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Original Research Article

Performance Evaluation of Local Organism in Wastewater Treatment

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Abstract
Biofilters are a type of attached growth biological treatment that is considered effective among other biological treatments because of their more affordable energy operating costs, easy maintenance and operational requirements, and low environmental impact. However, there is still minimal research related to the use of local microorganisms for biological wastewater treatment. Therefore, this study aims to improve biological wastewater treatment in the cracker industry in Indramayu using local microorganisms equipped with a biofilter that utilizes natural andesite stone as a medium for microorganism growth. The best reduction in BOD anaerobically reached 79.45% and 58.91% aerobically, obtained at a flow rate of 11.11 ml/minute on the 53rd and 45th days. The increase in the BOD/COD effluent ratio from 0.22 to 0.47 during treatment indicated a decrease in biologically degradable compounds and an increase in the effectiveness of local microorganisms in reducing organic matter. Therefore, in this study, we successfully designed a biofiltration system derived from local microorganisms to effectively remove pollutants from wastewater, particularly in the cracker industry.

Keyword: Anaerobic aerobic system; biofilter; local microorganism; wastewater treatment

1. Introduction

In developing countries, inadequate wastewater treatment facilities are frequently encountered, resulting in serious environmental problems that threaten public health (Gwenzi et al., 2017, Deng et al., 2021). Excessive discharge of wastewater contaminated with pollutants causes eutrophication, resulting in the growth of harmful algae and a decrease in environmental quality (Wang et al., 2018). The presence of runoff carrying pollutants into water bodies or rivers causes pollution of lake water sources by organic materials and nutrients (Scholes et al., 2008, Chang et al., 2019). Therefore, it is necessary to treat wastewater in industries and households to reduce the levels of organic pollutants and nutrients so that it does not pollute water bodies or the environment.

Biological wastewater treatment has received considerable attention in the recent decades. Biological wastewater treatment offers easier handling, has relatively smaller effects on the environment, and has affordable operational costs depending on the composition of the treated water (Shalaby et al., 2008). There are two types of biological processing systems: suspended biological systems and attached growth (Verma et al., 2006). Biofilters are a type of attached growth biological processing that are considered effective among other biological processes owing to their affordable operational energy costs, easy maintenance and operational requirements, and low impact on the environment (Naz et al., 2016). Biofilters are conventional biofilm processes that combine several advantages, such as small environmental impacts, especially in terms of footprint, large processing capacity, and low waste turbidity results. Therefore, they are widely applied to remove nitrogen and organic matter in water treatment plants (WWTP) (Vigne et al., 2010).

Substrates or media are important components in a biofilter because they can prevent pollutants, contain reactive substances to transform pollutants, and function as biofilm adhesives. Therefore, the filler material in biofilters can influence the removal of pollutants or contaminants because of their varying properties in terms of elemental composition, number and volume of pores, and surface area (Saminathan et al., 2013, Yang et al., 2018, Guo et al., 2020, Deng et al., 2021). Some substrates commonly used in biofilter processing include gravel, clay, porous materials, sludge, wood chips, and corncobs. Gravel has the advantages of low cost and high hydraulic permeability but a low ability to trap pollutants and adhere to microorganisms (Kizito et al., 2017). Sludge, such as dehydrated alum sludge, can bind phosphate to form deposits (Yuan et al., 2020, Chang et al., 2019). Porous materials, such as zeolite and clay, can be suppliers of carbon sources in the denitrification process and carriers of biofilms (Yuan et al., 2020). Recently, several porous inorganic materials have been used, such as lava rock, as a driving force for removing contaminants from biofilters because of their high adsorption properties and relatively large surface area (Chang et al., 2019, Ni and Ng, 2019).

