EFFECTIVENESS OF THE COMBINATION OF MOVING BED BIOFILM REACTOR, ADSORPTION AND FENTON OXIDATION TO REDUCE BATIK WASTE WATER POLLUTION

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Abstract

Batik wastewater has a high organic and color content, requiring special treatment to meet environmental quality standards. This wastewater has an initial BOD_5 of 605.405 mg/L, COD 714 mg/L, TSS 360 mg/L, and Pt-Co color of 992.2, far exceeding the quality standards. This study aimed to determine the effectiveness of a Moving Bed Biofilm Reactor (MBBR) combination with rice husk geopolymer-based adsorption and Fenton oxidation post-treatment in removing pollutants from Sidoarjo batik wastewater. Variations in HRT, adsorbent mass, MBBR media type, and chemical ratio were the independent variables in this study. The results showed that the MBBR-adsorption treatment unit performed better than the MBBR without adsorption. The MBBR-adsorption unit with wood charcoal media, HRT 48 hours, and adsorbent mass 20 grams were the most optimal conditions for reducing COD and BOD_5, with removal values of 93.6% and 95.8%, respectively. Meanwhile, the most optimal color and TSS removal was achieved with a 48-hour HRT MBBR adsorption, Kaldness K3 media, and 20 grams of adsorbent mass, with values of 90.3% and 94.4%, respectively. The addition of the Fenton process after the MBBR adsorption process increased the efficiency of TSS and color removal, with a $FeSO_2$:H_2O_2 ratio of 1:3, resulting in a 50% increase in TSS and 52.2% increase in color removal.

Keywords: *moving bed biofilm reactor*, *adsorption*, *geopolymer*, *batik waste*, *Fenton oxidation*

Introduction

The batik production process goes through several stages that ultimately produce waste containing organic materials, TSS, and color. One technology that can be used to degrade high organic substances is by using microorganisms (Wahyu & Hendrasarie, 2022). One effective and simple method for treating batik wastewater is by using a Moving Bed Biofilm Reactor (MBBR). The use of different media types affects the MBBR process in removing pollutants. The removal effectiveness of MBBR treatment using wood charcoal media is three times better than PE plastic media in nitrification and denitrification capabilities (Liu et al., 2022). However, textile waste treated using MBBR was able to reduce COD by 79.31% at a 48-hour HRT but color removal was only able to reach 64.7% (Suryawan et al., 2022). Color processing can be optimized by adding physical processing, one of which is using adsorption. Previous research has modified fly ash into a geopolymer for adsorbent and is capable of adsorbing methylene blue dye up to 50.7 mg/g (Fitriani et al., 2021). Based on this background, this study will apply geopolymer from rice husk ash as an adsorbent by combining it with an aerobic Moving Bed Biofilm Reactor in batch to reduce batik wastewater pollutants.

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Research Methodology

This study used batik wastewater from a batik in Jetis Batik Village, Sidoarjo, East Java. The equipment used in the study included a storage tank, a flow control tank, an aerobic MBBR reactor, a settling tank, an adsorption column, an effluent tank, and a post-treatment reactor. A diagram of the batik wastewater treatment reactor can be seen in Figure 1.

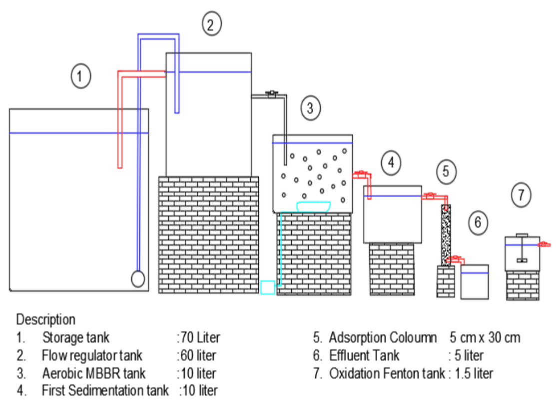

Figure 1. Sketch of the Research Reactor

The parameters tested included BOD_5, COD, TSS, and color. Preliminary research in this study included initial testing of the batik wastewater characteristics and a seeding process followed by biomass acclimatization. The results of the initial batik wastewater characteristic analysis are presented in Table 1.

