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Original Research Article

Application of Anaerobic Aerobic Biofilter Systems for Reducing Organic Matter in Cracker-Wastewater Treatment

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Abstract
Wastewater treatment using traditional systems is considered expensive because it requires considerable energy and installation. The current study assessed the existence of a combination process that can reduce costs and is easy to operate. This study evaluates the performance of an anaerobic-aerobic biofilter system to treat industrial wastewater from cracker production. The combination of anaerobic and aerobic biofilters can significantly reduce Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), which are important parameters for wastewater quality. Sampling was carried out on the influent channel of the fish cracker industry. Sampling uses the SNI 6989.59:2008 regulation in the form of a wastewater test sampling method. The results showed that the biofilter achieved BOD removal of up to 84.90% and COD reduction of more than 89.02% when operated with an extended Hydraulic Retention Time (HRT) of up to 24 h. The results also showed that in wastewater treatment, HRT optimization should be considered for maximum pollutant removal, as shorter retention times proved less effective in reducing COD and BOD organic loads. These findings suggest that anaerobic-aerobic biofilter systems are viable and scalable solutions for industries seeking efficient and environmentally friendly wastewater treatment options.

Keywords: Biofilter; anaerobic aerobic system; wastewater treatment; industrial wastewater

1. Introduction

In the food processing industry, wastewater containing organic matter, nutrients, and suspended solids is generally produced, which impacts the environment and causes problems (Deng et al., 2021). Wastewater treatment is considered expensive owing to the high cost of energy and its installation in traditional technology (Sattler, 2011). Traditional treatment systems often rely on aerobic biological methods for their treatment, but this technology requires a large amount of energy and produces a large amount of sludge residue. Therefore, there is a need for a technology that can reduce the levels of pollutants in wastewater but still considers cost and operational aspects.

One of the technologies currently being developed to treat wastewater is the use of a biofilter that integrates anaerobic and aerobic processes. This technology provides an efficient and energy-saving approach for wastewater treatment (Ghanimeh et al., 2018). This hybrid biofilter provides advantages for industrial wastewater management because of its capacity to handle high organic loads while reducing operational costs (Stazi and Tomei, 2018). In addition, this technology can produce biogas, reduce sludge residue, and reduce energy consumption. In the anaerobic phase, microorganisms degrade organic matter, whereas the aerobic phase removes the remaining pollutants, thereby improving the quality of the waste.

Jang et al. (2015) used a combination of anaerobic-aerobic thermophilic nesophilic in high-strength food wastewater treatment and showed that this system was able to remove COD and ammonia content in water, reaching 90%. However, maintaining microbial stability and optimizing operational parameters are important because they are in line with the reactor performance of the combined process (Jang et al., 2015; Tian et al., 2016). Integrating anaerobic and aerobic biofilter systems balances energy efficiency and high pollutant removal rates. Said et al. (2024) highlighted the potential of anaerobic-aerobic biofilters using plastic honeycomb media, achieving an average removal efficiency of 92.5% for Biochemical Oxygen Demand (BOD), 91.1% for Chemical Oxygen Demand (COD), and 97.2% for Total Suspended Solids (TSS). The system also reduced ammonia and total coliform levels by 97.1% and 99.9%, respectively. Escalante-Estrada et al. (2019) reinforced this, showing that anaerobic-aerobic biofilters filled with volcanic rock and organic media achieved COD removal efficiencies of 86-93% while being cost-effective and sustainable for small-scale applications. Their study further emphasized the adaptability of this system, which maintained high removal efficiencies over a wide range of hydraulic retention times and organic loads. Yang et al. (2015) showed that a combined anaerobic-aerobic biofilter utilizing this ceramic media achieved 97% chemical oxygen demand (COD) removal, 99% ammonia nitrogen (NH_4-N) reduction, and 89% tetracycline degradation, even under low-temperature conditions (16°C). This improved performance is due to the ceramic media's high porosity and rough surface, which facilitate better microbial attachment and biofilm formation, thereby improving the system's resistance to shock loads and maintaining high processing efficiency. Although the anaerobic-aerobic biofilter system provides promising results, there are still challenges in adapting this technology to various food industry applications. Cracker-production wastewater is characterized by fluctuating organic loads and oil and chemical oxygen demand (COD) concentrations, which require a robust system that can handle variations while maintaining high treatment efficiency. Research has identified the anaerobic-aerobic sequencing biofilter system as a potential solution, but its full performance under different operational conditions has not been explored (Shi et al., 2017).

Traditional treatment methods are considered to be too complex and expensive, especially for small businesses. This study provides a cost-effective and scalable solution to help industries meet environmental standards and reduce pollutants through a combined anaerobic-aerobic biofilter system to treat cracker-production wastewater. The system combines anaerobic and aerobic processes to achieve high pollutant (BOD and COD) removal at a low operational cost. Unlike traditional systems, this hybrid method optimizes wastewater treatment by using andesitic stone media to enhance microbial attachment and biofilm formation (Zulkifli et al., 2022). This study offers a novel solution by combining anaerobic and aerobic stages with an optimized hydraulic retention time (HRT). This approach has not been widely applied in treating cracker wastewater, making it a valuable contribution to wastewater treatment. With the increasing regulations on wastewater discharge, this system offers a timely solution for sustainable wastewater management.

