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RESEARCH ARTICLE

Performance Evaluation of an Anaerobic-Aerobic Biofilter in the Wastewater Treatment System of a Mortuary Facility

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Abstract: Mortuary facilities generate wastewater with elevated concentrations of organic matter, suspended solids, oils and grease, ammonia, and microbial contaminants, necessitating effective treatment to mitigate environmental and public health risks. This study evaluates the performance of an anaerobic-aerobic biofilter wastewater treatment plant (WWTP) serving a mortuary facility in Makassar City. Wastewater samples were collected at the influent and effluent points of the system during July and August 2025 and analyzed for BOD₅, COD, TSS, oil and grease, NH₃-N, and total coliforms. The influent wastewater exhibited high pollutant loads (e.g., BOD₅: 58.1–58.4 mg/L; COD: 139.50–140.33 mg/L; TSS: 63.2–64.9 mg/L; NH₃-N: 13.42–13.94 mg/L; coliforms: 9532–9541 CFU/100 mL). Treatment by the biofilter consistently reduced these contaminants, producing effluent concentrations within applicable national standards. Removal efficiencies in July ranged from 45.56–67.81%, while efficiencies in August ranged from 52.11–70.03% for physicochemical parameters. Microbial removal was also effective, achieving 75.55% and 77.58% reduction in July and August, respectively. These findings demonstrate that the anaerobic-aerobic biofilter performs reliably under routine operating conditions, effectively reducing organic pollutants, suspended solids, oils and grease, ammonia, and total coliforms in mortuary wastewater. The system provides compliant effluent quality without additional treatment stages, indicating its suitability for managing medium-strength, high-organic-load wastewater generated by mortuary activities. As research on mortuary wastewater biofilters remains limited, this study provides new evidence on system performance and helps address an existing knowledge gap

Keywords: Anaerobic-Aerobic Biofilter, Wastewater Treatment, Mortuary Wastewater, Effluent Quality, Removal Efficiency.

1. Introduction

Wastewater originating from mortuary activities represents a specialized type of liquid waste with distinct public health and environmental implications. It is generated from the washing of human remains, handling of bodily fluids, and use of chemical agents during preparation or embalming processes. Several studies indicate that mortuary and funeral facilities may release biological and chemical pollutants with concentrations exceeding those found in typical domestic wastewater (Gwenzi, 2020).



Microbiological risks have become an important scientific focus, particularly through the concept of the thanato-resistome, which refers to antimicrobial-resistant bacteria associated with cadavers and mortuary practices. Research shows that pathogenic and resistant microorganisms may persist on human remains even after embalming; chemical preservatives reduce but do not eliminate microbial viability (Balta et al., 2019; Uy et al., 2022).. Consequently, mortuary effluent may contain elevated loads of coliforms and other pathogens.

In parallel, studies on necroleachate from burial environments reveal additional concerns. Necroleachate contains readily biodegradable organic compounds, ammonia, and pathogens such as *E. coli* and *Salmonella*, with documented impacts on soil and shallow groundwater quality. Hydrogeological investigations have confirmed vertical and lateral migration of decomposition fluids, influenced by soil structure, porosity, and groundwater depth (Azevedo et al., 2023; Dent, 2002; Morandi et al., 2024). These findings underscore that both preparation and burial stages contribute to environmental microbiological loading.

Mortuary wastewater also exhibits complex chemical characteristics, often containing high concentrations of BOD, COD, TSS, oils and grease, and ammonia. Additional concern arises from embalming chemicals such as formaldehyde, which is known to inhibit key microbial processes within biological treatment units. Laboratory studies report full inhibition of acetate utilization in methanogenic cultures at $\sim 10 \text{ mg}\cdot\text{L}^{-1}$ and partial irreversible inhibition at higher concentrations (Qu & Bhattacharya, 1997). Formaldehyde exposure has also been shown to suppress sulfide production in anaerobic systems (Zhang et al., 2008) and generate residual toxicity in biological treatment effluents (Kajitvichyanukul et al., 2006). These inhibitory effects highlight the need for treatment technologies capable of maintaining stability under chemically stressful conditions.

