426-011-4380-1>

Xiao, J., Guo, S., Wang, D., & An, Q. (2024). Fenton-Like Reaction: Recent Advances and New Trends. *Chemistry – A European Journal*, 30(24), e202304337. <https://doi.org/10.1002/chem.202304337>

Xu, H., Li, M., Wu, F., & Zhang, J. (2015). Optimization of Fenton oxidation process for treatment of hexogen industrial wastewater using response surface methodology. *Desalination and Water Treatment*, 55(1), 77–85. <https://doi.org/10.1080/19443994.2014.912962>

Xu, H.-Y., Wang, Y., Shi, T.-N., Zhao, H., Tan, Q., Zhao, B.-C., He, X.-L., & Qi, S.-Y. (2018). Heterogeneous Fenton-like discoloration of methyl orange using Fe₃O₄/MWCNTs as catalyst: Kinetics and Fenton-like mechanism. *Frontiers of Materials Science*, 12(1), 34–44. <https://doi.org/10.1007/s11706-018-0412-5>

Xu, J., Fan, P., Dong, Y., Xu, L., & Zheng, Y. (2020). Oriented oxidation of all alkanes in soils. *Journal of Hazardous Materials*, 399, 123078. <https://doi.org/10.1016/j.jhazmat.2020.123078>

Xu, J., Gu, K., Wang, P., Cheng, P., Che, H., Tang, C., Zhang, K., & Ao, Y. (2025). Piezo-catalytic in-site H₂O₂ generation and activation across wide pH range to

drive hydroxyl radical-mediated pollutant degradation. *Nature Communications*, 16(1), 7908. <https://doi.org/10.1038/s41467-025-63337-x>

Xu, J., Rong, Y., Liu, L., Bai, W., & Dai, J. (2024). Efficient Fenton oriented oxidation of petroleum hydrocarbons in soil by regulating hydrophilic functional groups in soil organic matter. *Journal of Environmental Chemical Engineering*, 12(1), 111772. <https://doi.org/10.1016/j.jece.2023.111772>

Xu, J., Yang, C., Li, L., Huang, T., & Huang, R. (2018). Enhancing the Removal of Sorbed Crude Oil from Soil Through Multiple Oxidation Steps in Stepwise Fenton Processes. *Soil and Sediment Contamination: An International Journal*, 27(5), 369–382. <https://doi.org/10.1080/15320383.2018.1479831>

Xu, X., Pliego, G., Zazo, J. A., Liu, S., Casas, J. A., & Rodriguez, J. J. (2018). Two-step persulfate and Fenton oxidation of naphthenic acids in water. *Journal of Chemical Technology & Biotechnology*, 93(8), 2262–2270. <https://doi.org/10.1002/jctb.5569>

Yabuno, Y., Tamai, M., Shiraishi, T., Teshima, N., Shiode, K., Yasui, T., Miyake, K., Nishikawa, T., Matsumoto, K., Nakanishi, H., Murata, S., Komatsu, K., Ogita, D., & Inoue, K. (2026). Commercial-scale, long-term operation of an energy-efficient ultrafiltration plant employing hydraulic rapid mixing for coagulation and compressed air-driven backwash. *Desalination*, 630, 120180. <https://doi.org/10.1016/j.desal.2026.120180>

Yamabe, S., & Yamazaki, S. (2018). A DFT study of proton transfers for the reaction of phenol and hydroxyl radical leading to dihydroxybenzene and H₂O in the water cluster. *International Journal of Quantum Chemistry*, 118(6), e25510. <https://doi.org/10.1002/qua.25510>

Yang, C., Chu, G.-W., Feng, X., Li, Y.-B., Chen, J., Wang, D., Duan, X., & Chen, J.-F. (2025). Mixing Intensification for Advanced Materials Manufacturing. *Engineering*, 44, 135–144. <https://doi.org/10.1016/j.eng.2024.12.019>