The purpose of this study was to evaluate the performance of a pilot-scale anaerobic-aerobic biofilter system for treating cracker-production wastewater. Specifically, this study assessed the removal efficiency of major pollutants, namely COD and BOD, under various operational conditions. These parameters indicate the amount of organic matter present, which is critical for assessing the efficiency of wastewater treatment systems (Wei et al., 2023). Cracker-production wastewater contains high levels of organic pollutants, making chemical oxygen demand (COD) and biochemical oxygen demand (BOD) the most relevant measures to evaluate treatment performance. In addition, regulatory agencies often use COD and BOD levels to determine compliance with the wastewater discharge standards. Therefore, by focusing on these parameters, the treatment system can meet legal requirements while providing a practical assessment of the system's effectiveness in reducing organic pollutants. In addition, this study explored the potential of optimizing the hydraulic retention time (HRT) and flow rate to achieve sustainable and scalable wastewater treatment. This study will contribute to the development of sustainable wastewater management strategies by providing insight into the operational feasibility of anaerobic-aerobic biofilters.

2. Methods and Materials

2.1. Wastewater Source and Characterization

Wastewater samples were collected from a local cracker-production facility in Indramayu Regency, Indonesia. Wastewater in this industry comes from several fish cracker-production activities, such as fish washing, fish brining, and washing production equipment. Sampling was carried out on the influent channel of the fish cracker industry. Sampling uses the SNI 6989.59:2008 regulation in the form of a wastewater test sampling method. Laboratory testing was performed as quickly as possible to avoid water transformation or the addition of other pollutants. Table 1 show the characteristics of the initial parameters identified in the wastewater were COD, BOD, ammonia, and TSS.

Table 1. Characteristic of wastewater

Parameters	Value	Quality Standards*	Unit
pH	7.0 – 7.2	6-9	
COD	2090.65- 2531.53	300	mg/l
BOD	603.64 – 697.54	100	mg/l
Ammonia	5.07 – 5.63	5	mg/l
TSS	417 – 454	100	mg/l

* Regulation of the Minister of Environment of the Republic of Indonesia Number 5 of 2014 concerning Wastewater Quality Standards, Appendix XIV Wastewater Quality Standards for Businesses and/or fishery product processing activities.

2.2. Bioreactor System

This study used a pilot-scale anaerobic-aerobic biofilter system designed to treat wastewater generated from crackers. Figure 1 shows the pilot scale design of the aerobic anaerobic biofilter system. The biofilter was made of 5 mm thick glass and measured 35 cm × 30 cm × 35 cm, which was assembled into one interconnected unit. This system consisted of two main units: an Anaerobic Biofilter Unit and the Aerobic Biofilter Unit. The Anaerobic Biofilter Unit is a reactor with a fixed bottom that supports microbial degradation of organic matter. This unit operated under mesophilic conditions, ensuring stable microbial growth and efficient COD reduction. The aerobic biofilter unit is designed to polish anaerobic waste by removing residual COD, BOD, and TSS. Oxygen was supplied continuously to maintain DO levels between 2 and 4 mg/l, increasing microbial degradation in the aerobic phase using a Hailea 6602 type aerator.

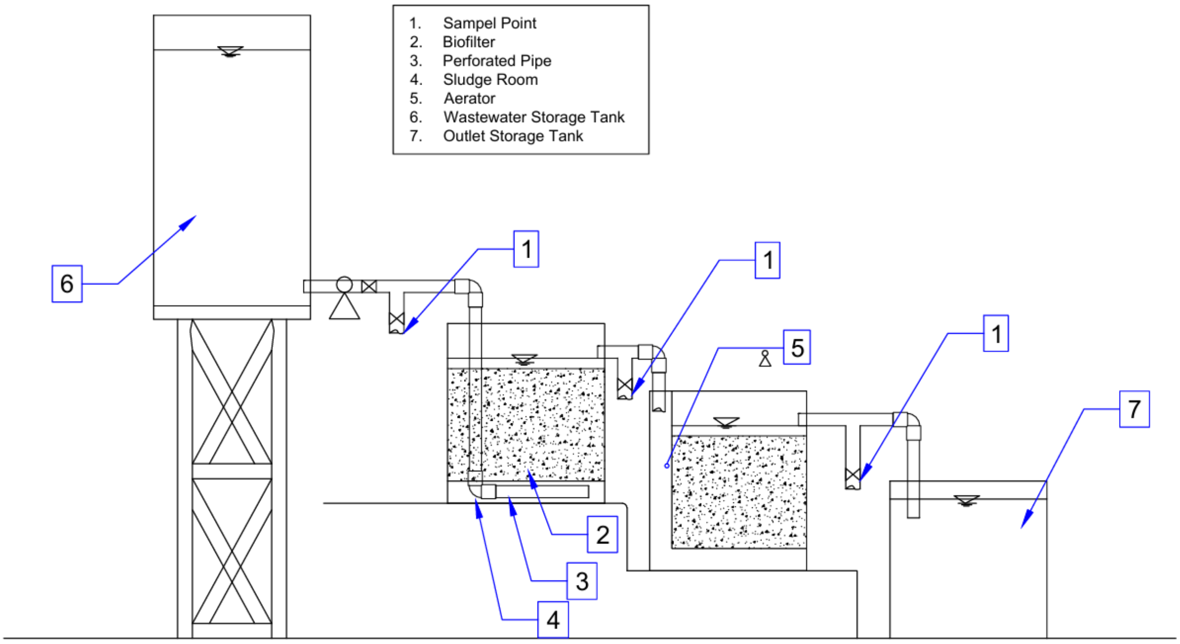

Figure 1. Anaerobic aerobic biofilter system

The Anaerobic aerobic biofilter system was operated for 55 days. The flow control system was equipped with flow meters and pumps to regulate the hydraulic retention time (HRT) and maintain consistent flow rates in both stages (Bafrani et al., 2024). HRT plays an important role in designing and operating the reactor and greatly affects the output power of the water flow, as variations in HRT have a direct influence on the type and quantity of bacteria in the bioreactor (Ye et al., 2020; Sobieszuk et al., 2017). The system was operated with varying hydraulic retention times (HRT) to determine the optimal conditions for pollutant removal (Hamdani, 2024). In the anaerobic and aerobic stages, there were variations in the HRT and water flow rates, as shown in Table 2. During days 1-14 using a 4-hour HRT, days 15-20 using an 8-hour HRT, days 21-26 using a 12-hour HRT, days 27-32 using a 16-hour HRT, days 33-43 using a 20-hour HRT, and days 44-55 using 24-hour HRT.