When using a biofiltration system, the core concept involves enhancing the growth of functional microorganisms within the filter medium to establish biofilms capable of degrading organic substances, facilitating denitrification, and removing carbon compounds. Saminathan et al. (2013) used a combination of up-flow aerated biofilter (UAB) and denitrification shallow biofilter (DSB) to see the effect of air/water ratio, C/N ratio, and wastewater quality results that meet national emissions. Tian et al. (2016) employed a combined aerobic–anaerobic biofilter system for phosphorus recovery from wastewater streams. Ibrahim et al. (2020) combined bioaugmentation with a three-stage biofilter to reduce pathogenic microorganisms and identified the performance of adding bacteria to bioaugmentation materials. Wang et al. (2016) used a biofilter that combined media containing neutralized waste acid (NUA) and dried alum sludge (DAS) to reduce the nitrogen content in livestock wastewater. Most previous studies have focused on the use of commercial inoculants or conventional microbial additives, biofilter optimization, media characteristics, and operational parameters, but few have emphasized the role of local microorganisms in pollutant removal in wastewater. To date, few studies have used local microorganisms from chicken manure as a material in biological wastewater treatment and natural andesite rock as a medium. The potential of natural andesite stone as a low-cost local medium with high roughness and surface area to enhance biofilm attachment has been little explored and understudied in the literature. Therefore, this study aimed to analyze the characteristics of wastewater from the cracker production process and the effectiveness of anaerobic-aerobic biofilters with local microorganisms developed on natural andesite stone fragments as a medium.

2. Methods and Materials

2.1. The Source of Wastewater Used

The influent wastewater utilized for all experimental analyses was collected from a fish cracker processing facility located in Indramayu Regency, Indonesia. The cracker industry uses fish as a raw material for the cracker mixture. Wastewater from fish cracker production is directly discharged into the drainage channel in the surrounding environment. The water body in the wastewater drainage channel has a blackish color and foul odor. The results of monitoring and checking in the industry showed that there was no treatment of the wastewater, so the water body was polluted by cracker industry wastewater. The wastewater produced from fish cracker production comes from the processes of washing fish, melting ice, brining fish, and washing production equipment. The influent samples were placed in plastic drums for initial BOD and COD tests. Laboratory experiments were performed in the shortest possible time to avoid excessive chemical transformation due to prolonged sample storage. The physicochemical parameters used in this study were BOD, COD, Ammonia, and total suspended solids. Measurements were conducted at the inlet section of the drainage channel in the fish cracker production area. A summary of the wastewater characteristics evaluated in this study is presented in Table 1.

Table 1. Characteristic of cracker industry Wastewater

Parameters	Value (mg/l)
COD	2299.18
BOD	676.08
Ammonia	5.36
TSS	433

2.2. Local Microorganism

The method in this research uses a newly developed processing biofilter and utilizes local microorganisms as biofilms and andesite stones as biofilter media, aimed at decreasing the levels of organic matter, ammonia, and TSS in wastewater generated from the cracker industry. Microorganisms developed to assist in the pollutant reduction process originate from chicken manure, which is fermented aerobically and anaerobically. Some additional ingredients in the production of local microorganisms include palm sugar, rice washing water, and coconut water. The ground chicken manure was mixed with other ingredients, stirred until smooth, and then fermented for 14 d. In aerobic fermentation, it is incubated using a jerry can connected to a hose so that oxygen can enter through the hose. Anaerobic fermentation was performed in closed jerry cans attached to a hose and connected to a bottle filled with water. Treating this so that oxygen does not enter the jerry can, and the gas in the jerry can come out and be bound by H_2O.

2.3. Experimental Design and Operation of Biofilter

An overview of the experimental biofilter setup is illustrated in Figure 1. The biofilter was constructed from glass material with a 5 mm thickness and dimensions 35 × 30 × 35 cm, with two units arranged into one interconnected series unit. The anaerobic and aerobic reactors were connected and supplemented with biofilter media in the form of gray andesite stone fragments with a rough surface obtained from stone craftsmen with a size of 0.5 – 1 inch. A combination of anaerobic and aerobic systems was applied to enhance the treatment performance of wastewater from cracker production, especially at the COD, BOD, and TSS levels.

The bioactivator was obtained from the local microorganisms. The working system of this biofilter utilizes bottom-up gravity to drain water, and is regulated using a small tap. The reactor was designed with small perforations to ensure even distribution of flow across the reactor. In the aerobic reactor, an air supply was added in the form of a Hailea 6602 type aerator, to maintain the dissolved oxygen in the waste and ensure the availability of sufficient oxygen in the processing process. This approach aligns with the findings of Saminathan et al. (2013), who maintained a dissolved oxygen concentration of 3 mg/L to support microbial activity and promote both organic matter degradation and nitrification.

The wastewater, assisted by a pump, flows into a plastic drum with a capacity of 500 L and then flows to the anaerobic and aerobic reactors by gravity. The medium was inserted into the reactor positioned at a height of approximately 30 cm, reaching the outlet of each reactor. The water output rate was regulated by using tap water. The flow rate was divided into six HRT cycles: 4, 8, 12, 16, 20, and 24 h. The water flow rates for each HRT are listed in Table 2.