- Yang, H., Wu, Y., Zheng, X., Wu, S., Zhang, B., Hu, L., Guo, X., & Wu, B. (2023). A review on gaseous pollutants purification using H₂O₂-based Fenton-like reactions. *Journal of Environmental Chemical Engineering*, 11(5), 111066. <https://doi.org/10.1016/j.jece.2023.111066>
- Yao, W., Ma, X., Li, S., Gao, Y., Nian, F., & Zhou, L. (2018). Theoretical study of mechanism and kinetics for the reaction of hydroxyl radical with 2'-deoxycytidine. *Structural Chemistry*, 29(5), 1359–1366. <https://doi.org/10.1007/s11224-018-1122-4>
- Yasuma, N., Narita, Z., Sasaki, N., Obikane, E., Sekiya, J., Inagawa, T., Nakajima, A., Yamada, Y., Yamazaki, R., Matsunaga, A., Saito, T., Watanabe, K., Imamura, K., Kawakami, N., & Nishi, D. (2019). Psychological intervention for universal prevention of antenatal and postnatal depression among pregnant women: Protocol for a systematic review and meta-analysis. *Systematic Reviews*, 8(1), 297. <https://doi.org/10.1186/s13643-019-1238-7>
- Yazici Guvenc, S., & Varank, G. (2021). Degradation of refractory organics in concentrated leachate by the Fenton process: Central composite design for process optimization. *Frontiers of Environmental Science & Engineering*, 15(1), 2. <https://doi.org/10.1007/s11783-020-1294-1>
- Yin, Y., Xu, H., Zhu, Y., Zhuang, J., Ma, R., Cui, D., & Jiao, Z. (2023). Recent Progress in Applications of Atmospheric Pressure Plasma for Water Organic Contaminants' Degradation. *Applied Sciences*, 13(23), 12631. <https://doi.org/10.3390/app132312631>
- Yong, S. C., Shuit, S. H., Thiam, H. S., Tee, S. F., & Issabayeva, G. (2026). Fenton oxidation as a practical primary treatment for raw paper mill wastewater: A real case study. *Environmental Progress & Sustainable Energy*, 45(3), e70362. <https://doi.org/10.1002/ep.70362>
- Yonteck, C. L., Longo, P. J., Bursaw, K. L., & Acosta, S. A. (2025). Large Diameter HDPE Design Considerations and Lessons Learned. *Pipelines 2025*, 191–198. <https://doi.org/10.1061/9780784486368.021>

- Yu, R. (2015). Effective Pharmaceutical Wastewater Degradation via SCWO with Ethylene Glycol. *Polish Journal of Environmental Studies*, 24, 249–252. <https://doi.org/10.15244/pjoes/27174>
- Yu, X., Cabrera-Reina, A., Graells, M., Miralles-Cuevas, S., & Pérez-Moya, M. (2021). Towards an Efficient Generalization of the Online Dosage of Hydrogen Peroxide in Photo-Fenton Process to Treat Industrial Wastewater. *International Journal of Environmental Research and Public Health*, 18(24), 13313. <https://doi.org/10.3390/ijerph182413313>
- Yun, D., Kang, D., Cho, K. H., Baek, S.-S., & Jeon, J. (2023). Characterization of micropollutants in urban stormwater using high-resolution monitoring and machine learning. *Water Research*, 235, 119865. <https://doi.org/10.1016/j.watres.2023.119865>
- Zaman, B., Hardyanti, N., Pramesti, I. A., & William, G. S. (2024). The effect of fenton oxidation on the quality of pharmaceutical industry wastewater: A case study of bod, cod, toc, and turbidity parameters. *IOP Conference Series: Earth and Environmental Science*, 1414(1), 012036. <https://doi.org/10.1088/1755-1315/1414/1/012036>
- Zeng, G., Shi, M., Dai, M., Zhou, Q., Luo, H., Lin, L., Zang, K., Meng, Z., & Pan, X. (2023). Hydroxyl radicals in natural waters: Light/dark mechanisms, changes and scavenging effects. *Science of The Total Environment*, 868, 161533. <https://doi.org/10.1016/j.scitotenv.2023.161533>
- Zeng, H., Zhang, G., Ji, Q., Liu, H., Hua, X., Xia, H., Sillanpää, M., & Qu, J. (2020). pH-Independent Production of Hydroxyl Radical from Atomic H^{*}-Mediated Electrocatalytic H₂O₂ Reduction: A Green Fenton Process without Byproducts. *Environmental Science & Technology*, 54(22), 14725–14731. <https://doi.org/10.1021/acs.est.0c04694>
- Zhang, C., Lei, L., Li, Y., & Chen, J. (2017). Integrated Ozonation and Biotreatment of Bio-Treated Pulp Wastewater. *BioResources*, 12(2), 3864–3875. <https://doi.org/10.15376/biores.12.2.3864-3875>