Table 2. Hydraulic retention time and and water flow rate

HRT (hour)	Water flow rate (ml/minte)
4	66.67
8	33.33
12	22.17
16	16.67
20	13.33
24	11.11

3. Result and Discussion

3.1 Characterization of Cracker Wastewater

The characteristic test was carried out in the initial stage to identify the concentration of pollutant levels (Deblonde et al., 2011; Hamdani, 2024). In this study, BOD and COD parameters were used to determine the pollution in the cracker wastewater. Based on the results of the characteristic tests, the cracker wastewater exceeded the established quality standards. The average BOD concentration in the influent was 653.60 mg/l with a set quality standard of 100 mg/l, whereas the average COD in the influent was 2337.71 mg/l with a set quality standard of 200 mg/l. Therefore, it is necessary to treat the cracker wastewater to ensure that it does not pollute the receiving water body.

3.2 Wastewater Treatment Efficiency of pilot-scale anaerobic aerobic system

3.2.1 Acclimatization

Acclimatization is an important stage in biological wastewater treatment, which helps in the development of an efficient treatment process (Tiwari et al., 2021). The acclimatization process is able to provide can increase the percentage reduction in pollutant levels in water. This stage plays an important role in stabilizing the treatment process and achieving higher removal efficiency for parameters such as COD and BOD. Acclimatization helps develop a robust microbial population capable of efficiently degrading organic and inorganic compounds in the incoming wastewater. Without proper acclimatization, the microbial community may experience stress, leading to inefficiencies in treatment and unstable reactor performance (Hamon et al., 2018). The importance of acclimatization lies in its ability to optimize microbial activity and biofilm formation. During this phase, the microorganisms undergo physiological and metabolic adjustments to process specific substrates present in the wastewater. These adjustments ensure that the microbes are well equipped to handle varying organic loads and pollutant concentrations, which are common in industrial wastewater such as cracker production (Chen et al., 2017).

Figure 2 shows the acclimatization process in the aerobic anaerobic biofilter system in the cracker industry wastewater treatment. The acclimatization phase starts on day one to day eight. On Day 1, the effluent concentrations under anaerobic and aerobic conditions were relatively high, with values of 2628.45 mg/l and 2656.35 mg/l respectively. This initial peak in effluent level is common in wastewater treatment processes as the microbes have not yet adapted to the specific influent characteristics. However, during the operational period, both systems showed a significant decrease in effluent concentration, reaching 2242.78 mg/l for anaerobic and 1912.63 mg/l for aerobic treatment on day 8. This downward trend indicates that the microbial populations in each system are undergoing acclimatization, a phase in which microorganisms adjust their metabolic capabilities to process specific organic and inorganic contents in the influent more efficiently (Yu et al., 2024). This result is in line with Hamon et al. (2018) research, which showed a more effective pollutant reduction of 34% after the acclimatization process of biomass used in the removal of pharmaceutical molecules in oncology ward wastewater.

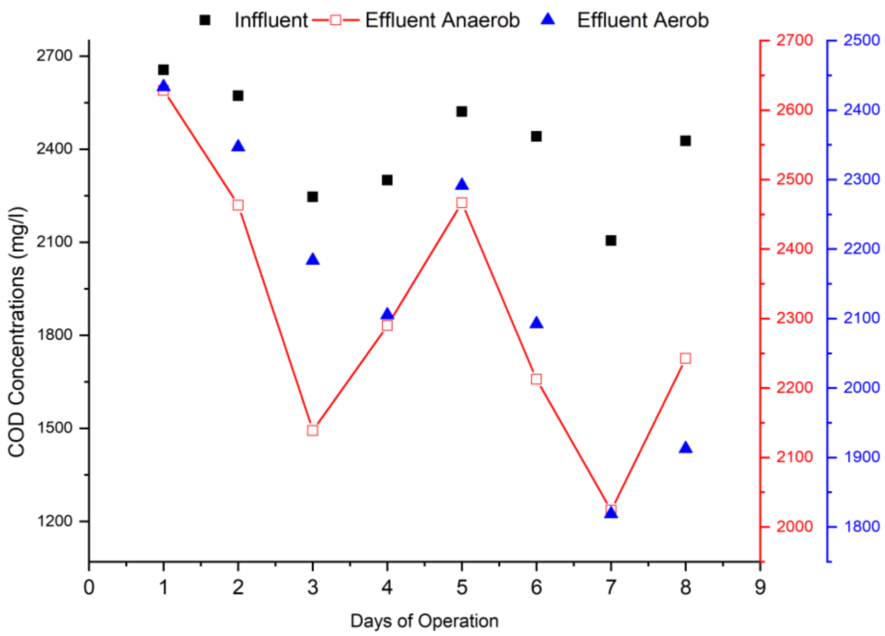

Figure 2. COD concentration in anaerobic aerobic biofilter system during acclimatization