Table 2. Water flow rate based on hydraulic retention time

Hydraulic retention time (hour)	Water flow rate (ml/minutes)
4	66.67
8	33.33
12	22.17
16	16.67
20	13.33
24	11.11

3. Results and Discussion

The microbial and biofilm structures in the biofilter media are important components of this system for achieving the desired wastewater treatment efficiency (Naz et al., 2015). Various microbes that live in the media, whether intentionally added or grown by chance, act as biocatalysts and bioremediation agents to eliminate contaminants and pathogenic microbes (Sharvelle et al., 2008). The use of local microorganisms as a supporting material for the formation of active biofilms within a pilot-scale biofiltration unit andesite stone media aims to reduce the reactor start-up period in the wastewater treatment process. The efficiency of processing wastewater from cracker production was evaluated starting on the first day with an HRT of 4 hours.

3.1. Seeding and Aclimatization

Both seeding and acclimatization stages were conducted within the same reactor system with an andesite stone as the filter media. The crackered wastewater sample was placed in a reactor containing filter media, and local microorganisms from chicken manure were added. Seeding was stopped on day 3, when the andesite stone media showed patches of living microbes forming biofilms. The presence of spots on the andesite stone indicated that microorganisms attached to form biofilms (Yeshanew et al., 2016). The acclimatization process was carried out from day 3 until day 14 was thickened. This study used COD parameter was employed in this study to assess the capability of biofilms in degrading organic matter present in wastewater samples. Figure 1 shows that on days 1 to 5, the COD tended to fluctuate with a difference of more than 10%. These fluctuations generally occur in the early seeding phase because the microbes have not yet reached metabolic equilibrium, and the adaptation process forms attachments to the andesite media and the initial biofilm matrix. This resulted in an unstable rate of organic compound degradation and variable COD removal. This is in line with the research by Li et al. (2022), who showed that fluctuations in the biofilter system are caused by microbial responses and substrate competition during the initial acclimatization period. On days 6–14, COD was relatively stable, with fluctuations of less than 10%. The success of acclimatization can be indicated by the thickening of the biofilm and the percentage of COD decrease without dilution.

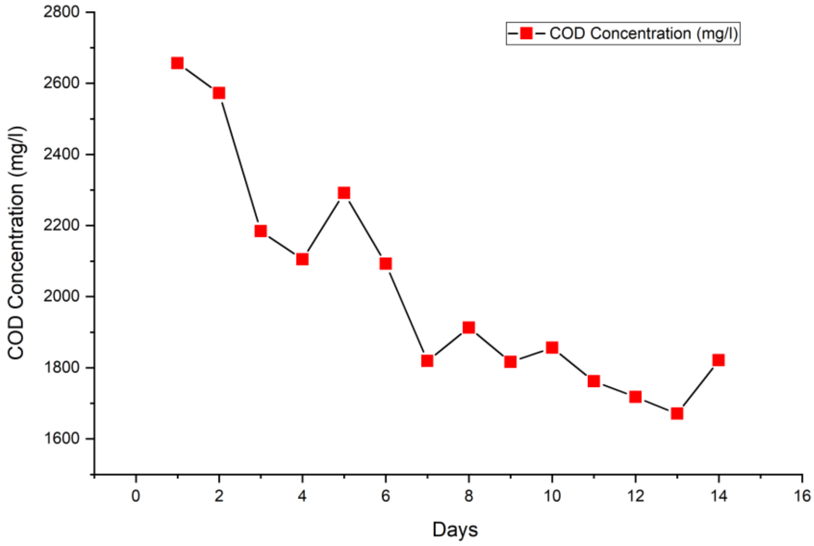
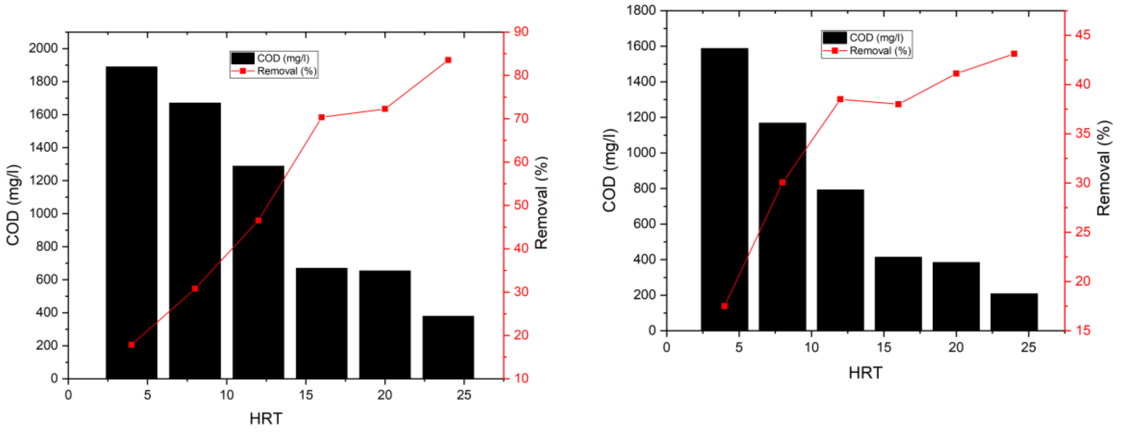


