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# Optimizing Community Health Center Effluent Treatment with Moving Bed Biofilm Reactor Technology Combined with Activated Carbon and Chlorine

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## ABSTRACT

Community Health Centers are small-scale hospitals that serve community medicine in Indonesia. These activities generate wastewater containing various contaminants, such as pathogens, chemicals, and nutrients, which can pollute the environment and endanger human health. So, efforts are needed to reduce their impact through wastewater treatment. This research applies an anaerobic-aerobic biofilter system with Moving Bed Biofilm Reactor (MBBR) technology combined with activated carbon and chlorine in treating wastewater. The treatments in the study were different service capacities and wastewater treatment, with three replicates in each treatment. The residence time of wastewater in the system is 4 h. The results showed that combining MBBR technology, activated carbon, and chlorine could reduce temperature, TSS, pH, $BOD_5$, COD, $NH_3$, and Coliform values in wastewater in three Community Health Center services. Thus, it can be concluded that the different services and wastewater treatment efforts, combined with MBBR, activated charcoal, and chlorine, have been proven to affect and improve the quality of wastewater from the Community Health Center to meet the effluent quality standards.

## INTRODUCTION

Community health centers, as part of health facilities in Indonesia, play an important role in public health but also generate a lot of wastewater containing various contaminants such as pathogens, chemicals, and nutrients. Improper management of this wastewater can cause severe environmental pollution and pose a great risk to the surrounding community (López-Ramírez et al. 2024, Rahmi et al. 2024). These residues can affect soil microorganisms, disrupt ecological processes, and possibly contaminate crops in agriculture (Patel et al. 2019). Therefore, wastewater treatment is crucial in maintaining both environmental and public health, especially with limited resources and infrastructure (Capps 2019, Santos et al. 2020). Biological treatment of liquid waste using an aerobic, anaerobic biofilter system is being developed. One of the environmentally friendly wastewater treatment is by using bacteria that can be decomposers in the biodegradation process (Madan et al. 2022, Waqas et al. 2023)

Environmental considerations also underlie the development of biological wastewater treatment where the environmental impact is smaller than chemical treatment (Dutta & Bhattacharjee 2021, Liu et al. 2021). Many systems have been used for secondary wastewater effluent treatment, such as activated sludge systems, trickling filters, Biodisc or Rotating Biological Contactors (RBC), oxidation ponds, and constructed wetlands. However, compliance with regulatory standards for effluent management often requires big costs and sophisticated technology. Therefore, there is an urgent need for practical and cost-effective wastewater treatment methods (Capps 2019, Saraswati et al. 2021, Waqas et al. 2023). We need effective and efficient wastewater treatment technology to overcome this problem (López-Ramírez et al. 2024, Yuan et al. 2019).

In sometimes cases, biological treatment is also unable to effectively treat wastewater due to the hazardous and biologically resistant components contained in the wastewater. Therefore, physicochemical processes can be one of the appropriate solutions to be combined (Valand et al. 2019, Zhang et al. 2024). Moving Bed Biofilm Reactor (MBBR) technology has been recognized as effective in treating wastewater with high organic matter content (di Biase et al. 2019, Santos et al. 2020). Moving Bed Biofilm Reactor (MBBR) utilizes moving media in the reactor to facilitate the growth of biofilms that play an important role in degrading organic matter present in wastewater. In addition, this technology also has advantages in terms of operational flexibility and ease of maintenance compared to conventional wastewater treatment systems (Eid et al. 2024, Ongena et al. 2023).

However, relying solely on the MBBR is insufficient to remove all contaminants in wastewater. Therefore, it is necessary to integrate additional technologies, such as activated carbon and chlorination, to improve treated water quality. Activated carbon can be an adsorbent (Sultana et al. 2022, Valand et al. 2019). Activated carbon is one of the materials with essential properties, namely adsorption (Chen et al. 2021). On the other hand, chlorine is necessary for disinfection, killing pathogens and microorganisms that may still be present after the primary treatment (He et al. 2022, Mulyati et al. 2022). In addition, combining chlorine pre-treatment with other methods, such as microalgae-based systems, has improved overall treatment efficiency by reducing pollutants such as detergents and phenols in wastewater (Hu et al. 2020).

Integrating an MBBR with activated carbon can significantly reduce high contaminant levels in wastewater treatment, especially in decentralized systems (Al Hosani et al. 2022). It shows the practical potential of implementing this technology in community health centers. MBBR systems have even been successfully used in various industries, including municipalities, paper mills, pharmaceuticals, and fish farms, demonstrating their versatility and effectiveness in treating different types of wastewater (Alizadeh et al. 2019). In addition, MBBR applications offer operational advantages by producing less sludge than traditional activated sludge processes, contributing to cost savings and operational efficiency (Suryawan et al. 2021).