Aerobic microbes show faster adaptation rates owing to the availability of oxygen, which favours higher growth and metabolic rates, allowing these microbes to degrade organic matter more effectively. This increases energy production through oxidative phosphorylation, a highly efficient mechanism compared to anaerobic respiration or fermentation. The higher energy yield from aerobic metabolism favours rapid microbial growth and increased enzymatic activity, which allows these microbes to break down organic matter more effectively. These observations are in agreement with research on microbial acclimatization, where aerobic conditions generally promote faster adaptation and stability in wastewater systems (Chen et al., 2017). The gradual decrease in effluent concentration indicates that the microbial communities in anaerobic and aerobic systems are effectively acclimatized to metabolize the influent, with aerobic microbes achieving this stability more quickly (Pronk et al., 2015). On days 7 and 8, both systems showed a stable operational phase, as indicated by the relatively low effluent concentration, implying that the acclimatization phase was almost complete. This also shows that the microbes developing in the biofilm have adapted to the influent characteristics and are able to thrive on the biofilm. Studies on wastewater treatment systems have confirmed that acclimatization not only reduces the level of effluent contaminants but also increases the robustness of the microbial population, making the treatment process more robust and consistent over time (Tiwari et al., 2021; Japar et al., 2021).

3.2.2 COD Removal

The initial period of operation showed limited COD reduction, especially in the anaerobic stage, owing to the microbial acclimatization process and biofilm development. As the system stabilized over time, the COD reduction efficiency increased because the microbes in the biofilter adapted and formed a biofilm capable of decomposing organic pollutants. This also shows that microbes need time to adapt to the wastewater composition and form biofilms. Biofilms play an important role in biofiltration, as they provide a surface area for microbial attachment, which increases the rate of biodegradation (Guarin and Pagilla, 2021; Zheng et al., 2022; Deena et al., 2022).

The results showed that the combination of anaerobic and aerobic processes, variation in Hydraulic Retention Time (HRT), and variation in flow rate contributed significantly to the reduction of the high COD content in wastewater. The COD concentration in the wastewater was consistently high, between 2,100 and 2,500 mg/l. This shows the characteristics of organic wastewater, which has high organic matter content and thus requires efficient degradation methods (Rodriguez-Sanchez et al., 2018; Ma et al., 2022). Figure 3 and table 3 shows the COD concentration during the treatment of the cracker wastewater using an aerobic anaerobic biofilter system. The anaerobic stage showed varying levels of effectiveness in COD reduction. By Day 33, with an HRT of 20 h, the COD of the anaerobic effluent was reduced to 577.07 mg/l, indicating effective microbial degradation due to a longer HRT that optimized the process of decomposing organic pollutants. This finding is in line with recent studies showing that longer retention times improve the stability and efficiency of anaerobic breakdown, providing microbes with sufficient time to decompose complex organic matter (Velvizhi, 2019).

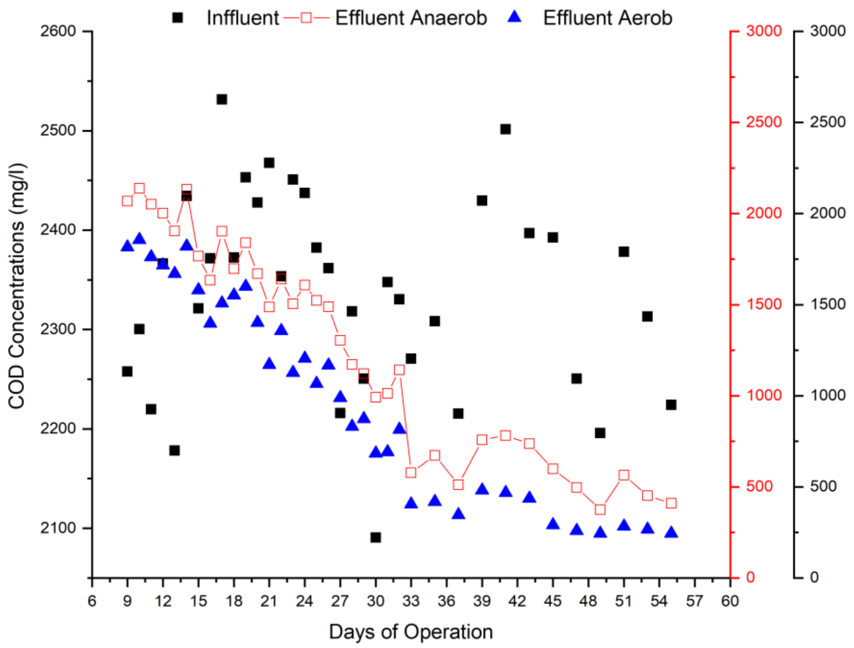

Figure 3. COD concentration in influent and effluent from biofilter treatment

On day 9, with an HRT of 4 h, the aerobic effluent COD had a value of 2,656.35 mg/l, reflecting limited reduction. As the HRT increased, the effectiveness of the aerobic stage increased and was able to reduce the COD levels in the wastewater decreased. This can be seen on day 33, with an HRT of 20 h, the COD concentration decreased significantly to 404.60 mg/l. On day 47, at an HRT of 24 h, the system reached one of its lowest COD levels (259.84 mg/l). Aerobic microbes actively participate in the oxidation of organic compounds remaining after anaerobic processing, where simpler organic compounds and methane precursors are decomposed into carbon dioxide and water, thereby reducing the COD. Zhang et al., 2020 in their study showed that the aerobic process becomes increasingly efficient as the HRT is prolonged, mainly due to increased oxygen contact and prolonged microbial activity, which ensures complete degradation of the remaining organic matter (Nogueira et al., 2002).