Figure 1. Daily COD concentration test reading

3.2. Removal of Organic Matter

Several methods are often used to remove organic material in wastewater treatment, such as adsorption, chemical oxidation–reduction, filtration, hydrolysis, and biodegradation processes (Vymazal and Březinová, 2015). The microbes on the substrate play an active role in the degradation of organic materials. Organic matter in wastewater is typically expressed in terms of chemical oxygen demand (COD) and biological oxygen demand (BOD), both of which can be reduced through combined aerobic and anaerobic degradation pathways (Zhao et al., 2020).

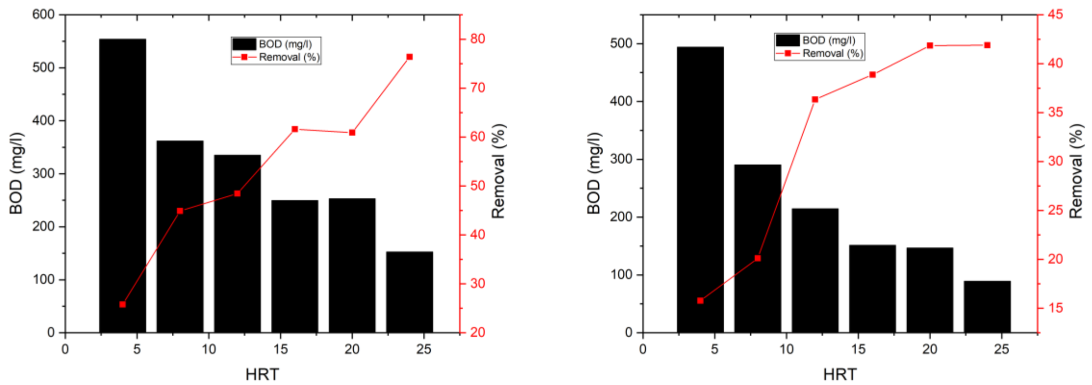
Biofiltration led to a marked improvement in the elimination of organic pollutants from wastewater. The results of the removal of organic materials from the cracker-industry wastewater are shown in Figure 2. The COD concentration of wastewater before treatment was 2299.18 mg/l during the 4-hour HRT research period with a flow rate of 66.67 ml/min and over a period of 14 days. The removal efficiency results showed that COD from wastewater increased significantly with operational time, with the highest anaerobic removal efficiency of 78.40 %. The aerobic process was continued such that the COD level decreased to 186.38 mg/l at a flow rate of 11.11 ml/min. In the 55-day experimental period, the combined anaerobic–aerobic system achieved its peak removal efficiency on day 51, when operated at a water flow rate of 11.11 mL/min. The gradual decline in COD levels could be caused by the length of the wastewater treatment process; the longer the process, the more organic matter settles and oxidizes. In addition, the combination of processes also affects the level of COD reduction; in the anaerobic process, COD meets the quality standards, and the aerobic treatment COD decreases. Therefore, the combination of anaerobic and aerobic systems provides an optimal treatment for COD levels in cracker industry wastewater. In addition, researchers also found the introduction of indigenous microorganisms effectively enhanced the COD removal process because biofilms could form on the 3rd day, indicated by yellow spots on andesite rocks.