Table 1. Initial Characteristics of Sidoarjo Batik Wastewater

Parameter	Unit	Standard*	Test Result	Analysis
COD	Mg/L	150	714	Do not
BOD	Mg/L	60	605.4	meet the
TSS	Mg/L	50	360	quality
Color	Pt-Co	200	992.2	standard

* Regulation in the Ministry of Environment of the Republic Indonesia no. 16 of the year 2019

Seeding was carried out by adding one tablespoon of table sugar per day to the activated sludge as a nutrient (Anisa et al., 2017). This nutrient supply process was carried out by considering a C:N:P ratio that meets the initial needs of microorganisms under aerobic conditions, namely 100:5:1 (Hendrasari et al., 2023). According to research by Anisah & Hendrasarie (2022), the seeding process can be stopped when the MLSS reaches 2000-5000 mg/L. The seeding process ends when a brownish, non-removable biofilm approximately 1 cm thick forms. Observations are conducted for 30 days until a brownish, non-removable layer of mucus forms, confirming the growth of microorganisms in the medium (Metcalf & Eddy, 2003). MLSS testing yielded results of 3250 mg/L in kaldness media and 3540 mg/L in wood media.

The acclimatization process involves the addition of wastewater at varying concentrations (Sekarani & Hendrasarie, 2020). This process is carried out in stages, increasing the wastewater concentration to 20%, 50%, and 80%. Acclimatization is carried out in batches over a period of 9 days. This study obtained a final COD reduction of 71.43% under aerobic conditions using kaldness media and 66.67% using wood media. This acclimatization process is considered successful if the COD reduction reaches >50% of the initial concentration (Hendrasari & Trilta, 2019). It also meets the steady-state requirement, namely, that COD reduction fluctuations do not exceed 10% (Wahyu & Hendrasari, 2022).

The main research can be conducted after the preliminary research has been successfully and successfully completed. The batik waste to be processed is fed into two types of MBBR reactors: one with kaldness K3 media and one with wood charcoal, with a loading time of 20 minutes. The MBBR is run with an aeration flow of 15 l/minute and varying HRTs for each medium: 8 hours, 24 hours, and 48 hours. The water then flows into a settling tank with a retention time of 2 hours. Several samples are taken for analysis, followed by adsorption processing. Each water from the settling tank enters the adsorption column with a residence time of 60 minutes, with varying adsorbent masses of 20 grams and 15 grams. The treated water with the best BOD_5, COD, TSS, and color values is then subjected to post-treatment.

Results and Discussion

Effect of Hydraulic Retention Time (HRT), adsorbent mass, and MBBR-adsorption media type on the removal of batik waste pollutants

Figure 2, 3, and 4 show the removal of BOD, while Figure 5, 6, and 7 show the removal of COD.