Table 3. COD concentration after wastewater treatment with Biofilter anaerobic aerobic system

Days of Operation	COD Concentration (mg/l)			HRT (hours)	Water Flow rate (ml/minute)
	Inffluent (mg/l)	Effluent Anaerob (mg/l)	Effluent Aerob (mg/l)		
9	2,257.70	2,067.65	1,815.91	4	66.67
10	2,300.40	2,138.73	1,856.35	4	66.67
12	2,366.51	2,002.57	1,717.51	4	66.67
15	2,321.34	1,766.27	1,580.72	8	33.33
19	2,453.23	1,839.41	1,599.93	8	33.33
20	2,427.82	1,671.02	1,401.47	8	33.33
21	2,467.75	1,486.71	1,170.35	12	22.17
25	2,382.50	1,522.55	1,067.65	12	22.17
26	2,361.87	1,488.65	1,168.25	12	22.17
27	2,215.83	1,303.60	989.35	16	16.67
30	2,090.65	991.90	684.55	16	16.67

Days of Operation	COD Concentration (mg/l)			HRT (hours)	Water Flow rate (ml/minute)
	Inffluent (mg/l)	Effluent Anaerob (mg/l)	Effluent Aerob (mg/l)		
32	2,330.35	1,142.25	815.35	16	16.67
33	2,270.56	577.07	404.60	20	13.33
35	2,308.42	672.55	418.25	20	13.33
41	2,501.56	782.45	468.58	20	13.33
45	2,392.53	598.23	291.35	24	11.11
51	2,378.24	563.35	283.50	24	11.11
53	2,312.93	451.27	267.38	24	11.11
55	2,224.18	409.94	244.23	24	11.11

The effect of HRT is shown in figure 4, which shows the percentage of COD removal based on the HRT. The initial HRT of 4 h showed limited COD removal, with relatively high effluent levels after each treatment stage. Along with the gradual extension of the HRT to 8, 12, 16, and 24 h, the COD decreased significantly. This indicates that a longer HRT provides a longer interaction between the wastewater and microbial biofilm, resulting in more thorough biodegradation (Velvizhi, 2019; Loh et al., 2021). This is in line with the research of Maurya et al. (2023), which stated that extended HRT gives biofilm-forming microbes sufficient time to stabilize and achieve optimal breakdown of complex organic compounds. A longer HRT also prevents excess substrate, which can inhibit microbial activity and result in a less efficient COD reduction.

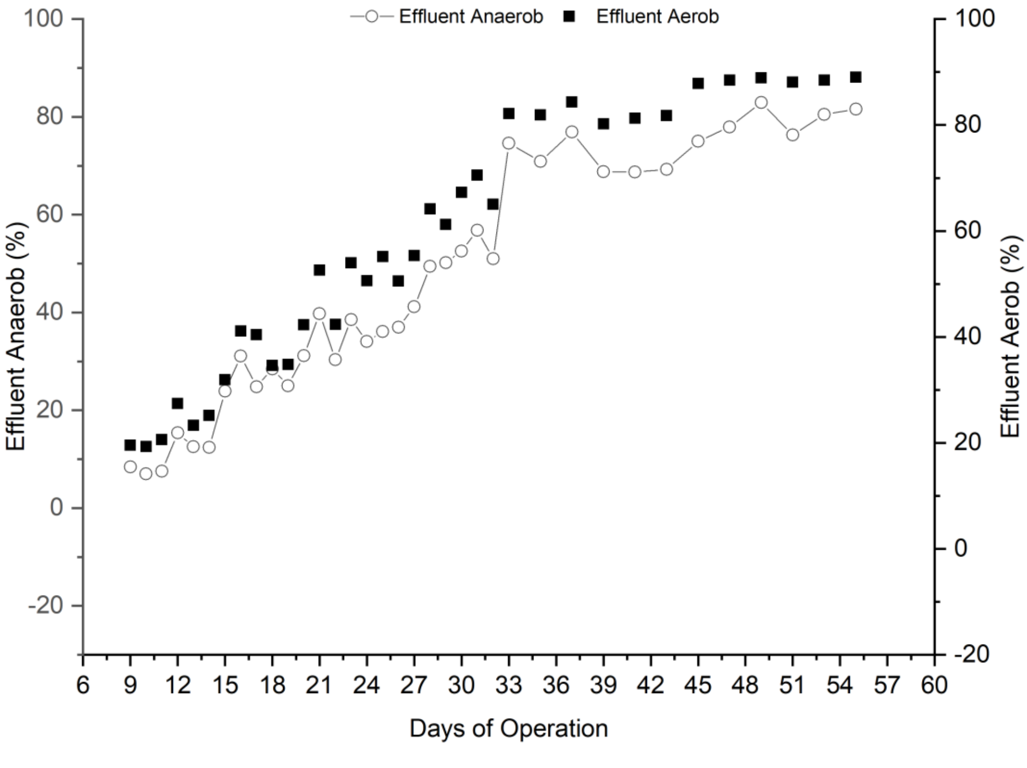

Figure 4. Removal % of COD from treated wastewater after biofilter process

In the combined treatment of anaerobic and aerobic biofilter systems, they work together to reduce pollutants in cracker wastewater. Anaerobic treatment is effective in breaking down complex organic compounds through hydrolysis and fermentation, which simplifies the organic load for aerobic treatment. The aerobic stage completes the oxidation of simplified compounds, thereby achieving a more substantial COD reduction. The results showed that the anaerobic aerobic biofilter system achieved a COD reduction of more than 80%, especially with high organic loads, because each stage handles different aspects of the organic matter. The combination of anaerobic-aerobic treatment, coupled with optimized HRT, allows COD reduction from an initial influent level of 2,400 mg/l to a final effluent level below 300 mg/l, reflecting an overall increase in efficiency. An anaerobic aerobic biofilter system provides sustainable and efficient COD removal by integrating anaerobic and aerobic microbes (Sheoran et al., 2022).