Among available options, anaerobic–aerobic biofilter systems are widely applied for medium-strength organic wastewater. Their sequential configuration—anaerobic degradation followed by aerobic oxidation—has demonstrated reliable performance in reducing organic matter, suspended solids, and nitrogenous compounds in various wastewater types (Fu et al., 2016; Potgieter et al., 2019; Rebah et al., 2010). However, published research specifically evaluating the performance of biofilters for mortuary effluent, particularly in the presence of aldehyde-based preservatives, remains scarce. This gap limits the development of technical guidelines and operational standards tailored to mortuary wastewater management.

Based on this context, the present study aims to evaluate the performance of an anaerobic–aerobic biofilter system at a mortuary facility in Makassar City in reducing key physicochemical and microbiological parameters in mortuary wastewater, as well as to determine the system's capacity to comply with applicable effluent standards and the potential need for additional disinfection stages.

2. Literature Review

2.1 Characteristics of Mortuary Waste and Chemical Contaminants

Mortuary facilities generate complex waste streams that often include biodegradable organic compounds, suspended solids, fats and oils, as well as preservative chemicals used in embalming such as formaldehyde, glutaraldehyde, alcohols, and phenol. These substances pose environmental and toxicological risks, especially if discharged without proper treatment. Studies indicate that embalming effluents can contain very high concentrations of formaldehyde and other persistent chemicals, which can leach into soil and groundwater and affect microbial activity in conventional wastewater treatment systems (Kleywegt et al., 2019; Oliveira et al., 2013; Richardson et al., 2024).

Professional guidelines emphasize minimizing the use of toxic or persistent embalming chemicals. The National Funeral Directors Association (NFDA) recommends reducing phenolic-based products and other hazardous substances and using only necessary amounts

for preservation. These best practices highlight the importance of understanding the chemical characteristics of mortuary waste for designing effective treatment and management systems (NFDA, 2025)

2.2 Toxicity of Preservatives and Implications for Biological Systems

Formaldehyde is a highly toxic and potentially carcinogenic compound that can severely inhibit microbial activity in biological treatment systems. High concentrations of formaldehyde (e.g., above ~200–250 mg/L) have been shown to reduce biomass production, damage biofilm structure, and impair microbial respiration in both aerobic and anaerobic reactors (Crous & Haarhoff, 2011). Meanwhile, although some microbes can biotransform phenol, the presence of formaldehyde significantly inhibits the complete degradation of phenol and disrupts denitrification processes (Eiroa et al., 2025).

As an alternative to synthetic aldehyde preservatives, natural aldehydes such as vanillin have been proposed due to their lower toxicity and improved biodegradability (Briou, 2025). Research on microbial metabolism also indicates that high concentrations of phenolic compounds and formaldehyde exert strong inhibitory effects, whereas aromatic aldehydes like vanillin are better tolerated (Zhao et al., 2024). These findings are critical for designing mortuary waste treatment systems that are both environmentally safe and biologically stable.

2.3 Biofilm Resilience in Anaerobic–Aerobic Biofilter Technology

Anaerobic–aerobic layered biofilter technology is highly effective for treating wastewater with high organic load and complex chemical composition. The biofilm that develops on the filter media enables microbial communities to survive fluctuations in environmental conditions and exposure to toxic compounds. A field study on hospital wastewater demonstrated that an anaerobic–aerobic biofilter system significantly reduced COD, BOD, and coliform counts.

Previous applications of anaerobic–aerobic biofilter systems have reported high removal efficiencies, with BOD and COD reductions typically ranging from 85–96%, depending on the filter media and operational parameters (Sembiring et al., 2024; Setiyawan et al., 2023). In comparison, the removal efficiencies observed in the present study fall within a moderate range, which is reasonable given the presence of embalming preservatives and other inhibitory compounds characteristic of mortuary wastewater. This comparison indicates that although mortuary effluents present greater treatment challenges, the biofilter system remains capable of achieving acceptable performance within the expected range for biofilm-based treatment processes.