Integration of MBBR with other treatment technologies, such as ozonation or membrane filtration, was also shown to improve overall treatment efficiency and reduce the environmental footprint of the wastewater treatment process (Alharthi et al. 2022, Banti et al. 2023, Dai et al. 2023, Tang et al. 2020) In addition, incorporating granular activated carbon coated on a carrier surface inside an MBBR has been shown to significantly increase the removal of chemical oxygen demand and total suspended solids, underscoring the positive impact this combination has on pollutant removal efficiencies (Nur Dhamirah & Aida Isma 2019). In line with this, another study found that chlorine effectively reduced antibiotic-resistant genes in wastewater during disinfection (He et al. 2022) and prevented nosocomial infections in healthcare facilities (Duvernay et al. 2020). This paper informs efforts to reduce the impact of small-scale hospital wastewater on the environment through wastewater treatment using MBBR combined with activated charcoal and chlorine.

## MATERIALS AND METHODS

The research is an experimental study of a wastewater treatment system combining Moving Bed Biofilm Reactor (MBBR) biofilter technology with activated carbon and chlorine. The parameters observed are physical parameters, including temperature and total suspension solid; chemical parameters, including pH, $BOD_5$, COD, and $NH_3$; and biological parameters, which are coliform. Effluent samples were collected from wastewater discharged by inpatient facilities at the Community Health Center. The treatments tested were service and effluent treatment with three replications of each observation at each location. The types of services were Service-1 community health centers serving an average of 84235 people/year, Service-2 community health centers serving an average of 122633 people/year, and Service-3 community health centers serving an average of 43934 people/year. Parameter measurements were taken before and after treatment and compared to the control without treatment. The residence time of wastewater in the system is four hours.

Samples taken at the specified service are analyzed at the environmental laboratory with proper handling following applicable standards. Then, the samples are tested using the test methods and standards shown in Table 1.

The materials used were the Kaldness model K1 Plus, activated carbon, and 90% chlorine solution. The activated

Table 1: Sample Analysis Method.

| No. | Parameters | Source | Methods |
|---|---|---|---|
| 1 | $NH_3$ | mg.L$^{-1}$ | Spectrophotometer |
| 2 | TSS (Total Suspended Solids) | mg.L$^{-1}$ | Gravimetry |
| 3 | Temperature | °C | Thermometer |
| 4 | pH (Degree of Acidity) | - | Potentiometry |
| 5 | Total Coliform | /100mL | MPN |
| 6 | BOD (Biological Oxygen Demand) | mg.L$^{-1}$ | Titrimetric/ Potentiometry |
| 7 | COD (Chemical Oxygen Demand) | mg.L$^{-1}$ | Spectrophotometer UV-VIS |

carbon used in this study was characterized by a scanning electron microscope (SEM) to observe its surface morphology. SEM testing was carried out with a magnification of 5000x and 10000x to get a detailed picture of activated carbon's pore structure, which can be seen in Fig. 1.

Natural bacterial growth was carried out in the MBBR biofilter reactor containing Kaldness K1 Plus with the amount of media as much as 40% of the reactor volume (24 L of a total of 60 L reactor) (Fig. 2). After 21 days, a biofilm layer was formed on the MBBR media that supported the biodegradation process.

The wastewater treatment system uses four cylindrical plastic containers with a capacity of 60 L. The first container is used for settling wastewater, and the second container is an aerobic reactor processing container that uses MBBR technology. The third container contains activated carbon, which functions as an adsorbent media, and the third container is then connected to a chlorinator for disinfection. A picture of the applied wastewater treatment system is illustrated in Fig. 3.

The wastewater in this experiment came from three community health center services, which amounted to 35m$^3$.day$^{-1}$. The residence time used for wastewater treatment was calculated as follows (Cruz-Salomón et al. 2017).

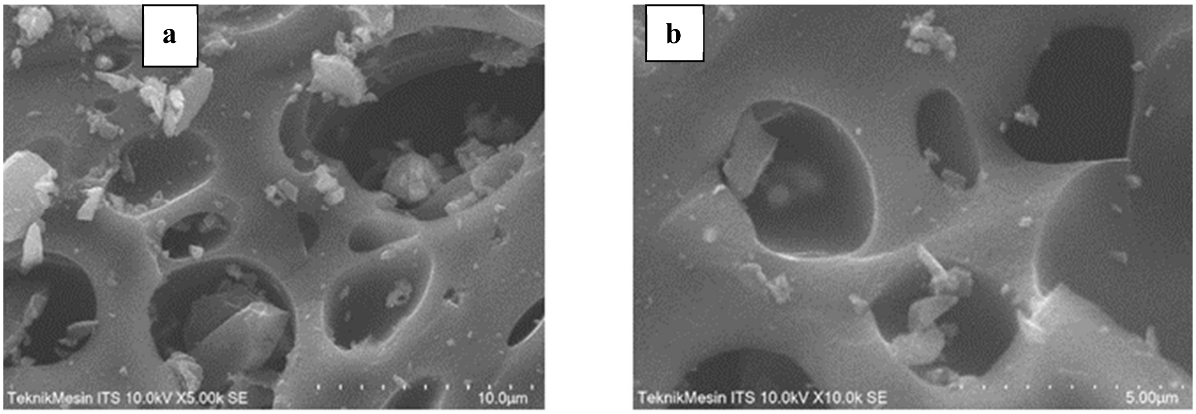

Fig. 1: Surface morphology of (a) 5000x magnification activated carbon and (b) 10000x magnification activated carbon.