3.2.3 BOD Removal

The inlet BOD concentration ranged from to 600-700 mg/l during the observation period, and wastewater with a high organic load characterizes industrial wastewater and requires treatment to degrade pollutants in water. The high BOD in the inlet wastewater indicates the need for a system that can achieve substantial organic load reduction, which has been emphasized in recent studies focused on wastewater treatment (Sangamnere et al., 2023). The anaerobic stage showed initial fluctuations in the BOD removal efficiency, especially at a shorter HRT (4 h). The reduction in BOD in the aerobic and anaerobic treatments based on HRT is shown in figure 5 and table 4. Along with the increase in HRT, the anaerobic stage showed an increase in BOD removal efficiency. On Day 33, with an HRT of 20 h, the BOD of the anaerobic effluent decreased significantly to 240.15 mg/l. Higher retention times promote microbial stabilization, which optimizes the removal of dissolved organic matter in anaerobic systems (Liu et al., 2020).

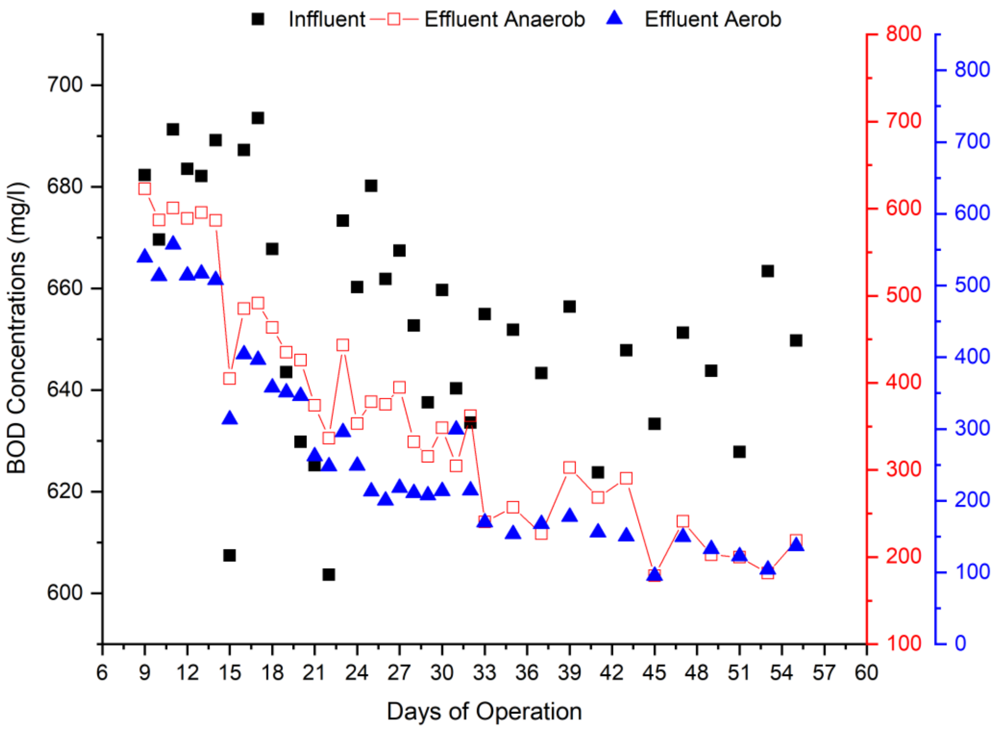

Figure 5. BOD concentration in influent and effluent from biofilter treatment

After the anaerobic treatment, the aerobic stage further reduced the BOD concentration, achieving substantial improvement with a longer HRT. The initial reduction in BOD during the aerobic stage was moderate. On day 9, the BOD of the aerobic effluent was 622.8 mg/l, indicating that additional treatment was limited to a 4-hour HRT. However, as the HRT increased, the effectiveness of the aerobic treatment increased sharply. On day 33 with a 20-hour HRT, the BOD concentration of the aerobic effluent was reduced to 169.93 mg/l, reflecting effective microbial oxidation under aerobic conditions.

The efficiency of the aerobic stage in BOD reduction is consistent with recent studies emphasizing the role of aerobic processes in decomposing dissolved organic compounds that remain after anaerobic treatment. Aerobic biofilms actively participate in the oxidative degradation of organic matter, which is facilitated by increased oxygen availability and longer HRT, which enhances microbial activity (Wu et al., 2024).