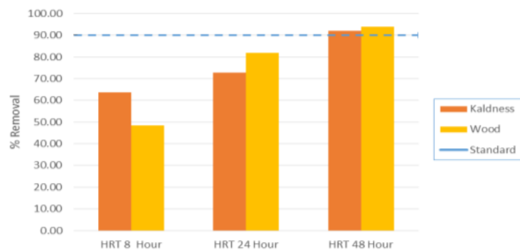

Figure 2. BOD removal MBBR

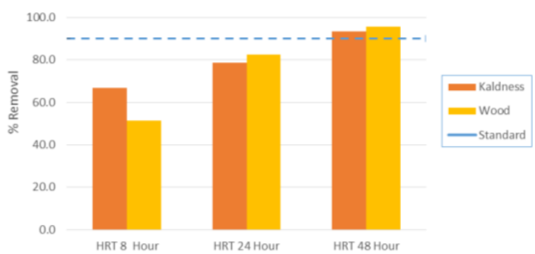

Figure 3 BOD removal MBBR-Adsorption 15 gram

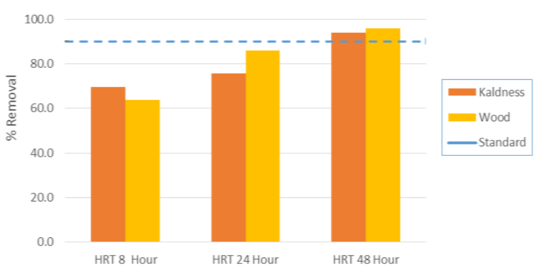

Figure 4. BOD removal MBBR-Adsorption 20 gram

The BOD Removal graph shows a comparison of BOD (Biological Oxygen Demand) removal efficiency using two media, namely Kaldness K3 Media and Wood Charcoal Media, at three variations of Hydraulic Retention Time (HRT): 8 hours, 24 hours, and 48 hours. In general, the graph shows that BOD removal efficiency increases with increasing HRT time for both media. For Kaldness K3 Media, efficiency increased from 63.64% to 93.94% at 48 hours. Meanwhile, the wood charcoal media also showed an increase from 48.48% to 93.94% at the optimal 48-hour HRT. BOD levels in wastewater decreased significantly after undergoing the MBBR process with the addition of adsorbent and increased hydraulic retention time (HRT). The most significant reduction was achieved with the use of 20 grams of adsorbent, resulting in a BOD reduction of 95.8% at 48 hours, MBBR-Adsorption

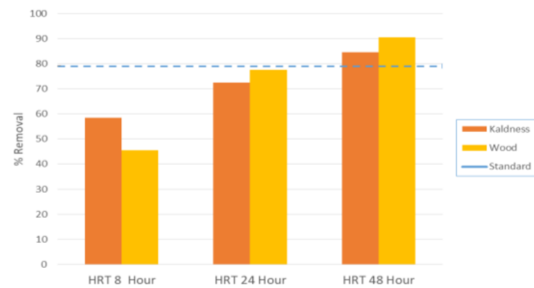

Figure 5. COD removal MBBR

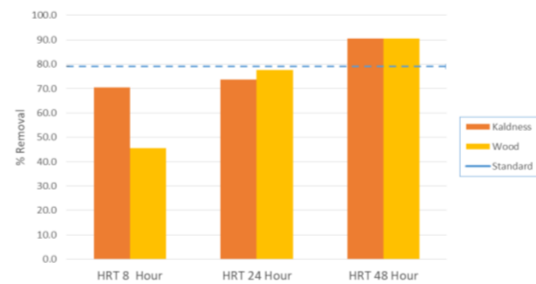

Figure 6. COD removal MBBR-Adsorption 15 gram

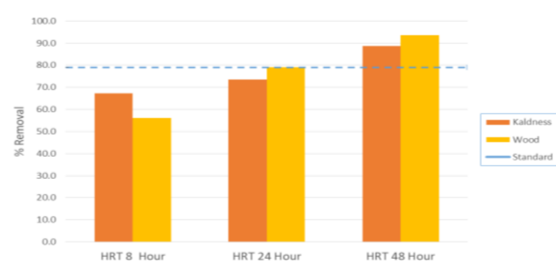

Figure 7. COD removal MBBR-Adsorption 20 gram

Furthermore, the Chemical Oxygen Demand (COD) in the Moving Bed Biofilm Reactor (MBBR) system with a 48-hour HRT using kaldness media achieved the highest removal rate of 84.64%, while the wood charcoal media achieved the highest removal rate of 90.4%. The graph above shows that the Chemical Oxygen Demand (COD) levels in wastewater decreased significantly after undergoing the Moving Bed Biofilm Reactor (MBBR) process with the addition of adsorbent and an increase in Hydraulic Retention Time (HRT). Optimal efficiency was achieved using 20 grams of adsorbent, with COD decreasing by 93.6% after a 48-hour HRT of MBBR adsorption.