Fig. 2: Kaldnes Type K1 Plus.

Fig. 3: Model of wastewater treatment system.

$$\tau = \frac{Vreaktor\ P3}{Q} \qquad \ldots(1)$$

Description:
τ = Residence time
Vreactor = Reactor volume (in liters)
Q = Effluent flow rate into the reactor (in liters per day)

The parameter removal efficiency was calculated using the following formula (Dolatabadi & Ahmadzadeh 2019):

$$\text{Efficiency} = \frac{\overline{X}\ Before\ treatment - \overline{X}\ After\ Treatment}{X\ Before\ treatment}\,100\% \qquad \ldots(2)$$

The data obtained were analyzed using tables and graphs, and the differences in service and processing treatments were tested with a two-way analysis of variance (Two-way ANOVA). Fig. 4 illustrates the abstract of this research.

## RESULTS AND DISCUSSION

### Wastewater Characteristics

The pre-treatment wastewater exhibited physical characteristics, including odor and a brownish turbid appearance. Laboratory analysis showed that temperature and pH values were within acceptable limits based on

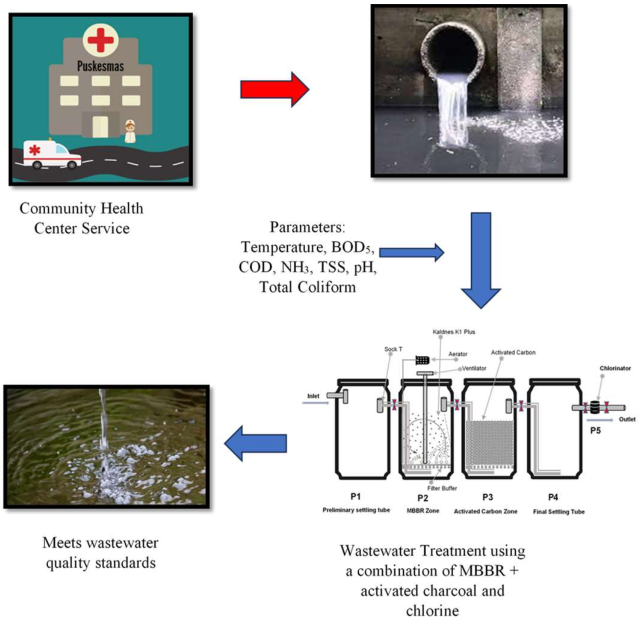

Fig. 4: Infographic abstract of the research.

Table 2: Characteristics of Community Health Center Wastewater in 2024.

| No. | Parameters | Community Health Center | | | Unit | Maximum rate* |
|---|---|---|---|---|---|---|
| | | Service 1 | Service 2 | Service 3 | | |
| 1 | Organic Material | 211,72 | 432,92 | 195,92 | $mg.L^{-1}$ | |
| 2 | Temperature | 28 | 29 | 29 | $^oC$ | <30 |
| 3 | pH | 7,64 | 7,45 | 7.63 | - | 6 - 9 |
| 4 | $BOD_5$ | 112.1 | 224.1 | 249.6 | $mg.L^{-1}$ | 30 |
| 5 | COD | 410 | 520 | 680 | $mg.L^{-1}$ | 100 |
| 6 | TSS | 150 | 300 | 316 | $mg.L^{-1}$ | 30 |
| 7 | Ammonia | 23,525 | 47,625 | 47.2 | $mg.L^{-1}$ | 10 |
| 8 | Total Coliform | 24000 | 24000 | 24000 | $MPN.100mL^{-1}$ | 3000 |

*Wastewater quality standard
Source: primary data

regulatory standards, while parameters such as BOD, ammonia, COD, and TSS exceeded quality standards. The initial characteristics of the wastewater effluent can be seen in Table 2.

## Wastewater Parameters

**Temperature:** The results showed that the average temperature of untreated wastewater from Service-3 was 29$^o$C, Service-2 was 29$^o$C, and Service-3 was 28.7$^o$C. At the same time, the treated wastewater decreased to Service-1 of 28.6$^o$C, Service-2 of 28.3$^o$C, and Service-3 of 28.7$^o$C. The three wastewater sources have different temperature values and removal rates. The average temperature value of each treatment can be seen in Fig. 5.

Fig. 5 shows that the average wastewater temperature after treatment has decreased from 28.3-28.7°C. It shows that the wastewater treatment process causes a decrease in media temperature but not significantly. Temperature variations can impact microorganisms. Higher water temperatures can lead to decreased dissolved oxygen levels and increased oxygen consumption by microorganisms (Wang et al. 2023). These findings are consistent with the results reported by Lewar et al. (2020), where the study showed that BOD and COD removal rates reached 83.96% and 84.02%, respectively, with the highest efficiency observed at 35°C (Lewar et al. 2020).

**TSS (Total Suspended Solids):** The suspended solids contained in the wastewater decreased with the treatment process. The average decrease in TSS content after treatment with MBBR biofilter technology is shown in Fig. 6.