(a) (b)

Figure 2. Removal % of COD (a) anaerobic and (b) aerobic from treated wastewater after biofilter process

Figure 3 illustrates the biofilter's performance in enhancing wastewater quality over the course of the operational period. The influent BOD concentration in wastewater from the cracker industry was 696.30 mg/l, while the concentration in wastewater that had been treated through the combined anaerobic–aerobic system, the BOD concentration decreased to 415.67 mg/l for 14 days of treatment with a 4-hour HRT and a flow rate of 66.7 ml/min. The final result of BOD concentration on the 55th day with the combined anaerobic aerobic system showed a decrease to a concentration of 84.69 mg/l. The first day's samples showed the highest BOD values, which allowed for the initial washing of particles and dissolved organic matter. After the adjustment, the BOD values began to decline. A decrease in BOD values indicates that microorganisms are starting to adapt to and decompose organic matter. In line with research by Saminathan et al. (2013), which showed that on the 4th day, the BOD value increased due to washing of particles, which caused a brownish-yellow color in the treated waste. The particle washing process is temporary, and over time, wastewater quality increases, as indicated by a significant decrease in BOD values(Rock et al., 1984, Saminathan et al., 2013). After the peak point at HRT of 14 hours in anaerobic conditions then it levels off and decreases to maintain the local microorganisms in the media constant and even achieve stable purification. Under these stable conditions, microorganisms compete to obtain substrates from the organic materials contained in wastewater. It can be interpreted that after the peak point, microorganisms in the biofilm compete for substrate (Dalahmeh et al., 2014).



(a) (b)

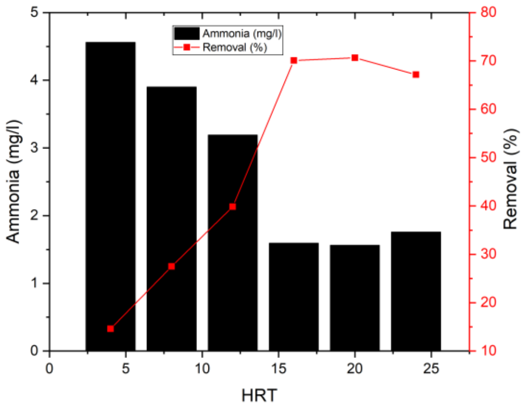
Figure 3. Removal % of BOD (a)anaerobic and (b) aerobic from treated wastewater after biofilter process

Apart from combined anaerobic–aerobic treatment configurations processing factors, continuous reduction in COD and BOD levels also occurs because of the efficiency of the media selected in the biofilter. Researchers have found that recirculation in batches affects the development of biofilms that reduce pollutants. Recirculation through the reactor layer provides organic or inorganic nutrients to the local microorganisms in the biofilm, resulting in more active biofilm development. Continuous recirculation causes COD and BOD to decrease and the DO concentration of wastewater to increase (Rehman et al., 2012). Similar observations were reported by Naz et al. (2016), which showed an increase in organic matter reduction caused by increasing temperature and efficiency of developing the stone media used in biofilters. Utilizing indigenous microbial communities further expedites the degradation of organic compounds within the wastewater. When microorganisms reach the surface of andesite rocks, local microorganisms attach to the media surface and metabolize organic pollutants as sources of carbon and energy (Dalahmeh et al., 2014, Ibrahim et al., 2020).