Increasing the HRT from 8 to 48 hours can increase BOD_5 and COD reduction by more than 80% due to increased microbial activity, resulting in greater organic matter decomposition (Aldris & Farhoud, 2020). Wood charcoal media produces better BOD and COD reduction due to the presence of macropores, which increase the biofilm surface area, resulting in thicker biofilms and increased organic matter degradation activity (Shitu et al., 2023). The addition of a column adsorption system with activated carbon geopolymer adsorbent to this system significantly contributed to the reduction of BOD5 and COD. This adsorbent is capable of absorbing dissolved organic compounds that are non-biodegradable or slow to decompose, thus supporting the activity of microorganisms in the biofilm (Zhang et al., 2021).

Figure 8, 9 and 10 show the removal percentage of TSS each variation.

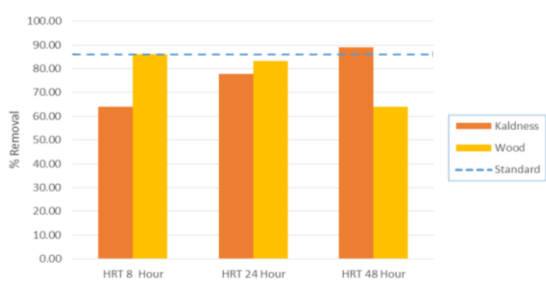

Figure 8. TSS removal MBBR

The Total Suspended Solids (TSS) Removal graph shows a comparison of TSS removal efficiency using two media: Kaldness Media and wood charcoal media, at three different Hydraulic Retention Times (HRTs): 8 hours, 24 hours, and 48 hours.

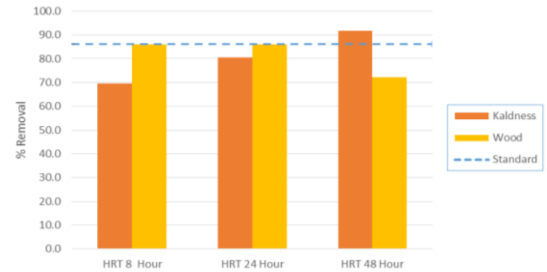

Figure 9. TSS removal MBBR-Adsorption 15 gram

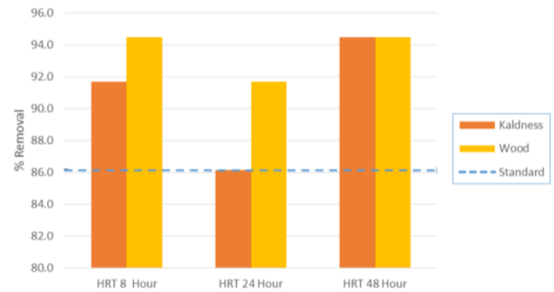

Figure 10. graph of TSS removal MBBR-Adsorption 20 gram

Overall, the graph shows variations in TSS removal efficiency for both media. For Kaldness Media, efficiency increased from 77.78% at 8 hours to 63.89% at 24 hours, and then increased again to 88.89% at 48 hours. Meanwhile, wood charcoal media showed an efficiency of 86.11% at 8 hours, then decreased to 63.89% at 48 hours.

From these data, it can be concluded that TSS removal efficiency is influenced by the interaction between media and HRT time. Kaldness media showed optimal improvement at 48 hours, while wood media was more effective at 8 hours. The efficiency of TSS removal in kaldness media can be influenced by the length of contact between the media and the wastewater, as decomposition due to the presence and growth of bacteria also increases with increasing HRT (Khudhair et al., 2023). Meanwhile, research by Arabgol (2021) found that wood charcoal media exhibits denser biofilms but significantly more significant removal due to its smoother surface and larger surface area due to macropores. Excessive accumulation of microorganisms causes slouching, and the biofilm is easily detached due to hydrodynamic shear from aeration. This results in higher solids production, resulting in increased TSS at a given HRT and requiring longer settling.