Microorganisms are important in sewage treatment by utilizing organic pollutants as nutrients. They absorb dissolved organic pollutants through sorption, while organic particles adhere to their cell walls through adsorption. In addition, microorganisms produce enzymes that can break down these organic particles, facilitating the removal of dissolved and particulate organic pollutants from sewage (Snyder & Wyant 2013.). The results showed a significant reduction in the Total Suspended Solids (TSS) content in wastewater after treatment. For example, TSS levels in Service-1 wastewater decreased to an average of 8 $mg.L^{-1}$, marking a reduction of 142 $mg.L^{-1}$, with a combination of Moving Bed Biofilm Reactor (MBBR) and activated carbon biofilter technologies achieving 94% efficiency. Similar reductions also occurred in wastewater from Service-2 and

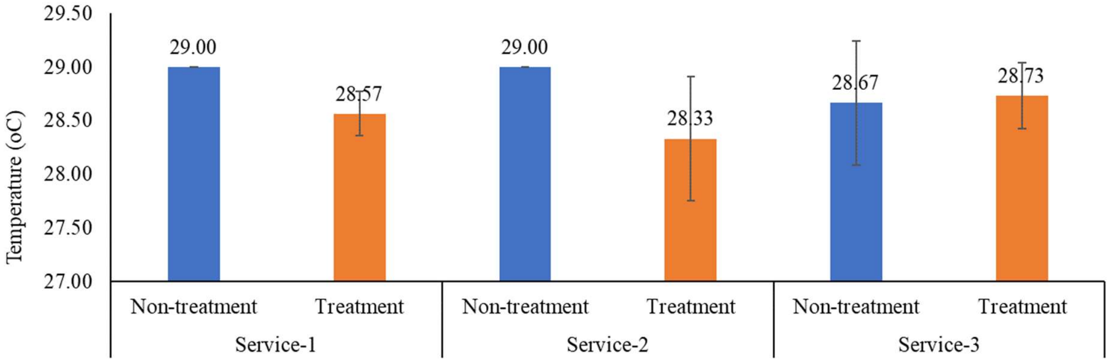

Fig. 5: Untreated and treated wastewater temperature values.

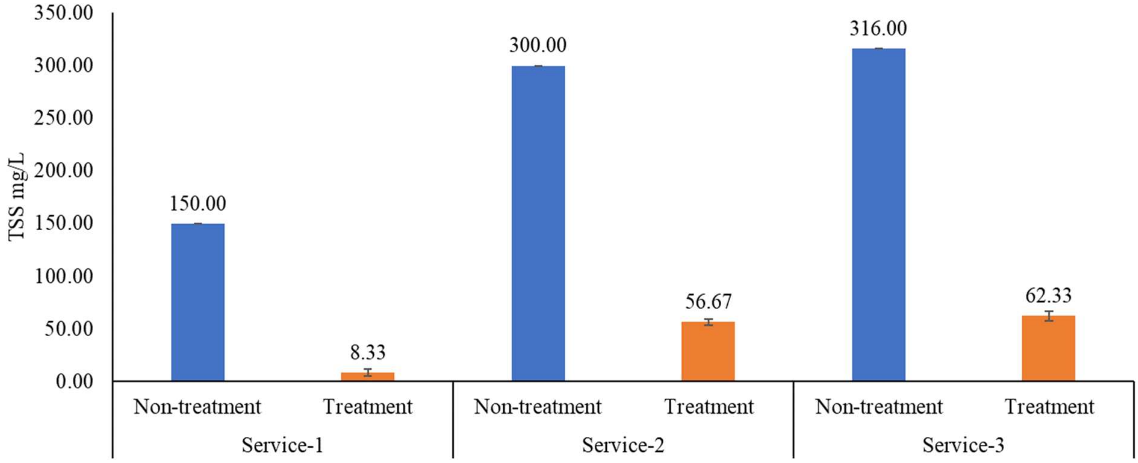

Fig. 6: TSS value of wastewater without and treatment process.

Service-3, where TSS levels decreased to 57 mg.L$^{-1}$ and 62 mg.L$^{-1}$, with average reductions and efficiencies of 81% and 80% using MBBR combined with activated carbon and chlorine.

This finding aligns with research conducted by Nhut et al. (2019), who reported an SS removal efficiency of 91,8% in domestic wastewater using MBBR (Nhut et al. 2019). Integrating biofilters with activated carbon proved very important in reducing TSS levels in wastewater. The high surface area of activated carbon, facilitated by its porous structure, increases its adsorption capacity. These pores provide sufficient space for adsorbates to interact with activated carbon, thereby increasing the efficiency of the adsorption process. As a result, activated carbon integrated into MBBR biofilter technology effectively reduces the TSS content in the wastewater.

**pH:** The results showed that the pH value without wastewater treatment for Service-1 was 7.7, Service-2 was 7.5, and Service-3 was 7.4. While the pH value after wastewater treatment decreased to Service-1 of 7.5, Service-2 of 7.3, and Service-3 of 6.9. The average pH value of each treatment can be seen in Fig. 7.