Extracellular polymeric substances (EPS) within the biofilm play a critical role in reactor stability, protecting microbial cells from environmental stress and supporting the degradation of toxic chemicals. Moreover, control strategies that alternate anaerobic and aerobic cycles, such as in A²/O (Anaerobic–Anoxic–Oxic) processes, benefit from biofilm resilience: the structure allows efficient denitrification and adapts to operational parameters like hydraulic retention time (HRT), which is vital when contaminant loads fluctuate.

3. Research Method and Materials

3.1 Study Site and Wastewater Source

The study was conducted at a mortuary facility in Makassar City, South Sulawesi, Indonesia. The facility generates wastewater primarily from the washing of human remains, handling of bodily fluids, and cleaning of preparation areas. The wastewater is characterized by high organic content, suspended solids, oils and grease, ammonia, and microbial contaminants.

The anaerobic–aerobic biofilter wastewater treatment plant (WWTP) at the facility consists of a sequential system, starting with an anaerobic reactor followed by an aerobic biofilter. The system is designed for medium-strength wastewater and aims to reduce organic and nitrogenous compounds, suspended solids, and microbial load prior to discharge.

The anaerobic–aerobic biofilter system at the facility consists of a sequential treatment train comprising a grease trap, equalization tank, primary sedimentation chamber, anaerobic biofilter, aerobic biofilter, secondary settling tank, and a final chlorination unit (see Figure 1). Both the anaerobic and aerobic reactors are packed with PVC-based honeycomb (sarang tawon) media with high porosity (0.98), low density (30–35 kg/m³), and a specific surface area of 2.5 m²/m³, providing an extensive surface for biofilm development. The WWTP is designed for a hydraulic capacity of 2.5 m³/day, corresponding to an average flow rate of 0.11 L/s, with peak flows reaching 0.22 L/s, and hydraulic retention times ranging from 6–8 hours in the anaerobic unit to approximately 25 hours in the aerobic biofilter. Aeration in the aerobic chamber is supplied by blower-driven perforated-pipe diffusers (AMARA 100, 67 L/min), ensuring adequate oxygen transfer for aerobic degradation, while the equalization tank uses coarse-bubble diffusers for homogenization through pneumatic mixing prior to biological treatment.

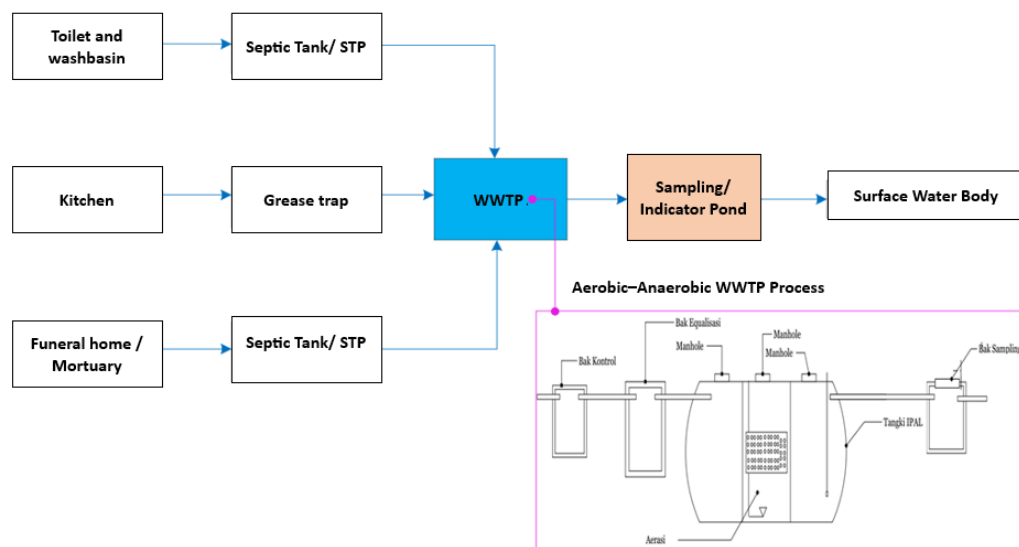


Figure 2: Flow of the Wastewater Treatment Plant (WWTP) Process

3.2 Study Site and Wastewater Source

Wastewater samples were collected at two points: the influent (raw wastewater entering the system) and the effluent (treated wastewater exiting the biofilter). Sampling was performed twice during the study period, in July and August 2025, to account for potential temporal variability. At each sampling event, three replicate samples were collected using sterilized polyethylene bottles and transported on ice to the laboratory for immediate analysis.