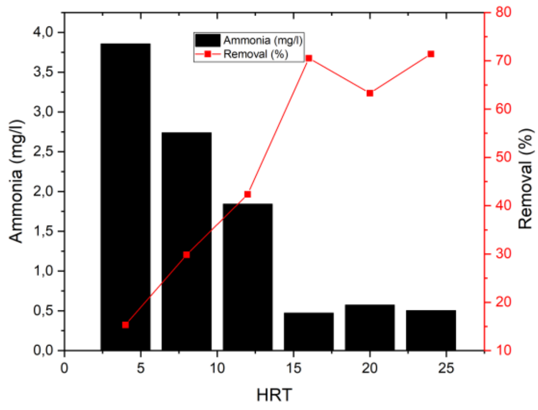
3.3. Removal of Ammonia

The significant improvement in water quality indicates a situation of biofilm formation in the biofilter reactor. The establishment of microbial communities in the biofilm promotes progressive elimination of contaminants through the biofilter mechanism. Rocher et al. (2012) found that 97% of ammonia (NH_3) was oxidized through the biofiltration process. Ammonia removal is carried out by microorganisms and absorption by media or substrates using an efficient conventional pathway involving nitrification followed by denitrification (Vymazal, 2007, Chang et al., 2019). Figure 4 shows that nitrogen removal accelerated with increasing operational time. Under anaerobic and aerobic conditions, the highest removal was observed at an HRT of 20 h with a flow rate of 13.33 ml/minute. The average influent ammonia level was 5.32 mg/l and experienced a gradual decrease on days 1, 10, 20, 30 and 40 by 1.15%, 15.40%, 30.93%, 69.52%, and 72.28% respectively anaerobically. Ammonia levels gradually decreased again after the 1st, 10th, 20th, 30th, and 40th days by 2.13%, 15.85%, 31.04%, 65.85%, and 65.52%, respectively. The ammonia removal efficiency increased with increasing drain time. The removal efficiency of ammonia increased after the HRT was extended from 4 h HRT, with removal of 14.59% to 70.63% at 20 h HRT.

Reducing the temperature also influences the nitrification rate in the wastewater treatment process because temperature can increase nitrification growth (He et al., 2007). Attached growth systems, such as biofilters, produce higher nitrogen reduction rates because of the use of media for microorganism attachment (Mahmoud et al., 2011). Ammonia removal efficiency removal showed that, as the flow rate decreased, ammonia removal increased. In this study, the highest percentage of ammonia removal was produced on the 40th day with an HRT of 20 h and a flow rate of 13.33 ml/minute. The more stable and slow the water flow rate, the more the reduction process in ammonia can run optimally. Microorganisms can optimally reduce pollutants because they are not disturbed by the rapid flow of water. These findings align with Subari et al. (2018), who observed an increase in ammonia removal after reducing flow rates because hydrodynamic conditions had a negative impact on biofilm stability. Excessive flow conditions can disrupt ammonia-converting microorganisms, ultimately diminishing overall removal effectiveness (Bar-Zeev et al., 2012, Gomes et al., 2014) .



(a)



(b)

Figure 4. Removal % of ammonia (a)anaerobic and (b) aerobic from treated wastewater after biofilter process

The denitrification process under aerobic conditions plays a major role in wastewater treatment, particularly in the removal of nitrogen compounds. In conventional denitrification, nitrogen is reduced to nitrogen gas under anoxic or anaerobic conditions using nitrate as an electron acceptor. In aerobic denitrification, oxygen and nitrate function as electron acceptors simultaneously, which plays a role in the simultaneous removal of nitrogen compounds and maintenance of oxygen-dependent microbial activity. This process is beneficial in aerobic systems because it allows simultaneous nitrification and denitrification. In aerobic denitrification, oxygen typically supports the oxidation of organic matter, while nitrate is reduced to nitrogen gas, providing an alternative pathway for nitrogen removal in oxygen-rich environments (Wallace and Austin, 2008, Hu et al., 2014).

3.4. Removal of Suspended Solid

Suspended solids in wastewater come fromcoagulated by-products of fish processing residue, additives for making crackers, and other flavoring ingredients during the cracker-making process. Initial influent contained around 433 mg/l of TSS, which was reduced to nearly 71 mg/l following treatment. The results show that a biofilter using local microorganisms can reduce TSS levels in wastewater by up to 83%, even though in this treatment, the treated wastewater does not meet quality standards. Solid removal is generally carried out through mechanical operations including filtration and sedimentation (Saminathan et al., 2013). The main removal mechanisms in the anaerobic phase are sedimentation and particulate trapping using andesite rock, which causes retention and microbial attachment. Furthermore, the aerobic reactor stabilizes the remaining particulates through gradual reduction as biologically non-degradable solids adhere permanently to the biofilm(Ji et al., 2014). Yang et al. (2018) stated that filtration-based media with high surface roughness increase particulate binding and improve solid-phase removal efficiency.