A decrease in pH can result from oxygen consumption during the decomposition of organic matter, leading to increased levels of $CO_2$, which in turn affects pH stability. In biological processes, pH plays a vital role in nitrification. The optimal pH conditions for nitrosomonas and nitrobacter bacteria range from 7.5 to 8.5 (Faust et al. 2024, Park et al. 2022). This is consistent with the statement that the ideal acidity (pH) for the growth of autotrophic ammonia-oxidizing bacteria is in the range of 7.5 to 8.5 (Albina et al. 2019).

**$BOD_5$ (Biochemical Oxygen Demand):** The $BOD_5$ content of the wastewater after treatment decreased significantly. Fig. 8 shows the average $BOD_5$ content in all treatments.

Fig. 8 shows that the average $BOD_5$ decreased significantly after treatment. The $BOD_5$ values of wastewater

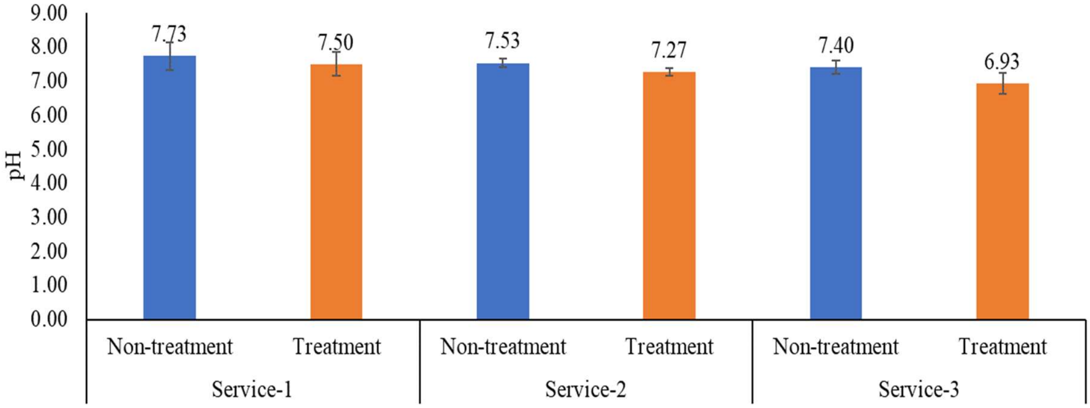

Fig. 7: Wastewater pH value without and treatment process.

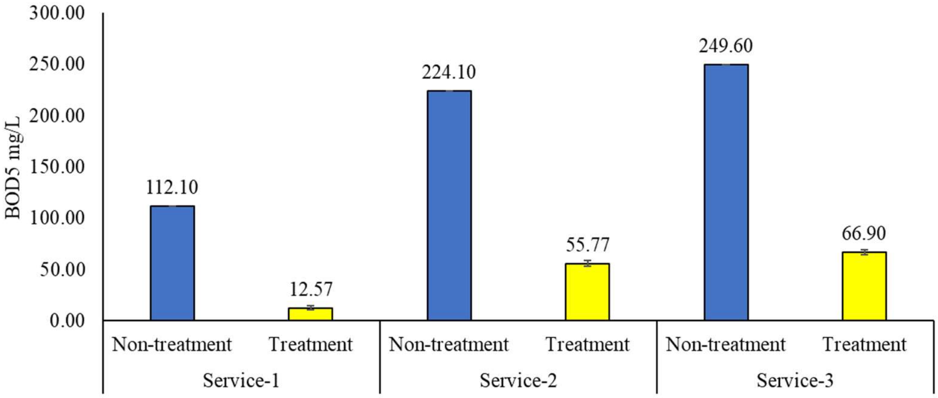

Fig. 8: $BOD_5$ values of wastewater without and treatment process.

from Service-1 decreased to 13 $mg.L^{-1}$ on average, marking a reduction of 100 $mg.L^{-1}$, with the MBBR biofilter technology combined with activated carbon, achieving 89% efficiency. Similarly, wastewater from Service-2 decreased to an average of 56 $mg.L^{-1}$, with a reduction of 168 $mg.L^{-1}$ and 75% efficiency using MBBR combined with activated carbon. The BOD $value_5$ from Service-3 showed an average decrease of 67 $mg.L^{-1}$, with a reduction of 183 $mg.L^{-1}$, and an efficiency of 73% using MBBR combined with activated carbon.

In comparison, research by Aniriani et al. (2022) on wastewater treatment in the Pondok Pesantren Mahasiswa IPAL of Lamongan Islamic University showed a reduction in BOD by 61.75%. (Aniriani et al. 2022). Another study by Osmani et al. (2021) reported a decrease in BOD of 91% (Osmani et al. 2021), and certainly, this study shows the level of BOD removal from health center wastewater using the MBBR method with Kaldness Media (K1 Plus) combined with activated carbon, can be said to be effective because it achieves optimal removal rates ranging from 73% to 89%.

**COD:** The results of measuring the COD content of wastewater in various treatments can be seen in Fig. 9.

Based on Fig. 9, it can be seen that the average COD content has decreased after treatment. Wastewater from Service-1 dropped to an average of 55 $mg.L^{-1}$, with a reduction of 355 $mg.L^{-1}$, achieving 87% efficiency using MBBR biofilter technology combined with activated carbon. Similarly, wastewater from Service-2 dropped to an average of 127 $mg.L^{-1}$, with a reduction of 393 $mg.L^{-1}$ and 76% efficiency using MBBR combined with activated carbon. Service-3 showed a decrease to 188 $mg.L^{-1}$ on average, with 492 $mg.L^{-1}$ reduction and 72% efficiency using MBBR combined with activated carbon.

