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JURNAL TEKNOSAINS

Performance of moving bed biofilm and lamella clarifier hybrid technology to improve hospital wastewater quality

Indonesian title: Kinerja teknologi hibrid moving bed biofilm dan lamella clarifier untuk peningkatan kualitas air limbah rumah sakit

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ABSTRAK

Pencemaran badan air permukaan akibat buangan limbah domestik, termasuk dari rumah sakit, menjadi isu serius yang mengancam kesehatan masyarakat dan kualitas lingkungan. Air limbah rumah sakit umumnya mengandung konsentrasi tinggi bahan organik (COD, BOD), padatan tersuspensi (TSS), serta senyawa patogenik yang dapat melebihi baku mutu sesuai Permen LHK No. 68 Tahun 2016. Penelitian ini bertujuan mengevaluasi kinerja kombinasi Moving Bed Biofilm Reactor (MBBR) dengan media Kaldness K1 dan Lamella Clarifier dalam menurunkan kadar COD, BOD, TSS, serta menstabilkan pH efluen limbah rumah sakit pada skala laboratorium. Metode penelitian menggunakan pendekatan eksperimental dengan rancangan IPAL laboratorium yang terdiri dari unit MBBR dan Lamella Clarifier. Sampel air limbah diambil secara grab sampling dari inlet IPAL rumah sakit, kemudian dilakukan pengolahan dengan variasi pengenceran 20%, 30%, dan 50% serta waktu tinggal 24 jam. Parameter yang dianalisis meliputi COD, BOD, TSS, dan pH. Data hasil pengolahan dianalisis secara statistik menggunakan uji paired t-test untuk mengetahui signifikansi penurunan konsentrasi sebelum dan sesudah perlakuan. Hasil penelitian menunjukkan kombinasi kedua unit ini mampu menurunkan BOD rata-rata 56%, COD 34%, dan TSS 53%, dengan pH efluen stabil pada 7,3–7,6 sehingga memenuhi baku mutu. Analisis statistik menunjukkan perbedaan signifikan ($p < 0,05$) antara kondisi inlet dan outlet, yang mengindikasikan efektivitas sistem. Dengan demikian, integrasi MBBR dan Lamella Clarifier layak dipertimbangkan sebagai solusi pengolahan air limbah rumah sakit yang efisien, stabil, dan sesuai regulasi lingkungan.

Kata kunci: *Moving Bed Biofilm Reactor; Lamella Clarifier; air limbah; rumah sakit.*

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ABSTRACT

Surface water pollution caused by the discharge of domestic wastewater, including that from hospitals, is a serious issue that threatens public health and environmental quality. Hospital wastewater typically contains high concentrations of organic matter (COD, BOD), suspended solids (TSS), and pathogenic compounds that may exceed the quality standards set by the Ministry of Environment and Forestry, as outlined in Regulation No. 68 of 2016. This study aims to evaluate the performance of a combination of a Moving Bed Biofilm Reactor (MBBR) using Kaldness K1 media and a Lamella Clarifier in reducing COD, BOD, and TSS levels, as well as stabilizing the effluent pH of hospital wastewater at the laboratory scale. The research employed an experimental approach, utilizing a laboratory wastewater treatment plant design comprising MBBR and Lamella Clarifier units. Wastewater samples were collected by grab sampling from the hospital treatment plant inlet, then diluted to varying concentrations of 20%, 30%, and 50%, and subjected to a 24-hour retention time. The analyzed parameters included COD, BOD, TSS, and pH. The treatment results were statistically analyzed using a paired t-test to assess the significance of concentration reductions before and after treatment. The results indicated that the combination of these two units achieved average reductions of BOD by 56%, COD by 34%, and TSS by 53%, with effluent pH between 7.3 and 7.6, meeting quality standards. Statistical analysis revealed significant differences ($p < 0.05$) between inlet and outlet conditions, indicating the system's effectiveness. Therefore, the integration of MBBR and Lamella Clarifier is considered a viable solution for efficient, stable, and regulation-compliant hospital wastewater treatment.