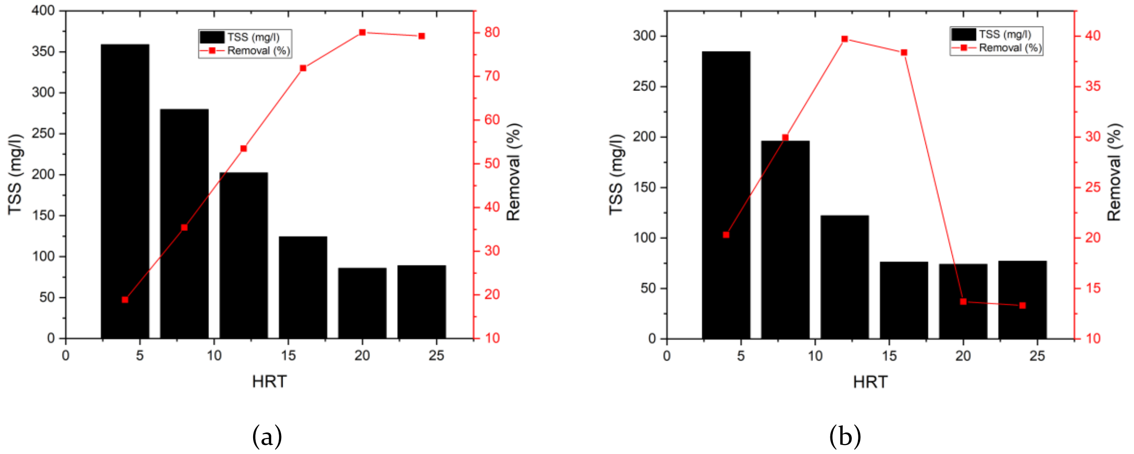


Figure 5. Removal % of total suspended solid (a)anaerobic and (b) aerobic from treated wastewater after biofilter process

Figure 5 shows a graph of the removal efficiency of solid suspenders. In the anaerobic process, the decrease in suspended solid levels continues to increase and can function optimally. However, after the advanced aerobic process, the overall decrease in suspended solid levels was stable, and there was no significant decrease. This shows that apart from filtration, the use of other treatments for removing TSS is necessary for processing cracker wastewater. In line with research by Saminathan et al. (2013) who stated that the most effective process for removing suspended solids is using filtration and sedimentation. In addition, some suspended solids cannot be removed because they cannot be decomposed and gradually become part of the biofilm (Ji et al., 2014).

3.5. Ratio of BOD/COD

BOD and COD are widely applied indicators to evaluate the presence of organic substances in water, whereas sulfate, chloride, ammonium, heavy metals, and others are used as measures of inorganic matter (Lee and Nikraz, 2014, Bader et al., 2022). BOD and COD are considered important measurements for determining the extent of water pollution, as indicated by the BOD/COD ratio. an elevated ratio typically signifies reduced biodegradability of the wastewater. Figure 6 shows the BOD/COD ratios in the crackered wastewater. The findings revealed that every treatment produced a ratio below 1. The BOD/COD ratio value in this study has a minimum value of 0.22, which indicates that the organic material content is not too high and is not difficult to decompose, and the results of processing cracker waste water are not toxic. Andrio et al. (2019) stated that the BOD / COD radio can be categorized as toxic, difficult to decompose and high organic matter if it is less than 0.1. The maximum value of the ratio after the anaerobic and aerobic processes was 0.43, demonstrating that the organic constituents present in cracker wastewater are readily biodegradable. The BOD/COD ratio, with a value of 0.4 indicates that it is easily biodegradable, and a ratio value greater than 0.5, indicates the best value. (Samudro and Mangkoedihardjo, 2010, Lee and Nikraz, 2014). This shows that the water resulting from processing with the aerobic anaerobic system in this study meets the standard requirements for the BOD/COD ratio.