3.3 Study Site and Wastewater Source

The following physicochemical and microbiological parameters of the wastewater were analyzed using standardized methods:

- pH:** SNI 06-6989.11-2004
- BOD₅:** SNI 6989.72-2009
- COD:** SNI 6989.73-2009
- TSS:** SNI 06-6989.3-2004
- Oil and Grease:** SNI 6989.10-2011
- Ammonia (NH₃-N):** SNI 06-6989.30-2005
- Total Coliform:** APHA 9222 B-2017
- Temperature:** SNI 06-6989.23-2005

3.4 Performance Evaluation



The removal efficiency of the biofilter system for each parameter was calculated using the following equation:

$$Removal\ Efficiency\ (\%) = \frac{C_{inlet} - C_{outlet}}{C_{inlet}} \times 100 \quad (Eq. 1)$$

Where C_{inlet} and C_{outlet} represent the concentrations of the parameter in the influent and effluent, respectively.

3.5 Compliance Assessment

The treated effluent was assessed against Indonesian national effluent standards as stipulated in PERMENLHK No. P.68/Menlhk/Setjen/Kum.1/8/2016. All analyses were conducted in a KAN-accredited laboratory (ISO/IEC 17025:2017).

4. Results and Discussion

4.1 Wastewater Characteristics at Inlet and Outlet

As shown in Table 1, influent wastewater from the mortuary facility exhibited high concentrations of organic matter, suspended solids, oils and grease, ammonia, and microbial contaminants, reflecting the complex composition resulting from corpse washing, handling of bodily fluids, and the use of embalming chemicals. The physicochemical characteristics indicate a medium-strength, high-organic-load wastewater that requires effective biological treatment to reduce environmental and health risks.

Treatment through the anaerobic–aerobic biofilter resulted in substantial reductions in all measured parameters, bringing the effluent into compliance with national standards. The system maintained stable pH and temperature, supporting microbial activity and operational stability, while total coliforms were effectively reduced to levels within regulatory limits. These results demonstrate that the biofilter is capable of treating complex mortuary wastewater efficiently without the need for additional disinfection, consistent with findings from prior studies on sequential anaerobic–aerobic biofilm systems (Hariyani & Sarto, 2018).

Table 1: Inlet-Outlet Data for July and August 2025

Parameter	Quality Standard*	Measurement Unit	Inlet July	Outlet July	Inlet August	Outlet August
pH ¹⁾ **	6-9	-	8,3	7,8	8,3	7,7
BOD ₅	30	mg/L	58,1	20,32	58,4	19,73
COD **	100	mg/L	139,50	75,95	140,33	67,21
TSS **	30	mg/L	63,2	24,6	64,9	26,2
Oil & Grease **	5	mg/L	7,00	2,50	7,30	2,20
Ammonia, NH ₃ -N	10	mg/L	13,42	4,32	13,94	4,26
Total Coliform	3000	CFU/100 mL	9532	2331	9541	2139
Temperature ¹⁾	38	°C	30,1	28,1	30,6	28,4

* PERMENLHK No. P.68/Menlhk/Setjen/Kum.1/8/2016

** KAN-accredited (ISO/IEC 17025:2017)

¹⁾ In-situ (field) analysis results

4.2 Removal Efficiency

As summarized in Table 2 and illustrated in Figure 1, the anaerobic–aerobic biofilter achieved high removal efficiencies for BOD, COD, suspended solids, oils and grease, and ammonia, confirming its effectiveness in treating medium-strength, complex wastewater. Efficiencies were calculated using Equation 1, representing the percentage reduction of each parameter between influent and effluent. Total coliforms were also effectively reduced, with effluent levels consistently within regulatory limits.