Keywords: *Moving Bed Biofilm Reactor; Lamella Clarifier; Wastewater; Hospital*

INTRODUCTION

Water pollution is one of the most pressing environmental issues in Indonesia, particularly concerning the decline in river water quality caused by discharges from domestic, industrial, and healthcare facility wastewater. According to data from the Ministry of Environment and Forestry (KLHK, 2021), more than 73% of the 140 monitored rivers were classified as polluted. One of the major contributors to organic and chemical contamination in surface water is hospital wastewater, which typically contains high concentrations of Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), as well as pathogenic microorganisms.

Hospital wastewater is a significant contributor to organic and chemical pollution in surface water. This type of effluent generally contains high concentrations of Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and Total Suspended Solids (TSS), as well as pathogenic microorganisms such as *Escherichia coli* and other coliforms. For example, a study conducted at Dr. Soetomo General Hospital in Surabaya reported that the hospital's wastewater treatment plant (WWTP) was able to reduce BOD by approximately 72.52%, COD by 54.02%, and TSS (total suspended solids) relative to the total suspended solids after the treatment process (Dewi et al., 2022).

Conventional wastewater treatment methods, such as anaerobic–aerobic biofilter systems, have exhibited only partial efficacy (Handriyono, 2022). The study reported that COD removal efficiencies ranged from 80% to 85%; however, the overall performance of such systems was highly dependent on operational parameters. In addition, the anaerobic–aerobic biofilter system did not consistently ensure compliance with effluent quality standards (Handriyono, 2022). A hybrid technology combining MBBR and lamella clarifier was proposed to enhance wastewater effluent quality. MBBR technology enhances process stability by promoting biofilm development on specially designed carrier media, whereas a lamella clarifier increases clarification efficiency through the implementation of inclined-plate sedimentation.

The biofilm in the Moving Bed Biofilm Reactor (MBBR) system plays an essential role as the primary medium for the growth and development of microorganisms responsible for the biodegradation of pollutants. The biofilm is a layer of microorganisms attached to the surface of the carrier media that moves within the reactor. Microorganisms within the biofilm degrade dissolved and suspended organic matter, thereby reducing the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels in wastewater. The MBBR system utilizes biofilm growth on the surface of the media to increase the contact area between the biomass and the wastewater, thus achieving higher efficiency in organic matter degradation compared to conventional activated sludge systems (Rusten et al., 2006a). The formation of biofilm on the surface of biocarriers occurs through a process of cell attachment and growth, ultimately leading to the development of a mature biofilm.

Several previous studies have highlighted the limitations of conventional treatment systems. The TSS concentration in effluent from conventional wastewater treatment plants still exceeded regulatory standards (Kuncistati, 2009). Similarly, another study observed that COD removal efficiency reached only 45.8% (Aniriani et al., 2022). In addition, Nasoetion et al. (2017) evidence that anaerobic treatment methods achieved approximately 60% removal efficiency for BOD, COD, and TSS. These findings underscore the need for more innovative and integrated technological approaches to achieve optimal treatment efficiency and compliance with environmental regulations.

Therefore, this study aimed to evaluate the performance of hybrid technology, combining MBBR and lamella clarifier, at a laboratory scale in removing key pollutants from wastewater, including COD, BOD, TSS, and pH. The novelty of this research was in the systematic analysis of the technology performance under varying wastewater dilution levels (20%, 30%, and 50%) over a 7-day observation period. Furthermore, the study incorporated statistical analysis and a compliance assessment of Indonesian wastewater effluent quality standards to determine the overall feasibility of wastewater treatment using a combined MBBR and lamella clarifier.

Hospital wastewater is generated from domestic activities, including kitchens, bathrooms, nutrition units, and patient laundry. According to the Indonesian Minister of Health Regulation Number 3 of 2020, hospital wastewater is classified as non-toilet domestic wastewater. Domestic wastewater is typically categorized into two types: greywater and blackwater. Greywater originates from activities such as bathing and washing, whereas blackwater is generated from toilet use and typically contains high concentrations of pathogenic microorganisms (Ghaly et al., 2021).

The proportion of greywater in hospital domestic wastewater is generally higher, accounting for approximately 69%, while blackwater constitutes around 31% (Imhof, 2005). Although greywater is typically more readily biodegradable, it still poses a potential environmental threat due to the presence of complex organic and chemical substances. Therefore, the treatment of hospital wastewater is crucial to safeguarding the quality of receiving water bodies.