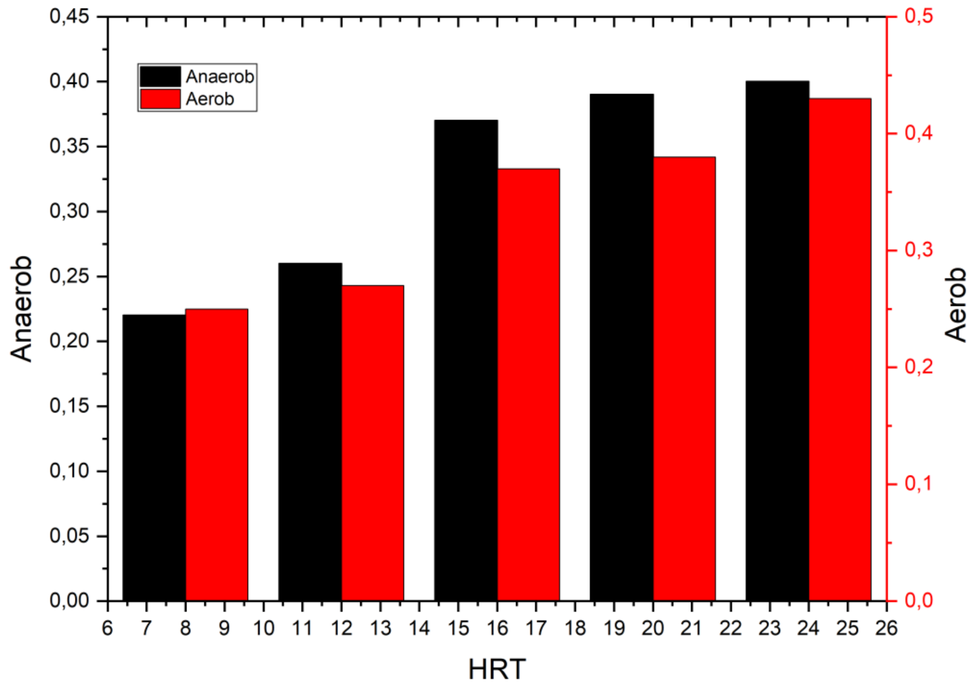


Figure 6. Ratio of BOD/COD

A large BOD/COD ratio indicates sufficient carbon availability for decomposition. A decrease in COD, accompanied by an increase in BOD levels, increased the ratio value. The biofilter based on local microorganisms in this study successfully increased the upward ratio, indicating improved carbon utilization and metabolic adaptation in the biofilter. Bader et al. (2022) stated that if the ratio value is more than 0.6 then the waste will be easily biodegradable. If the ratio is between 0.3 to 0.6, seeding with biological treatment is required to slow down the process because acclimatization to microorganisms is relatively slow and time-consuming. If the ratio is less than 0.3, biodegradation will not take place and cannot be treated by biological means because the waste inhibits the metabolic process. This is consistent with Deng et al. (2021) study that showed that a low BOD/COD ratio (<0.3) resulted in a decrease in the biodegradation process because the easily degradable carbon was insufficient to maintain microbial respiration. Compared to this study, which showed an increase in the BOD/COD effluent ratio from 0.22 to 0.47 during treatment, it was found that local microorganisms combined with andesite rock were effective in reducing organic matter.

3.6. Future Research Direction

Compared to other biological treatment methods in previous studies, this study showed that anaerobic-aerobic biofilters with local microorganisms are more efficient in removing ammonia and organic compounds. Conventional biofilters rely on commercial microbial inoculants or activated sludge, which require maintenance, higher aeration energy consumption, and longer start-up periods(Rehman et al., 2012). The use of local microorganisms from chicken manure in this study shortened the acclimatization time, resulted in faster biofilm formation on natural andesite stone media, and demonstrated stable removal performance during long operating times. This study proved that microorganisms from chicken manure combined with natural andesite stone media can enhance biofilm formation and pollutant removal efficiency; however, the microbial community structure in the degradation process has not been analyzed in depth. Further research is needed to investigate the dynamics of the microbial community using advanced molecular analyses, such as metagenomics and metatranscriptomics, to identify the dominant genera involved in organic degradation, nitrification, and denitrification under anaerobic-aerobic conditions. In addition, operational stability needs to be evaluated through long-term analysis of fluctuating organic load conditions, temperature variations, and loads commonly experienced in small-scale industrial wastewater systems. Previous studies have shown that biofilter performance can decline significantly when subjected to hydraulic stress or sudden pollutant surges (Deng et al., 2021). Therefore, pilot- and industrial-scale testing is required to evaluate the operational stability of biofilter systems based on indigenous microorganisms in industrial environments.

4. Conclusions

The highest percentages of organic matter removal, COD and BOD were 78.40%, ammonia was 76.10%, and total suspended solids were 83%. The highest COD removal occurred at the water flow rate with HRT, the highest BOD removal occurred at the water flow rate with HRT, the highest ammonia removal occurred at the water flow rate with HRT, and the highest TSS removal occurred at the water flow rate with HRT. the rise in the BOD/COD ratio from 0.22 to 0.47 suggested a reduction in easily biodegradable substances and an increase in the effectiveness of local microorganisms in reducing organic matter. Local microorganisms can adapt to wastewater and help biodegrade organic matter and other contaminants. Therefore, the use of a combination of anaerobic aerobic systems in this study is considered effective for the removal of organic matter, ammonia, and TSS in cracker-industry wastewater. This research developed a dual-phase anaerobic–aerobic biofiltration setup utilizing chicken manure–based indigenous microbes for pollutant removal from wastewater. From this study, it was found that the addition of chicken manure as a local microorganism material accelerated the formation of biofilms on biofilter media, thus accelerating the removal of pollutants. Additional investigation is necessary to clarify the correlation between microbial community structure and pollutant removal efficiency within biofilter systems.

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