The graph above shows that the Total Suspended Solids (TSS) content in wastewater decreased significantly after undergoing the Moving Bed Biofilm Reactor (MBBR) process with the addition of an adsorption unit. The most significant effect was seen with the use of 20 grams of adsorbent, reaching the highest removal point at an HRT of 48 hours. The addition of a column-type adsorption unit strengthens this process by absorbing fine particles and colloids in the adsorbent micropores that are not easily biodegradable and cannot settle optimally (Budirman, 2024).

Figure 11, 12 and 13 show the removal percentage of Color each variation.

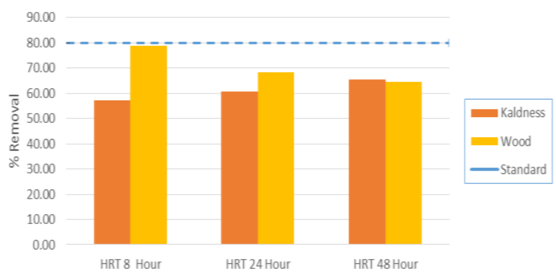

Figure 11. Color removal MBBR

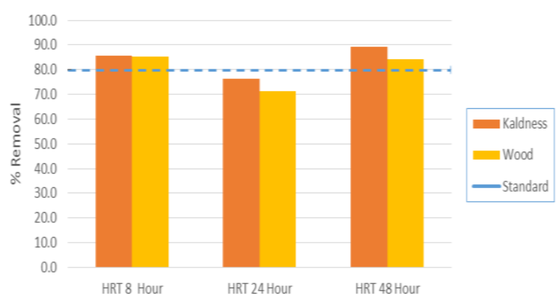

Figure 12. Color removal MBBR-Adsorption 15 gram

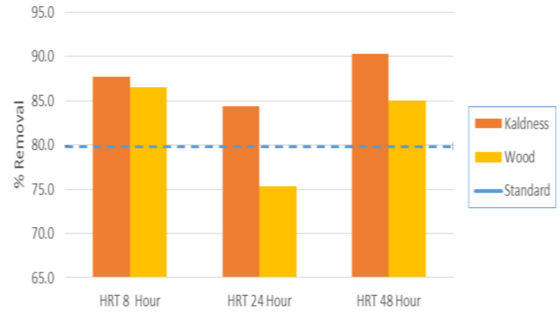

Figure 13. Color removal MBBR-Adsorption 20 gram

The graph shows a trend of increasing efficiency for the Kaldness K3 media, which increased from 57.14% (8-hour HRT) to 65.35% at 48 hours. Conversely, the wood charcoal media showed the highest efficiency of 78.93% at 8 hours, decreasing to 64.63% at 24 hours, and then increasing to 68.38% at 48 hours. Kaldness media showed a consistent increase in efficiency with longer HRTs. This is because longer HRTs allow time for microorganisms in the activated sludge system to decompose the dyes and other organic pollutants that contribute to waste color (Pratama & Hendrasarie, 2021). Kaldness media provides better initial performance due to its more stable geometric shape and structure and is designed to support biofilm evenly from the start (Pratap et al., 2024)

Wood charcoal media is more effective at shorter HRTs. This occurs because the degradation of dye compounds by wood charcoal media is influenced by the media's physicochemical properties (Zheng et al., 2020). The effectiveness of color removal decreases with long HRT due to the release of old, inactive biofilm (Mohanty & Paul, 2021). This release causes increased color because the azo dye from the wastewater has been adsorbed onto extracellular polymeric substances (EPS). EPS is a sticky matrix produced by microorganisms that binds microbial cells to the media surface and contains colored compounds. The released bacillus also produces humic/fulvic compounds such as melanin as degradation byproducts.