Table 2: Removal Efficiencies of the Anaerobic–Aerobic Biofilter (July–August 2025)

Parameter	July (%)	August (%)
BOD ₅	65,03%	66,22%
COD	45,56%	52,11%



TSS	61,08%	59,63%
Oil & Grease	64,29%	69,86%
Ammonia, NH ₃ -N	67,81%	69,44%
Total Coliform	75,55%	77,58%

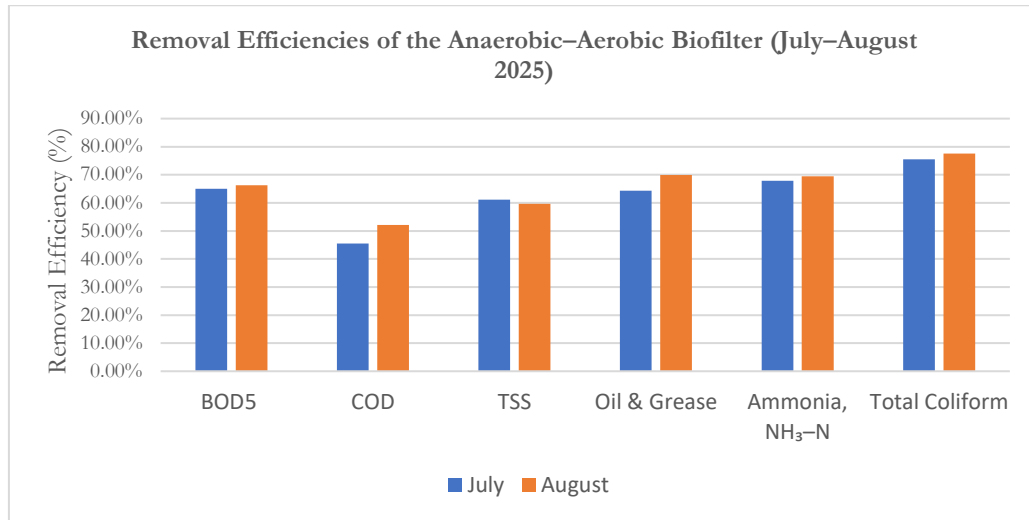


Figure 2: Comparison of removal efficiencies for key wastewater parameters in July and August 2025.

COD removal was slightly lower than BOD₅ removal because COD represents both biodegradable and non-biodegradable fractions of organic matter, whereas BOD₅ measures only the biodegradable portion. Mortuary wastewater contains preservative chemicals such as formaldehyde and phenolic compounds, which contribute to the non-biodegradable COD fraction and are more difficult for biofilm microorganisms to degrade. This results in comparatively lower COD removal despite effective BOD₅ reduction (Crous & Haarhoff, 2011; Metcalf & Eddy, 2014).

These findings are consistent with previous studies on sequential anaerobic–aerobic biofilm systems, which reported similar reductions in organic matter, suspended solids, and nitrogenous compounds under comparable operational conditions. Prior research on hospital and industrial wastewater demonstrates that such biofilters maintain stable microbial communities, effectively supporting both organic and nutrient removal even with variable influent characteristics. The observed variations in microbial reductions highlight the influence of operational parameters, including hydraulic retention time, biofilm development, and influent quality, emphasizing the need for continuous monitoring to ensure consistent effluent quality (Rahadi et al., 2018).

4.3 Operational Considerations and System Stability

The observed stability of the anaerobic–aerobic biofilter in this study suggests a robust performance under fluctuating influent conditions. Fixed-film biofilm systems are inherently resilient, as the attached microbial communities (biofilms) buffer against short-term load swings and maintain metabolic activity. This resilience is supported by recent reviews showing that biofilm-based anaerobic reactors enhance microbial retention and provide better resistance to inhibitory substances compared to suspended growth systems (Abera et al., 2024).