Wastewater quality assessment is generally based on four key parameters: COD, BOD, TSS, and pH. COD represents the amount of oxygen required to chemically oxidize both biodegradable and non-biodegradable organic and inorganic compounds (Metcalf & Eddy, 1991). BOD measures the quantity of dissolved oxygen consumed by microorganisms to degrade organic matter under aerobic conditions. Elevated BOD values indicate a high organic load, which can result in significant depletion of dissolved oxygen in receiving water bodies (Mays, 1996).

TSS indicates the concentration of undissolved solid particles in water, including sludge, sand, and other organic matter. Elevated TSS levels can impair water aesthetics, reduce the efficiency of subsequent treatment processes, and lead to sediment accumulation in water channels (Rinawati et al., 2016). Meanwhile, pH serves as an indicator of wastewater's acidity or alkalinity. Deviations from the optimal pH range can significantly impact the efficiency of biological treatment processes and have detrimental effects on aquatic ecosystems (Widayatno & Sriyani, 2008).

The MBBR is a wastewater treatment technology based on the growth of microorganisms on freely moving carrier media (attached growth process). The most used media is Kaldness K1, which has a high specific surface area (500–800 m^2/m^3). Kaldness K1 is made of High-Density Polyethylene (HDPE). This structure facilitates the formation of biofilms, enabling efficient degradation of organic compounds in wastewater (Rusten et al, 2006b). The system employs continuous aeration to maintain an adequate oxygen supply and keep the carriers in motion, thereby preventing excessive biofilm accumulation and ensuring sustained biological activity.

MBBR offers several advantages, including high process stability, adaptability to fluctuations in pollutant loads, and the elimination of complex sludge handling requirements. Previous studies have demonstrated that under optimal conditions, MBBR achieves COD and BOD removal efficiencies of more than 70% and 80%, respectively (Ahmed et al., 2020; Jabari et al., 2014). Moreover, Kaldness K1 media possesses a self-cleaning capability that helps to maintain biofilm thickness within the optimal range. This ensures consistent treatment performance.

The lamella clarifier is a physical treatment system designed to accelerate the sedimentation of suspended particles. It employs a series of inclined plates arranged in parallel, effectively reducing the vertical settling distance of particles and enhancing sedimentation efficiency within a compact footprint (Sugiharto, 2006). This system is particularly well-suited for post-biological treatment applications, such as following MBBR processes, to improve suspended solids removal further and produce a clearer wastewater effluent.

The lamella clarifier offers several advantages, including high TSS removal efficiency (80–95%), a relatively compact system footprint, and low operational requirements. With its 45° inclined-plate design and low Surface Overflow Rate (SOR), this technology is particularly well-suited for hospital and other healthcare facility applications where space availability is limited, as stated in the Indonesian Ministry of Environment and Forestry Regulation Number 5 Year 2021.

The combination of MBBR and lamella clarifier represents a promising technological solution for hospital wastewater treatment. The MBBR unit primarily facilitates the degradation of dissolved organic compounds, whereas the lamella clarifier enhances the separation efficiency of suspended solids that are not entirely removed during biological treatment. This combination yields a more stable and comprehensive treatment system compared to single-process approaches (Mazioti et al., 2017).

Method

This study was conducted on a laboratory-scale wastewater treatment system, comprising an MBBR equipped with Kaldness K1 media and a lamella clarifier with inclined plates. Wastewater samples were collected from a hospital domestic wastewater channel in Cimahi, West Java, Indonesia. The sampling technique used was grab sampling, with a volume of 10 L per sampling collection. The wastewater samples were subjected to dilute levels of 20%, 30%, and 50%. The analyzed parameters were COD, BOD, TSS, and pH, excluding microbiological aspects and subsequent disinfection stages.

The analytical procedure for testing pH, BOD, COD, and TSS parameters was carried out at the PT. The ITEC Solution Indonesia laboratory uses wastewater samples collected from the inlet and outlet of the treatment system. Sampling was conducted using the grab sampling method, in which water samples were taken directly from the inlet point (before treatment) and the outlet point (after treatment) using sterile 1-liter sampling bottles. The samples were then labeled according to the sampling points and immediately stored in a cool box at a temperature of approximately ±4°C to prevent any changes in their physicochemical characteristics prior to laboratory analysis.