Zhang, C., Wang, X., Zou, X., Tian, J., Liu, B., Li, J., Kang, L., Chen, H., & Wu, Y. (2018). Estimation of surface shear strength of undisturbed soils in the eastern part of northern China's wind erosion area. *Soil and Tillage Research*, 178, 1–10. <https://doi.org/10.1016/j.still.2017.12.014>

Zhang, M., Dong, H., Zhao, L., Wang, D., & Meng, D. (2019). A review on Fenton process for organic wastewater treatment based on optimization perspective. *Science of The Total Environment*, 670, 110–121. <https://doi.org/10.1016/j.scitotenv.2019.03.180>

Zhang, M., Zhang, Y., Zhong, H., Li, L., & Cao, Z. (2023). Interfacial evolution: A hydrothermal activation strategy to boost OER activity for stainless steel. *Journal of the Taiwan Institute of Chemical Engineers*, 153, 105201. <https://doi.org/10.1016/j.jtice.2023.105201>

Zhang, P., Liu, J., Yu, H., Cheng, D., Liu, H., & Yuan, S. (2023). Kinetic models for hydroxyl radical production and contaminant removal during soil/sediment oxygenation. *Water Research*, 240, 120071. <https://doi.org/10.1016/j.watres.2023.120071>

Zhang, T., Wen, Y., Pan, Z., Kuwahara, Y., Mori, K., Yamashita, H., Zhao, Y., & Qian, X. (2022). Overcoming Acidic H₂O₂/Fe(II/III) Redox-Induced Low H₂O₂ Utilization Efficiency by Carbon Quantum Dots Fenton-like Catalysis. *Environmental Science & Technology*, 56(4), 2617–2625. <https://doi.org/10.1021/acs.est.1c06276>

Zhang, Y., Wei, B., & Tang, R. (2023). Theoretical Study on the Mechanisms, Kinetics, and Toxicity Evaluation of OH-Initiated Atmospheric Oxidation Reactions of Coniferyl Alcohol. *Atmosphere*, 14(6), 976. <https://doi.org/10.3390/atmos14060976>

Zhao, J., Zhong, P., Luo, W., Zhang, S., Xu, S., Yu, Q., & Qiu, X. (2022). Insight into in-situ chemical oxidation by Fe(II)-containing minerals: The role of inherent Fe(II)-OH in Fe(II)-Al LDHs. *Chemical Engineering Journal*, 433, 133835. <https://doi.org/10.1016/j.cej.2021.133835>

Zhao, M., Cui, Z., Fu, L., Ndayisenga, F., & Zhou, D. (2021). *Shewanella* Drive Fe(III) Reduction to Promote Electro-Fenton Reactions and Enhance Fe Inner-Cycle. *ACS ES&T Water*, 1(3), 613–620. <https://doi.org/10.1021/acsestwater.0c00126>

Zhao, M., Zhang, S., Pan, D., Chen, L., Xiao, X., & Mei, K. (2026). Organic carbon mineralization and its impact on metal behavior in sediments of the Yellow Sea and East China Sea. *Journal of Marine Systems*, 255, 104221. <https://doi.org/10.1016/j.jmarsys.2026.104221>

Zhou, D., Tabassum, S., Li, J., Zhang, L., Zhang, N., Li, G., Altundag, H., & Khan, I. (2026). Efficient Fenton/biological activated carbon filter process for treating landfill leachates. *Environmental Science: Advances*, 5(6), 1594–1613. <https://doi.org/10.1039/D6VA00072J>

Zhou, S., Jia, Y., Fang, H., Jin, C., Mo, Y., Xiao, Z., Zhang, N., Sun, L., & Lu, H. (2024). A new understanding on the prerequisite of antibiotic biodegradation in wastewater treatment: Adhesive behavior between antibiotic-degrading bacteria and ciprofloxacin. *Water Research*, 252, 121226. <https://doi.org/10.1016/j.watres.2024.121226>

Zhu, J., Wang, Z., Lv, J., Song, X., Mu, S., & Liu, D. (2026). Flow and mixing of stirred tank reactors under continuous feeding. *Physics of Fluids*, 38(7), 078126. <https://doi.org/10.1063/5.0342465>

Zhu, W.-J., Cui, Y.-W., & Yang, H.-J. (2024). Treatment of volatile ethanol gas emitted by pharmaceutical manufacturing industry in a combination process of spraying absorption and wastewater biological treatment. *Journal of Environmental Chemical Engineering*, 12(6), 114582. <https://doi.org/10.1016/j.jece.2024.114582>