The results of Faggiano et al. (2023) showed that the chemical oxygen demand (COD) reached a maximum removal of 98.5% high removal efficiency. This study successfully reduced organic matter and nutrients from landfill leachate using an anaerobic-aerobic MBBR mobile media biofilm reactor and activated carbon adsorption integration (Faggiano et al. 2023). In a different study, the MBBR-MBR hybrid system developed by Yang and López-Grimau (2021) showed a COD removal efficiency of up to 93% when applied to wastewater from the textile sector in Spain, indicating the system's treatment is quite effective for industrial wastewater containing organic contaminants

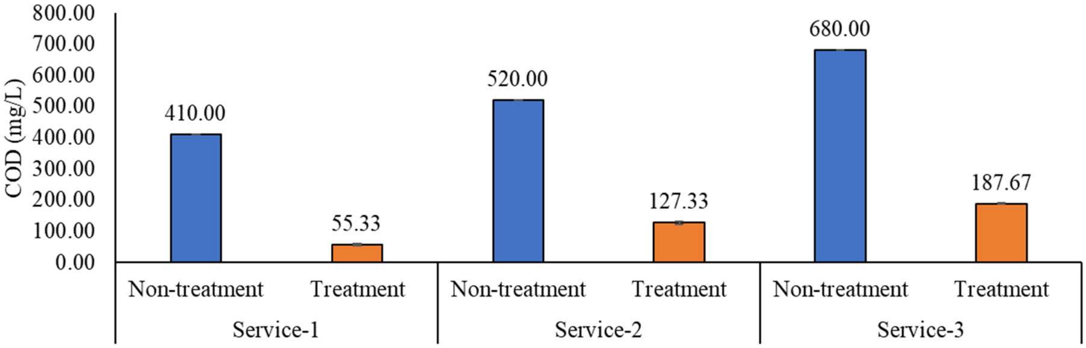

Fig. 9: COD values of wastewater without and treatment process.

(Yang & López-Grimau 2021). Nguyen Chuyen Thuan et al. (2024) found that granular activated carbon at a concentration of 20 $g.L^{-1}$ for 60 minutes can achieve a COD removal effectiveness of 56.8% (Thuan et al. 2024). These results indicate that GAC is efficient in COD removal and has great potential for wastewater treatment that requires the management of complex organic contaminants. These results confirm the effective use of activated carbon as an additional treatment in wastewater treatment systems.

Kaldness medium (K1) provides a large surface area (~500 $m^2.m^{-3}$) suitable for the attachment of aerobic bacteria (Banti et al. 2023). The smaller media volume compared to the reactor water volume encourages random movement and turbulence among the media under aeration, enhancing their rotation and movement effectiveness and thereby improving treatment efficiency (Ramadina 2023).

**$NH_3$:** The measurement results of Free Ammonia levels in wastewater in various treatments can be seen in Fig. 10.

Based on the test results, the average $NH_3$ content decreased significantly to 0 mg/L in all wastewater source treatments. $NH_3$ levels after treatment reached 100% efficiency with MBBR biofilter technology combined with activated carbon. These results are consistent with research conducted by Said et al. (2018), who reported ammonia removal efficiencies of 94.05%, 93.42%, 89%, and 79.6% at various contact times (12 h, 8 h, 6 h, and 4 h) in an aeration tank with a sludge circulation ratio of 1.0 Q = 0 R. At ammonia loading of 0.106 to 0.302 $kg.m^3.day^{-1}$, ammonia removal efficiencies ranged from 95.54% to 83.01% (Said & Syabani 2018). This condition is due to the availability of sufficient oxygen in the aerobic reactor, facilitating proper degradation by Nitrosomonas and Nitrobacter bacteria. Ammonium converted into nitrate-nitrogen is further converted into $N_2$ gas, which is released into the atmosphere through denitrification. In comparison, research by Dewi et al. (2019) using activated sludge achieved 94.70% effectiveness in reducing ammonia levels but required five days of treatment time (Dewi et al. 2019). Another study by Chávez et al. (2019) showed that activated carbon from coffee grounds is effective in absorbing ammonia liquid waste (Chávez et al. 2019). These findings underscore the effectiveness of MBBR biofilters combined with activated carbon in reducing ammonia content in the wastewater. Nonetheless, additional treatments such as activated carbon adsorption and ultraviolet light photolysis are still needed to optimize the treatment process of healthcare facility wastewater.

**Total Coliforms:** Fig. 11 shows the average total coliform content in wastewater at three service and treatment marks and processes. The untreated wastewater was 24,000/100 mL. The average Total Coliform content has decreased, i.e., wastewater from Service-1 decreased to 573/100 mL, marking a decrease of 23,427/100 mL with efficiency reaching 98%. Similarly, wastewater from Service-2 decreased to 610/100 mL on average, a reduction of 23,390/100 mL, with an efficiency of 97%, while Service-3 showed a decrease to 497/100 mL on average, a reduction of 23,503/100 mL, with an efficiency of 98%.