These compounds are brownish in color. Furthermore, with long HRT, the degraded color produces aromatic amine byproducts that are difficult to degrade due to enzymatic oxidation and color degradation (Wang et al., 2024).

The graph above also shows that the Kaldness Media Moving Bed Biofilm Reactor (MBBR) system is effective in reducing color intensity in wastewater, especially with the addition of an adsorption unit. The best efficiency was demonstrated with the use of 20 grams of adsorbent in the MBBR-K3 Adsorption, with an HRT of 48 hours. This significant color reduction is due to the combined role of biofilm in MBBR and the adsorption process by additional materials. MBBR is effective in breaking down colored organic compounds, especially when the HRT is extended. The color reduction is linear with the amount of adsorbent and the initial concentration of the colored compound due to the presence of van der Waals forces, hydrogen bonds, and electrostatic interactions in this system (Prakoso et al., 2023).

Effect of the hydrogen peroxide to ferrous sulfate ratio on TSS and color removal in the Fenton Oxidation Unit

Table 2 shows the removal percentages of TSS and color due effect of the hydrogen peroxide to ferrous sulfate ratio.

Table 2. TSS and color removal in the Fenton Oxidation

Ratio $FeSO_4$: H_2O_2	TSS (mg/L)	Removal TSS (%)	Color (Pt-Co)	Removal Color (%)
Inlet	20	-	148	-
1: 3	10	50	46,1	69
1 : 1,5	25	-25	102.1	31.4
0.5 : 1.5	15	25	82.9	44.3

This study used a pH of 3.4 because it is considered optimal for the Fenton reaction. The data in Table 4.9 shows the effect of varying the ratio of $FeSO_4$ to H_2O_2 in the Fenton oxidation process on the reduction of Total Suspended Solids (TSS) and waste color. After treatment with a $FeSO_4$:H_2O_2 ratio of 1:3, TSS removal was 50%, and color removal was 69%. Conversely, at a ratio of 1:1.5, TSS removal decreased (-25%) and color removal increased (31.4%). At a ratio of 0.5:1.5, TSS removal and color increased again to 25% and 44.3%, respectively.

At a ratio of 1:3, the H_2O_2 concentration is high enough to efficiently activate Fe^{2+}, but not excessively, preventing scavenging of -OH radicals (Krupinska, 2024). Conversely, at a ratio of 1:1.5, the low concentration of H_2O_2 results in a limited amount of -OH radicals being formed, making the degradation reaction ineffective. In fact, the accumulation of intermediate products or partial reactions can lead to increased TSS. This is also supported by a recent study that found that an imbalance in the ratio can cause the Fenton reaction to become inefficient and produce more complex chromophore compounds (Martínez et al., 2025). Increasing the hydrogen peroxide dose increases overall efficiency due to the increase in hydroxyl radicals (-OH) (Hakika et al., 2019).

Conclusions

Based on the data analysis, it can be concluded that the MBBR treatment unit optimally removed 90.4% COD and 93.94% BOD_5 in charcoal-treated wood with a 48-hour HRT, while the TSS removal was 88.89% with Kaldness K3 media. The most optimal color removal was achieved at an 8-hour HRT, at 78.93%. The MBBR unit, using wood media with the addition of 20 grams of adsorbent, was the most optimal condition, with COD, BOD_5, and TSS reductions occurring at a 48-hour HRT. Meanwhile, the most optimal color removal was achieved in the MBBR with a 48-hour HRT using Kaldness K3 media and 20 grams of adsorbent. The results showed that the MBBR-adsorption treatment unit performed better than the MBBR without adsorption. The MBBR-adsorption unit with wood charcoal media, HRT 48 hours, and adsorbent mass 20 grams were the most optimal conditions for reducing COD and BOD_5, with removal values of 93.6% and 95.8%, respectively. Meanwhile, the most optimal color and TSS removal was achieved with a 48-hour HRT MBBR adsorption, Kaldness K3 media, and 20 grams of adsorbent mass, with values of 90.3% and 94.4%, respectively. The addition of the Fenton process after the MBBR adsorption process increased the efficiency of TSS and color removal, with a $FeSO_2$:H_2O_2 ratio of 1:3, resulting in a 50% increase in TSS and 52.2% increase in color removal.