The MBBR unit consisted of a 5 Ls-tank, which was filled with Kaldness K1 biofilm carriers at a 30% filling ratio. Continuous aeration was supplied to ensure adequate oxygen availability and to maintain the movement of the carriers within the reactor. The lamella clarifier unit had a capacity of 3 L/S and was equipped with inclined plates positioned at a 45° angle (Figure 1).

(a) (b)

Figure 1.
Experimental scale reactor: (a) MBBR (Left) and lamella clarifier (Right); (b) Operating reactor
Source: Research documentation (2025)

To maintain biomass balance, sludge from the clarifier was recirculated back into the MBBR reactor. Three dilution treatments (20%, 30%, and 50%) were applied in this study. Each treatment was operated with a Hydraulic Retention Time (HRT) of 24 hours. Observations were conducted over a consecutive seven-day period. Pollutant removal efficiency was calculated using the following equation:

Eficiency (%) = (Cin − Cout) / Cin × 100%

Where:
Cin and *Cout* represent the influent and effluent concentrations, respectively

Source: (Metcalf & Eddy, 2014)

Statistical analysis was performed using a paired t-test with a 95% confidence level (α = 0.05). System feasibility was evaluated based on technical performance, compliance with environmental quality standards, and the operational stability of the treatment process.

Prior to operating the wastewater treatment system, a seeding and acclimatization process was carried out in the MBBR reactor. Seeding was performed by introducing activated sludge obtained from a conventionally operated hospital WWTP. The activated sludge contained a microbial community that was already adapted to degrading organic compounds in hospital wastewater, thereby facilitating rapid biofilm formation on the Kaldness K1 carriers within the reactor.

Following the addition of activated sludge, an acclimatization phase was carried out by introducing diluted hospital wastewater into the system under controlled operational conditions. The purpose of this acclimatization process was to allow microorganisms to gradually adapt to the specific characteristics of the wastewater used in this study, including concentrations of COD, BOD, and TSS. The acclimatization step also served to enhance microbial biological activity, ensuring greater efficiency in contaminant degradation during subsequent treatment operations.

During the acclimatization process, continuous oxygen aeration was supplied using a blower with an air flow rate adjusted to ensure sufficient oxygen availability for the growth of aerobic microorganisms. Aeration also served to maintain constant movement of the Kaldness K1 carriers within the reactor, promoting uniform biofilm development and preventing excessive microbial accumulation. The acclimatization period lasted for several days until visible biofilm formation was observed on the carrier surfaces. The biofilm was covered by a thin, whitish to brownish layer that evenly coated the Kaldness K1 media. These seeding and acclimatization steps were critical components of the successful operation in the MBBR biological system, because they directly influenced the initial process stability and the subsequent pollutant removal efficiency throughout the treatment stages.

The combination of MBBR and lamella clarifier represents a promising technological solution for hospital wastewater treatment. The MBBR unit primarily facilitates the degradation of dissolved organic compounds, whereas the lamella clarifier enhances the separation efficiency of suspended solids that are not entirely removed during biological treatment. This combination yields a more stable and comprehensive treatment system compared to single-process approaches (Mazioti et al., 2017).

RESULTS AND DISCUSSION

The initial wastewater characterization revealed COD, BOD, and TSS concentrations of 120 mg/L, 70 mg/L, and 55 mg/L, respectively. The initial pH of wastewater was 6.5. These initial characteristics did not comply with the wastewater effluent standards in the Indonesian Regulation of the Environmental and Forestry Minister Number 68 Year 2016.

The wastewater samples were collected from the inlet tank, which accommodates domestic discharges generated from various hospital activities, including the kitchen, bathrooms, and laundry facilities. These sources contribute a complex mixture of organic and inorganic pollutants, including detergents, soap residues, fats, oils, and suspended solids. The laboratory analysis results of the inlet samples prior to treatment revealed that the concentrations of key pollution indicators, pH, BOD, COD, and TSS, exceeded the inlet quality standards established by the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number 68 Year 2016 concerning domestic wastewater quality. Elevated values of BOD and COD reflect a high organic load in the wastewater, indicating the presence of biodegradable organic compounds from food waste, soap, and human activities. In contrast, the high TSS levels indicate the presence of significant particulate matter originating from washing and kitchen processes.