The results in Fig. 11 show that the effluent treatment effectively reduced coliform bacteria. Activated carbon has demonstrated its efficacy as an adsorbent for removing various contaminants from water, including harmful pathogens (Couso-Pérez et al. 2023). Activated carbon is known for its ability to adsorb organic substances, odor, taste, and other pollutants in water, thus improving water quality by reducing potentially harmful contaminants (Wysowska et al. 2021). The significant reduction of coliform bacteria in treated wastewater can also be attributed to chlorine's application in the reactor's final stage (Mulyati et al. 2022, Valentukeviciene et al. 2024)

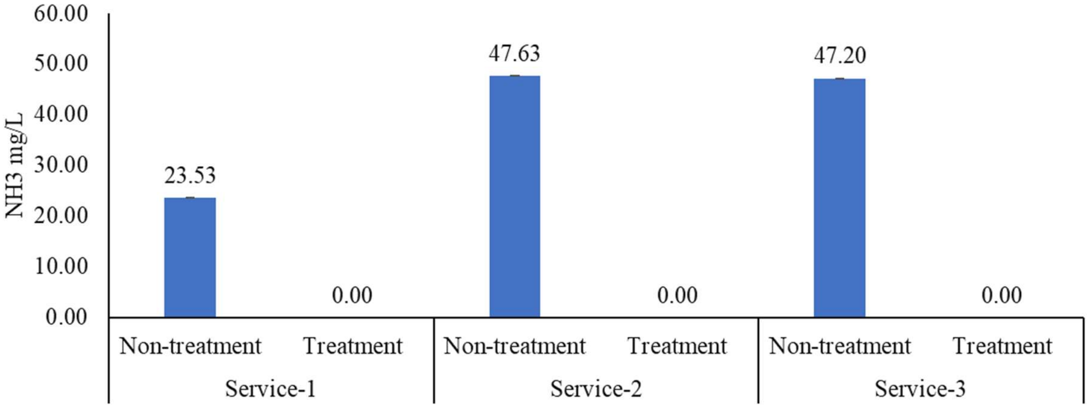

Fig. 10: Decrease in $NH_3$ wastewater without and treatment process.

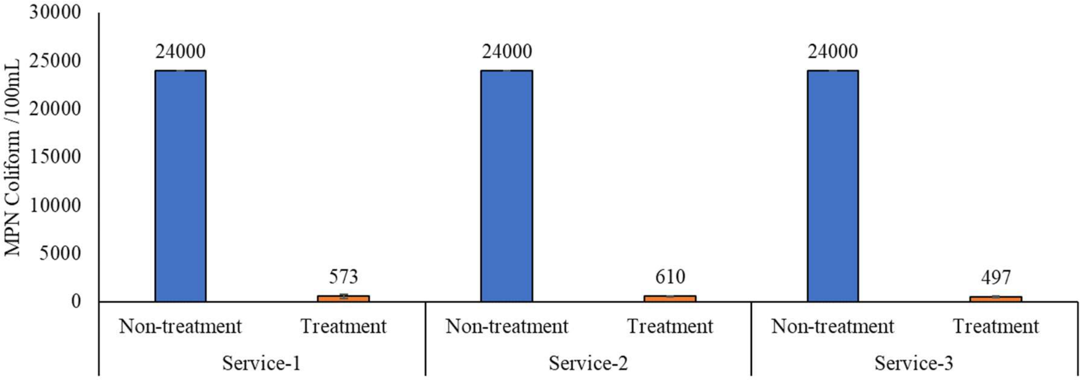

Fig. 11: Values of total coliform in wastewater without and with the treatment process.

Based on the ANOVA test results in Table 3, it can be explained that there are significant differences in several parameters between services and processing. The parameters tested include COD, BOD, TSS, Ammonia, Total Coliforms, pH, and temperature.

There is a significant effect between services on COD, BOD, $NH_3$, TSS, and pH concentrations, with a P-value <0.05. It indicates that the effluent conditions in each service are different and affect the treatment results. Various services may have variations in effluent composition, contaminant types, and other operational conditions that affect treatment effectiveness. However, there was no significant effect between services with temperature and total coliform, with p values > 0.05. It shows that the Service variation does not

Table 3: Two-way ANOVA test results between treatments.