Table 4. BOD concentration after wastewater treatment with Biofilter anaerobic aerobic system

Days of Operation	BOD Concentration (mg/l) Inffluent	Effluent Anaerob	Effluent Aerob	HRT (hours)	Water Flow rate (ml/minute)
9	682.34	622.80	539.29	4	66.67
10	669.64	587.09	513.16	4	66.67
12	683.57	588.98	514.12	4	66.67
15	607.43	405.02	313.54	8	33.33
19	643.51	435.00	351.20	8	33.33
20	629.80	426.22	345.90	8	33.33
21	625.20	374.13	262.23	12	22.17
25	680.23	378.48	213.25	12	22.17
26	661.90	375.37	200.16	12	22.17
27	667.45	394.68	218.24	16	16.67
30	659.70	348.20	213.32	16	16.67
32	633.60	362.17	214.50	16	16.67
33	654.95	240.15	169.93	20	13.33
35	651.90	257.32	153.60	20	13.33
41	623.80	268.50	155.75	20	13.33
45	633.34	178.45	95.66	24	11.11
51	627.82	199.90	122.52	24	11.11
53	663.40	181.70	103.90	24	11.11
55	649.76	218.83	136.93	24	11.11

Increasing the HRT from 4 h to 24 h was crucial for achieving better BOD removal in both treatment stages. A shorter HRT generally resulted in higher effluent BOD levels, whereas a longer retention time resulted in a significant reduction. On Day 55, with an HRT of 24 h, the BOD concentration in the aerobic effluent reached its lowest point of 103.90 mg/l, highlighting the benefits of extended HRT for both anaerobic and aerobic treatment stages. This Combined anaerobic aerobic system allows for a higher overall BOD removal, as each stage contributes to the decomposition of different organic fractions. The combined anaerobic-aerobic biofilter system resulted in higher BOD removal compared to the single-stage system, especially for wastewater with complex organic loads. Figure 6 shows the percentage removal of BOD. The system in this study achieved significant BOD reductions of up to 84%, reducing concentrations from initial levels of approximately 650 mg/l to final effluent levels below 200 mg/l with extended HRT.

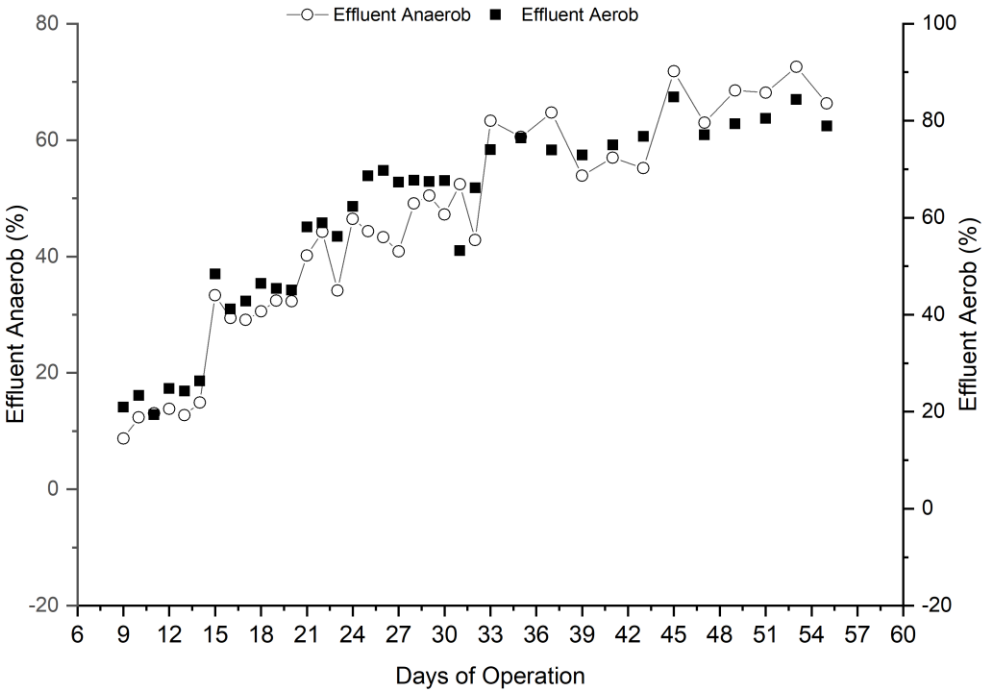

Figure 6. Removal % of BOD from treated wastewater after biofilter process

3.3 Ratio of BOD/COD

The BOD/COD (B/C) ratio is an important measure of wastewater biodegradability, with higher values indicating readily biodegradable organic matter and lower values indicating poorly biodegradable compounds (Wei et al., 2023). The increase and decrease in the B/C ratio are shown in Figure 7. The influent B/C ratio observed in this study ranged between 0.25 and 0.31, indicating moderate biodegradability, which is typical of industrial wastewater. A high B/C ratio in wastewater results in better biodegradability and is classified as above 0.50 as readily biodegradable, 0.30 to 0.50 as biodegradable, and 0.30 as fire retardant (Kumar et al., 2010). Pretreatment in the anaerobic stage showed a minimal reduction in the B/C ratio at shorter Hydraulic Retention Times (HRT), indicating limited damage to complex organic matter at shorter contact times. At a HRT of 4 hours HRT, the anaerobic effluent B/C ratio did not change with the influent ratio, indicating that most of the complex organic matter did not change in the early phase. This is in line with the research of Su et al. (2019), who showed that a shorter HRT often limits the anaerobic microbial community to fully adapt to complex wastewater, thus limiting the degradation capacity in the early stage.