The primary cause of these exceedances is the accumulation of organic materials and surfactants characteristic of hospital domestic wastewater, which typically exhibits higher pollutant concentrations than household wastewater due to continuous operational activities and the use of cleaning chemicals. Hospital effluents contain elevated concentrations of organic pollutants, detergents, and suspended solids that pose challenges for conventional treatment systems (Verlicchi et al., 2012).

Following treatment with the combined MBBR and lamella clarifier, effluent quality showed a significant improvement (Figure 2-5). BOD concentrations decreased to 18 mg/L (60% removal), COD was reduced to 48 mg/L (43.5% removal), and TSS dropped to 8 mg/L (65.2% removal). In addition, the pH was stabilized within the range of 7.2–7.6, which remained in compliance with effluent quality standards.

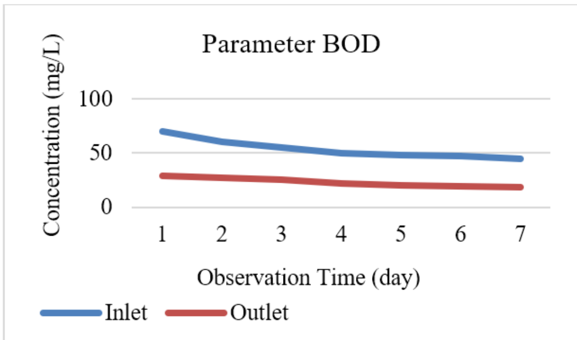

Figure 2.
Parameter BOD after MBBR and lamella clarifier treatment
Source: Author’s analysis (2025)

According to Figure 2, those findings highlighted the complementary functions of the two treatment units. The MBBR facilitated biological degradation through biofilm activity, while the lamella clarifier enhanced the physical separation efficiency of suspended solids. The system's performance was consistent with previous studies, which reported the high effectiveness of MBBR technology in removing organic matter (Aygun et al., 2008; Rusten et al., 2006b). For the COD parameter (Figure 3), the average influent concentrations ranged between 242 mg/L and 289 mg/L, depending on the level of dilution. The most significant reduction occurred between the third and fifth day, indicating that the microbial community within the MBBR system had begun to reach metabolic stability. By day seven, COD removal efficiency reached 81% at a 20% dilution, 78% at a 30% dilution, and 73% at a 50% dilution. This reduction reflected the successful degradation of organic compounds by the biofilm growing on the Kaldness K1 media, as well as the crucial role of aeration in maintaining optimal aerobic conditions.

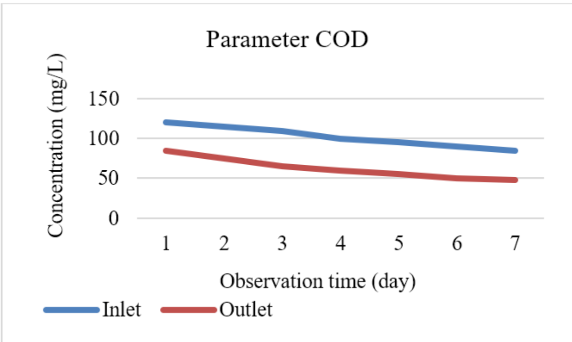

Figure 3.
Parameter COD after MBBR and lamella clarifier treatment
Source: Author's analysis (2025)

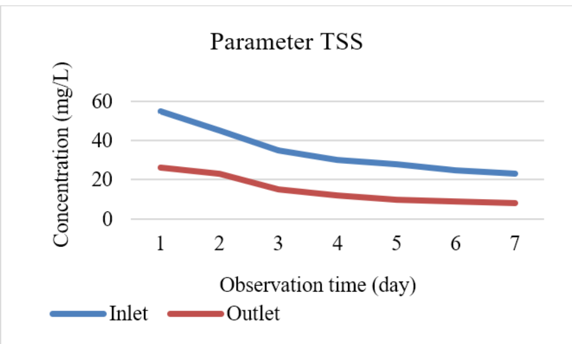

Figure 4.
Parameter TSS after MBBR and lamella clarifier treatment
Source: Author's analysis (2025)