| Treatment | Dependent Variable | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Services | COD | 121771.444 | 2 | 60885.722 | 11070.131 | 0.000’ |
| | BOD5 | 31114.534 | 2 | 15557.267 | 4663.294 | 0.000’ |
| | $NH_3$ | 570.632 | 2 | 285.316 | 1.30563E+31 | 0.000’ |
| | Coliform | 10033.333 | 2 | 5016.667 | 0.568 | 0.581 |
| | TSS | 44102.778 | 2 | 22051.389 | 3227.033 | 0.000’ |
| | pH | 0.608 | 2 | 0.304 | 4.022 | 0.046 |
| | Temperature | 0.043 | 2 | 0.022 | 0.162 | 0.852 |
| Processing | COD | 768386.722 | 1 | 768386.722 | 139706.677 | 0.000’ |
| | BOD5 | 101505.161 | 1 | 101505.161 | 30426.193 | 0.000’ |
| | $NH_3$ | 7004.545 | 1 | 7004.545 | 3.20533E+32 | 0.000’ |
| | Coliform | 2472451200 | 1 | 2472451200 | 280076.284 | 0.000’ |
| | TSS | 203947.556 | 1 | 203947.556 | 29845.984 | 0.000’ |
| | pH | 0.467 | 1 | 0.467 | 6.184 | 0.029 |
| | Temperature | 0.534 | 1 | 0.534 | 3.988 | 0.069 |
| Service * Processing | COD | 15164.778 | 2 | 7582.389 | 1378.616 | 0 |
| | BOD5 | 5928.268 | 2 | 2964.134 | 888.5 | 0 |
| | $NH_3$ | 570.632 | 2 | 285.316 | 1.30563E+31 | 0 |
| | Coliform | 10033.333 | 2 | 5016.667 | 0.568 | 0.581 |
| | TSS | 11493.444 | 2 | 5746.722 | 840.984 | 0 |
| | pH | 0.048 | 2 | 0.024 | 0.316 | 0.735 |
| | Temperature | 0.421 | 2 | 0.211 | 1.573 | 0.247 |

Source: primary data

significantly affect these two parameters. Treatment using an MBBR biofilter combination of activated carbon and chlorine significantly affected all parameters except temperature, with a p-value $< 0.05$. It means that this treatment is effective in reducing the concentration of BOD, COD, $NH_3$, TSS, pH, and Total coliforms in wastewater. For temperature, there was no significant difference after treatment ($P > 0.05$), indicating that this treatment did not significantly affect the wastewater temperature. The MBBR process and using activated carbon and chlorine did not appear to result in significant temperature changes.

There was a significant interaction between service and treatment on COD, BOD, $NH_3$, and TSS concentrations with p values $<0.05$. It is shown that the treatment effect varies by service. There was no significant interaction between service and treatment on total coliform, pH, and temperature, with p values $> 0.05$. It means that the effect of the treatments on these parameters is not affected by the service. The decrease in coliform, pH, and temperature stability was more influenced by the treatment mechanism than service differences.

The purpose of the combination of activated carbon, chlorine, and Moving Bed Biofilm Reactor (MBBR) is to reduce TSS, $NH_3$, COD, and other wastewater quality indicators (Madan et al. 2022). This combination increases the overall treatment effectiveness and accelerates the decomposition of organic and chemical contaminants (Alharthi et al. 2022). MBBR has the advantage of biofilm formation, which is very important for the biodegradation of pollutants. In addition, activated carbon is a very effective adsorbent for removing organic chemicals that are difficult to degrade in biofilters (Chen et al. 2021). Chlorine is used as a disinfectant after treatment to reduce pathogenic bacteria as much as possible before the wastewater is released into the environment (He et al. 2022). Combining these three technologies will provide a more effective and efficient treatment solution by accelerating pollution degradation and guaranteeing that the produced wastewater meets higher quality standards faster (Ongena et al. 2023).

The research demonstrates that treating wastewater from community health clinics using MBBR, activated carbon, and chlorine is effective. Parameters of water quality, such as TSS, $NH_3$, COD, BOD, and coliforms, all improved significantly. The excellent removal efficiencies attained across various parameters show the system's capacity to efficiently manage a range of pollutants. However, customized techniques based on individual wastewater characteristics are necessary, as demonstrated by the interplay between various services and the treatment process. The system works well, but depending on the operating environment and the characteristics of the service. Adjustments are thus necessary to achieve perfect performance.

It is essential to acknowledge that despite the study's noteworthy reduction in wastewater pollutant parameters, this research has several limitations. First off, the results of this research cannot be generalized to other healthcare facilities with distinct features since the study's parameters were restricted to three health centers with particular wastewater characteristics and service circumstances. The influence of external factors, such as unmeasured contaminants, was not fully considered, even though they may greatly impair system performance. Lastly, this research focused more on short-term outcomes than long-term effectiveness, which is crucial to guaranteeing the sustainable performance of this technology, given the potential for system degradation owing to biofilm accumulation or microbial resistance to chlorine.

## CONCLUSIONS

The combination of Moving Bed Biofilm Reactor (MBBR) technology, activated carbon, and chlorine effectively improved wastewater quality from the community health center, such as TSS, pH, BOD5, COD, $NH_3$ and Coliforms. The significant reduction efficiency is 89% for BOD5, 87% for COD, 94% for TSS, 100% for $NH_3$, and 98% for MPN Coliform. This combined treatment system is effective for small-scale hospital effluents such as community health centers. It has excellent potential to be adapted in various other health facilities, especially in resource-constrained areas. To ensure more comprehensive and sustainable implementation, further research is needed to assess the stability and effectiveness of this technology under various operational conditions and address challenges such as potential system degradation and adjustment to variations in effluent characteristics. Therefore, this technology is highly prospective for widespread adoption in sustainable medical waste management.

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