References

Akankshya, Dash, R. R., & Mohanty, S. (2021). Removal of organic matters and nutrients by using bio-balls and corn cobs as bio-film carrier in MBBR technology. In *Water Security and Sustainability: Proceedings of Down To Earth 2019*, 227-237. Singapore: Springer Singapore.

Aldris, B., & Farhoud, N. (2020). Wastewater treatment efficiency of an experimental MBBR system under different influent concentrations. *Dynosa Applied Science*, *1*(1), 20-28.

Anisa, Ana, & Welly Herumurti. (2017). Pengolahan Limbah Domestik Menggunakan Moving Bed Biofilm Reactor (MBBR) dengan Proses Aerobik-Anoksik untuk Menurunkan Konsentrasi Senyawa Organik dan Nitrogen., *Jurnal Teknik ITS*, *6* (2), 361-366.

Anisah, N., & Hendrasarie, N. (2022). Penerapan Waktu Siklus Singkat pada Granular Activated Carbon Sequencing Batch Reactor untuk Pengolahan Limbah Cair Rumah Makan. *Serambi Engineering*, *7* (4). 3803-3811.

Arabgol, R. (2021). MBBR Produced Solids: Particle Characteristics, Settling Behaviour and Investigation of Influencing Factors. *Doctoral Dissertation*. Université d'Ottawa/ University of Ottawa).

Budirman, B. (2024). Effectiveness Of Using Biofilter Technology Moving Bed Biofilm Reaktor (MBBR) Combination Of Activated Carbon And Chlorine In Puskemas Wastewater Treatment In Makassar City. *Doctoral Dissertation*. Universitas Hasanuddin.

Fitriani, E., & Purbasari, A. (2021). Application of low-cost mesoporous geopolymer for dye waste removal. In *IOP Conference Series: Materials Science and Engineering*, *1053* (1), 012002.

Hakika, D.C., Sarto, S., Mindaryani, A., & Hidayat, M. (2019). Decreasing COD in sugarcane vinasse using the fenton reaction: The effect of processing parameters., *Catalysts*, *9*(11), 881-892.

Hendrasarie, N., & Trilta, M. N. (2019). Removal of nitrogen-phosphorus in food wastewater treatment by the Anaerobic Baffled Reactor (ABR) and Rotating Biological Contactor (RBC). *In IOP Conference Series: Earth and Environmental Science*, *245*(1), 012017.

Hendrasarie, Novirina, & Firdinsyah, Iqdam Zarfandi. (2023). Integrated Anoxic-Oxic Sequencing Batch Reactor Combined with Coconut Fiber Waste as Biofilm and Adsorbent Media. *Journal of Ecological Engineering*, *24* (11), 176-189.

Khudhair, D. N., Zwain, H. M., Siadatmousavi, S. M., & Hosseinzadeh, M. (2025). Sensitivity analysis of operational parameters on excess sludge reduction in moving bed biofilm reactor (MBBR) system upgraded to integrated fixed film activated sludge (IFAS) process based on GPS-X environment. *Water Environment Research*, *97* (6), 70084.

Krupińska, I. (2024). Application of Fenton's Reaction for Removal of Organic Matter from Groundwater. *Molecules*, *29*(21), 5150-5170.

Liu, X., Tang, P., Liu, Y., Xie, W., Chen, C., Li, T., & Liu, B. (2022). Efficient removal of organic compounds from shale gas wastewater by coupled ozonation and moving-bed-biofilm submerged membrane bioreactor. *Bioresource Technology*, 344, 126191.