For the TSS parameter (Figure 4), fluctuations were observed during the first three days, likely due to the initial detachment of biofilm or residual activated sludge that had not yet been fully separated from the system. However, from day four onward, a marked decrease was observed, continuing through day seven. On the final day, TSS concentrations reached 19 mg/L for the 20% dilution, 22 mg/L for the 30% dilution, and 24 mg/L for the 50% dilution, corresponding to removal efficiencies ranging from 75% to 88%. These results highlighted the effectiveness of the lamella clarifier in separating suspended solids discharged from the MBBR unit.

Monitoring of COD, BOD, and TSS removal efficiencies was carried out over seven consecutive days (H1–H7). The results demonstrated a progressive and consistent decrease in concentrations for each parameter, indicating the performance of the MBBR and lamella clarifier systems in stabilizing the treatment process.

The BOD parameter exhibited a decreasing trend parallel to that of COD, albeit with slightly higher removal efficiencies at certain dilution levels. This is attributed to the fact that BOD primarily represented organic compounds that were more readily biodegradable. On day one, BOD values ranged between 125–150 mg/L, decreasing to 25–35 mg/L by day seven. The highest BOD removal efficiency was recorded at 84% under 20% dilution. This pattern indicated that the system effectively supported microbial biochemical processes in decomposing dissolved organic matter.

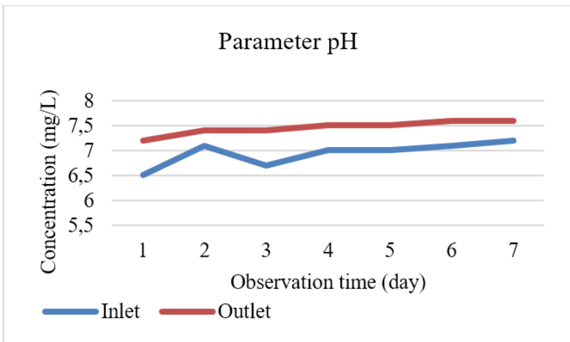

Figure 5.
Parameter pH after MBBR and lamella clarifier treatment
Source: Author's analysis (2025)

Meanwhile, as shown in Figure 5, the pH parameter exhibited only minor fluctuations throughout the observation period, remaining within a neutral range of 6.8 to 7.5. This pH stability indicated that no significant accumulation of acidic or alkaline compounds occurred during the treatment process. The consistently neutral pH also supported optimal conditions for the activity of aerobic microorganisms within the biofilm.

Overall, the weekly trends indicated that the combined MBBR and lamella clarifier system achieved high treatment efficiency within a relatively short period. The system's performance consistently improved over time, in line with the maturation of the biofilm and the stabilization of hydraulic conditions within the reactor. These findings suggested that a seven-day monitoring period was sufficient to evaluate the performance trends of the system on a laboratory scale.

Additionally, this staged treatment system was consistent with previous findings, which demonstrated the effectiveness of pilot-scale MBBR systems under varying operational conditions for hospital wastewater treatment (Mazioti et al., 2017).

Statistical analysis using a paired t-test revealed that the reductions in BOD, COD, and TSS concentrations were statistically significant, with p-values < 0.05. This confirmed the reliability and effectiveness of the treatment system's performance. Furthermore, all effluent samples monitored throughout the seven-day observation period consistently complied with the Indonesian domestic hospital wastewater discharge standards, indicating that the system maintained stable operational efficiency in accordance with regulatory requirements.

The findings of this study also highlighted several key advantages. First, the hybrid technology of MBBR and lamella clarifier enhanced the operational stability of the system, particularly under varying dilution conditions. Second, this combined system demonstrated robust potential for upscaling in urban hospitals, such as those in Cimahi, where space constraints and the demand for a compact, low-maintenance solution are critical considerations. Third, its cost-effectiveness and environmental sustainability were supported by minimal chemical usage and low sludge production, making it a practical and eco-friendly alternative for hospital wastewater treatment.