The sequential anaerobic–aerobic configuration used here enables complementary removal mechanisms: the anaerobic stage facilitates hydrolysis and degradation of complex organics, while the aerobic biofilm stage supports further oxidation of organics and nitrification of ammonia. This synergistic interplay has been successfully demonstrated in modern moving-

bed biofilm reactor (MBBR) systems, where sequential treatment improves both COD removal and nitrogen conversion (Wang et al., 2024).

Efficient ammonium removal in biofilter systems strongly depends on the structure and thickness of the biofilm. Recent research shows that biofiltration design (e.g., flow regime, carrier media) significantly affects nitrification performance: for example, unconventional flow patterns can optimize biofilm thickness and keep microbial activity stable, enhancing ammonium oxidation efficiency (Papciak et al., 2024).

Microbial community variability — particularly in terms of bacterial populations responsible for nitrogen metabolism — may contribute to fluctuations in microbial removal performance. A recent review pointed out that bacterial diversity, biofilm architecture, and operational parameters such as hydraulic retention time (HRT) and flow regime strongly influence pollutant removal stability in biofilters (Mulyadi et al., 2023).

4.4 Implication for Compliance and System Optimization

The performance of the anaerobic–aerobic biofilter demonstrates that the system is capable of producing effluent that consistently approaches applicable regulatory standards. The substantial reduction in organic matter, suspended solids, ammonia, and microbial indicators reflects the effective functioning of the sequential anaerobic and aerobic processes. This aligns with previous findings showing that dual-phase biofilm systems sustain high treatment efficiency due to their stratified microbial communities and the structural stability provided by attached growth media.

Maintaining long-term performance, however, requires continued operational optimization. Biofilm stability—which governs organic degradation and nitrogen transformation—is influenced by critical factors such as hydraulic retention time (HRT), nutrient balance, and aeration intensity. Prior research indicates that adequate HRT supports robust biofilm formation, enhances nitrification, and prevents biomass washout under varying influent loads (González et al., 2023; Kawan et al., 2022). In this study, the relatively stable effluent quality suggests that current operating conditions are generally adequate, although adjustments may be necessary during periods of elevated loading.

From a microbiological standpoint, mortuary wastewater presents episodic risks due to the presence of decomposition fluids and potential pathogenic organisms. Although effluent coliform concentrations remained within regulatory limits, the literature emphasizes the importance of post-treatment disinfection for systems handling high-risk effluents. Hybrid disinfection strategies—such as combined UV and chlorination—have been shown to enhance microbial inactivation and mitigate issues of regrowth commonly observed in UV-only systems (González et al., 2023; Shekhawat et al., 2023). Incorporating such measures would strengthen the reliability of pathogen removal and ensure consistent compliance.

Enhancements including periodic adjustment of HRT, routine assessment of media condition, and the integration of a disinfection stage would help improve system resilience. These efforts would reinforce effluent safety and provide greater assurance that mortuary wastewater is treated effectively under both normal and fluctuating operational conditions.

This anaerobic–aerobic biofilter system could be implemented in similar facilities, such as funeral homes or small hospitals, by tailoring the filter size and hydraulic retention time to the specific wastewater volume and composition. Consistent operational performance can be ensured through routine maintenance, including periodic sludge removal and monitoring of critical parameters. Such replication offers an effective and cost-efficient strategy for the treatment of small-scale wastewater with high organic loads.

5. Conclusion

This study assessed the performance of an anaerobic–aerobic biofilter system used to treat mortuary wastewater based on operational data collected in July and August 2025. The results demonstrate that the system consistently reduced key physicochemical pollutants, achieving



removal efficiencies of approximately 49–65% for BOD, 46–52% for COD, 60–61% for TSS, 64–70% for oil and grease, and 68–69% for ammonia. Effluent concentrations met national discharge standards for all monitored parameters, and total coliform levels remained within permissible limits despite variable influent loads. Overall, the findings confirm that the biofilter system operates reliably under routine conditions and is effective in ensuring compliant effluent quality for mortuary wastewater.

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