Martinez, D. V., Schambach, J. Y., Davydovich, O., Mascarenas, M. R., Butler, S. C., Kolker, S., ... & Kent, M. S. (2025). Chelator-mediated Fenton post-treatment enhances methane yield from lignocellulosic residues via microbial community modulation. *Biotechnology for Biofuels and Bioproducts*, *18* (1), 73-89.

Metcalf, L. & Eddy, HP. (2003). Wastewater engineering treatment and reuse. *McGraw-Hill*. 227-237. 2nd Ed. Singapore: Springer Singapore.

Mohanty, S., & Paul, S. (2021). Biofilm formation, problems, and diseases: Methods for film eradication, a nanostructured material based approach. *Microbial Ecology of Wastewater Treatment Plants* (pp. 469-492). 2nd Ed. Elsevier.

Prakoso, R. D., Hayati, R. N., & Rahendaputri, C. S. (2023). Pemanfaatan Kayu Gaharu (Aquilaria malaccensis) Sebagai Adsorben Dalam Menurunkan Parameter Warna dan pH di dalam Limbah Cair Tekstil Sintetis., *Envirotek*, *15* (2), 181-185.

Pratama, A., & Hendrasarie, N. (2021). Efektivitas Penambahan Green Adsorbent Di Sequencing Batch Reactor Untuk Menurunkan Parameter Bod, Tss, Dan Warna Pada Limbah Industri Batik., *EnviroUS*, *2* (1), 9-17.

Pratap, V., Kumar, R., Kumar, S., & Yadav, B. R. (2024). Optimization of moving bed biofilm reactors for the treatment of municipal wastewater. *Environmental Research, 241*, 117560.

Sekarani, F.A., & Hendrasarie, N. (2020). Reduction of organic parameters in apartment wastewater using sequencing batch reactor by adding activated carbon powder. In *IOP Conference Series: Earth and Environmental Science*, *506* (1), 012026.

Shitu, A., Tadda, M. A., Li, H., Danhassan, U. A., Gouda, M., Zhou, J., & Zhu, S. (2025). Performance and microbial community structure of BC/FeC2O4/SB modified carriers on the nitrogen removal from mariculture wastewater. *International Journal of Environmental Science and Technology*, *22*(13), 1-16.

Suryawan, I. W. K., Helmy, Q., Notodarmojo, S., Pratiwi, R., & Septiariva, I. Y. (2021). Textile dye reactive black 5 (rb5) bio-sorption with moving bed biofilm reactor and activated sludge. *Indonesian Journal of Environmental Management and Sustainability*, *5* (2), 67-71.

Wahyu, E., & Hendrasarie, N. (2022). Penurunan kandungan zat pencemar organik pada air limbah rumah potong ayam dengan biofilter aerob menggunakan media kulit kerang. *Jurnal Envirous Teknik Lingkungan*, *3*(1), 19-25.

Wang, Z. Y., Ju, C. J., Zhang, R., Hua, J. Q., Chen, R. P., Liu, G. X., ... & Yu, L. (2021). Acceleration of the bio-reduction of methyl orange by a magnetic and extracellular polymeric substance nanocomposite. *Journal of Hazardous Materials*, *420*, 126576.

Zhang, D., Zhang, K., Hu, X., He, Q., Yan, J., & Xue, Y. (2021). Cadmium removal by MgCl2 modified biochar derived from crayfish shell waste: Batch adsorption, response surface analysis and fixed bed filtration. *Journal of Hazardous Materials*, *408*, 124860.

Zheng, Y., Zimmerman, A. R., & Gao, B. (2020). Comparative investigation of characteristics and phosphate removal by engineered biochars with different loadings of magnesium, aluminum, or iron. *Science of the Total Environment*, *747*, 141277