Compared to conventional anaerobic–aerobic biofilter systems, which often yield variable results and sometimes fail to meet effluent quality standards, the hybrid MBBR–lamella clarifier system has demonstrated more consistent and reliable performance (Handriyono, 2022; Kuncistati, 2009; Nasoetion et al., 2017). These findings supported the broader implementation of this hybrid approach as a sustainable solution for decentralized hospital wastewater treatment in Indonesia.

The feasibility evaluation of the combined MBBR and lamella clarifier system was assessed not only in terms of pollutant removal efficiency but also in terms of technical performance, operational stability, and compliance with environmental regulations. Technically, the findings demonstrated that the system maintained stable performance in reducing COD, BOD, and TSS concentrations across various levels of wastewater dilution. The average removal efficiencies for each parameter met the effluent standards stipulated in the Indonesian Ministry of Environment and Forestry Regulation Number 68 Year 2016. This indicated that the system is functionally viable for application in hospital domestic wastewater treatment.

The stability of the system was further evidenced by its ability to withstand fluctuations in organic loading throughout the seven-day observation period. MBBR technology provided flexibility in handling variations in pollutant concentrations, as the microorganisms growing on the Kaldness K1 media dynamically adapted to changing environmental conditions. Meanwhile, the lamella clarifier maintained a high removal efficiency of suspended solids even under variable influent loads. The hybrid of these two units resulted in a system that was relatively simple to operate, requiring minimal sludge management and occupying a small footprint. Therefore, this finding was suitable for application in space-constrained facilities such as medium-sized urban hospitals.

From a regulatory compliance perspective, the system demonstrated strong potential to meet Indonesian domestic wastewater discharge standards. All monitored parameters, including COD, BOD, TSS, and pH, were reduced below the permissible limits. This compliance served as a key indicator for assessing both environmental feasibility and legal suitability of implementing the system in healthcare facilities.

Overall, the hybrid technology of MBBR and lamella clarifier was strongly recommended as an efficient, adaptive, and regulation-compliant solution for domestic wastewater treatment. With proper design adjustments, this system had the potential to be implemented across various type C and D hospitals that required compact and cost-effective treatment installations while maintaining reliable operational performance. Additionally, with its compact footprint and relatively simple operational requirements, the MBBR and lamella clarifier system required only minor modifications to the existing wastewater treatment infrastructure, which was primarily composed of conventional treatment. Additionally, this hybrid technology features an energy-efficient operation system and minimal reliance on coagulant chemicals. Therefore, this system proved to be more cost-effective and environmentally sustainable in the long term.

However, to ensure optimal performance at full-scale implementation, further research was required to evaluate the long-term stability of the biofilm and the system's capacity. This is designed to handle the loading peak, which is commonly encountered in healthcare facilities. In addition, a comprehensive economic feasibility study should be conducted, including estimation of initial capital investment, operational and maintenance (O&M) costs, and a life cycle analysis to compare this hybrid technology with other available wastewater treatment technologies. Policy recommendations are also emphasized to address the need for regulatory support from local governments in promoting the adoption of decentralized biofilm-based treatment technologies as part of broader strategies for mitigating urban water pollution.

Overall, the findings provide a foundation for further research, both on a pilot project scale and at full scale, for implementation in hospitals facing challenges in wastewater management. Through a systematic and collaborative approach involving hospital staff, environmental engineers, and regulators, the combination of MBBR and lamella clarifier technology was supposed to be an innovative solution to support the achievement of sustainable environmental quality targets.

CONCLUSION

The hybrid technology of MBBR and lamella clarifier achieved removal efficiencies of 60% for BOD, 43.5% for COD, and 65.2% for TSS, while successfully stabilizing effluent pH within the acceptable range. All treated effluent parameters consistently complied with the national hospital wastewater discharge standards, demonstrating the technical and environmental feasibility of the system.

This study presents a sustainable sanitation technology solution for managing hospital wastewater in Indonesia. The recommended future studies include evaluating the system at both the pilot project and full scale, investigating the long-term stability of biofilm performance, and integrating further treatment utilizing a disinfection stage to enhance pathogen removal efficiency. Furthermore, a study on the economic aspects of this hybrid technology was also to be carried out.

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