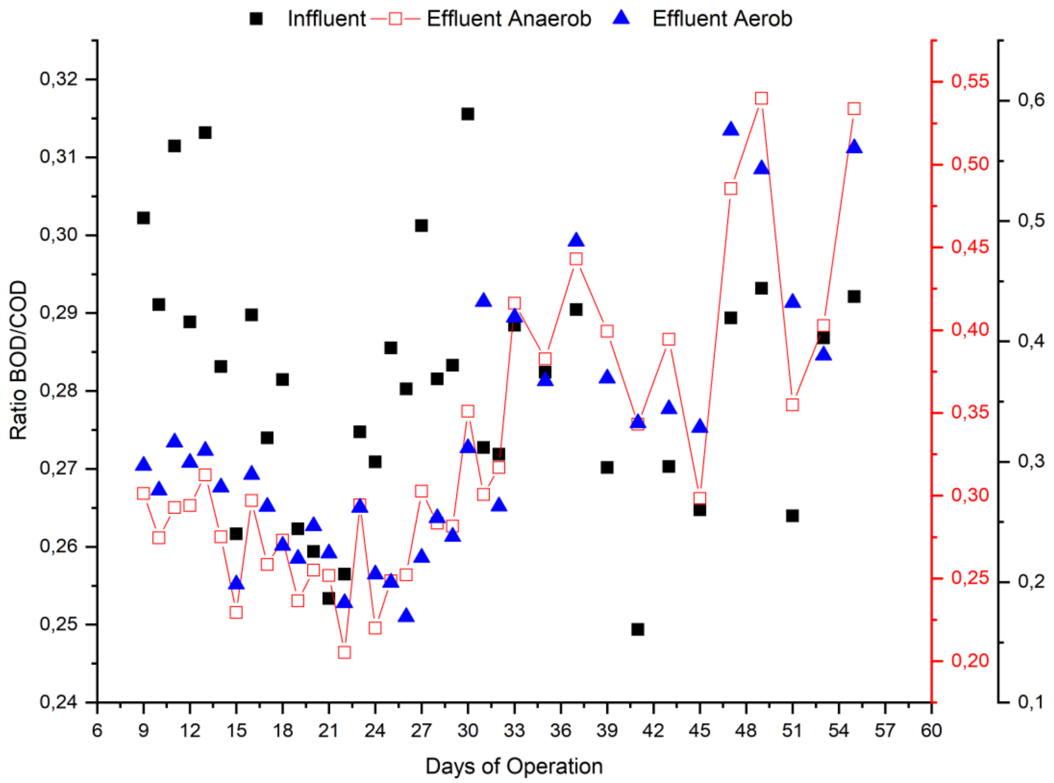

Figure 7. Ratio of BOD/COD

As the HRT increases, the anaerobic stage shows increasing efficacy, as indicated by the higher B/C ratio in the effluent. The increase in this ratio at extended HRTs, such as 16 and 20 h, indicated the accumulation of simpler organic compounds as poorly soluble substances that were broken down. Wang et al. (2022) stated that with increasing retention time, anaerobic microbes can convert complex and poorly biodegradable organic matter into simpler compounds that are more easily oxidized, thereby increasing the B/C ratio in the anaerobic effluent. The aerobic stage plays a significant role in improving the treatment process by significantly reducing the BOD/COD ratio, especially at longer HRTs, which underlines the role of aerobic biofilters in the complete degradation of these organic intermediates. At 24 h HRT, the significant reduction in the B/C ratio decreased to 0.561. This decrease in the ratio indicates that the aerobic stage, with a prolonged HRT, achieves extensive oxidation of biodegradable intermediates produced in the anaerobic phase, converting them into stable end-products such as CO_2 and water. Aerobic biofilters operate most effectively with sufficient retention time, allowing for thorough microbial oxidation and breakdown of residual organic compounds (Peterson and Summers, 2021). This study shows that a short HRT results in limited biodegradation, but with longer retention times, the system is able to decompose organic matter maximally, thereby increasing the B/C ratio. This approach is in line with modern biofilter studies that emphasize retention time as a key operational parameter to maximize biodegradability and overall system efficiency in complex wastewater treatment (Su et al., 2019; Waqas et al., 2023).

This significant reduction in pollutant levels indicates that the aerobic anaerobic biofilter system is capable of handling the high organic load commonly found in cracker-production wastewater. The combination of anaerobic and aerobic phases ensures that complex organic compounds are first broken down into simpler forms in the anaerobic phase and then further oxidized in the aerobic phase. The reduced levels of pollutants in wastewater indicate that industries can discharge effluents that meet regulatory standards, thereby minimizing environmental pollution. In addition, the system design is cost-effective and energy-efficient, making it accessible to small- and medium-sized enterprises (SMEs) that may struggle with expensive traditional treatment methods. This biofilter system also offers scalability, allowing industries to customize the system capacity according to wastewater production. By providing a practical and sustainable solution, anaerobic-aerobic biofilters support industries in adopting more environmentally responsible wastewater management practices.

4. Conclusions

The combined anaerobic aerobic biofilter system in this study showed that it was able to process cracker wastewater. The series of wastewater treatment processes ensured that the effluent quality was constant with high COD efficiency reaching 89.02% and BOD removal efficiency reaching 84.90%. The highest COD (89.02%) and BOD (84.90%) removal efficiencies were obtained by applying a 24-hour HRT with a water flow rate of 11.11 ml/min. The influent B/C ratio observed in this study ranged between 0.25 and 0.31, indicating moderate biodegradability which is typical of industrial wastewater. This combined biofilter system allows the anaerobic phase to break down complex organic matter into simpler compounds, which are then further oxidized by the aerobic phase, resulting in final waste that can be discharged into water bodies without polluting the environment. One of the main findings in this study is the importance of Hydraulic Retention Time (HRT). The results showed that shorter retention times resulted in limited pollutant removal, whereas longer times were able to decompose organic matter completely. These results suggest that anaerobic-aerobic biofilters can be a viable and environmentally friendly option for industries facing complex wastewater challenges, providing a viable solution for sustainable wastewater treatment.

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