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Analysis of the effectiveness of moving bed biofilm reactor and anaerobic-aerobic methods in reducing pollutants in domestic wastewater at the Kebun Melati reservoir wastewater treatment plant, Central Jakarta

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ABSTRACT

This study aims to evaluate the effectiveness of two domestic wastewater treatment methods, namely the Anaerobic-Aerobic system and the moving bed biofilm reactor (MBBR), in reducing pollutant concentrations at the Kebun Melati Reservoir wastewater treatment plant (WWTP), Central Jakarta. The research design employed a field experiment approach, including wastewater sampling before and after treatment and laboratory analysis of water quality parameters such as BOD, COD, TSS, ammonia, phosphate, and oil and grease. The Anaerobic-Aerobic system uses Kaldness and wasp nest biofilm media, while the MBBR system uses Kaldness media only. The results showed that both methods were effective in reducing BOD (up to 95.08%), COD (95.22%), TSS (99.22%), and ammonia (99.38%). However, phosphate and oil-fat removal was relatively low (8.61–38.59% and up to 28%, respectively). Based on these results, scientifically proven recommendations are presented, including the integration of additional treatment units such as chemical precipitation or advanced filtration to enhance phosphate and oil-fat removal. These recommendations are supported by the data analysis and are discussed in detail in the main body of the study. The limitation of this study lies in the scope of analysis, which only includes physical and chemical parameters. The originality of this research lies in the real-scale comparison of two biological treatment systems at the same location, providing concrete insights into their performance and operational challenges in urban domestic wastewater management.

Keywords: wastewater treatment, anaerobic-aerobic, MBBR; Kebun Melati Reservoir, WWTP efficiency.

INTRODUCTION

Rapid population growth and urbanization rates in Jakarta have led to a significant increase in domestic wastewater production. In many areas, including Kelurahan Kebun Melati, Tanah Abang, wastewater management is not yet supported by a centralized piping network, so domestic waste is discharged directly into neighborhood drainage channels that empty into water bodies such as the Kebun Melati Reservoir (Wirawan, 2019; Marisi et al., 2016). This condition exacerbates water pollution, impacting the quality of the environment and the health of the surrounding community.

As one of the flood control infrastructures and runoff storage of the Cideng River, Kebun Melati Reservoir plays a vital role in urban water management. However, the increasing volume of incoming domestic waste without adequate treatment has resulted in a decrease in physical, chemical, and biological water quality (Hartaja, 2015). Efforts to revitalize the WWTP using a biofilm-based biological system have been made, including the implementation of an Anaerobic-Aerobic system and the construction of a MBBR unit to reduce the pollutant load in this reservoir.

MBBR and anaerobic-aerobic systems are biofilm growth-based wastewater treatment technologies that have been widely applied globally. Both show high efficiency potential in removing organic pollutants and ammonia (Lestari and Rohaeni, 2020; Said and Santoso, 2015). However, the comparison of the performance of the two systems in the context of specific pollution loads such as in the Kebun Melati Reservoir has not been studied in detail, especially regarding the analysis of factors that affect biofilm performance under field operational conditions.

Based on this background, this study aims to analyze and compare the effectiveness of MBBR and anaerobic-aerobic systems in reducing domestic pollutants, identify operational factors that affect treatment efficiency, and provide technical recommendations for optimizing biofilm-based wastewater treatment systems in urban areas

MATERIAL AND METHODS

Research area

This research was conducted at the Kebun Melati Reservoir MBBR wastewater treatment plant (WWTP), located in Kebun Melati Village, Tanah Abang District, Central Jakarta. The site was selected due to its significance in managing domestic wastewater entering the reservoir (Figure 1 and Table 1).

Data source

Primary data

Primary data in this study were obtained through direct sampling from two wastewater treatment systems (Anaerobic-Aerobic and MBBR) located in Kebun Melati Reservoir. Wastewater samples were taken from the inlet (before treatment) and outlet (after treatment) of each system. The water quality parameters measured include: biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), ammonia (NH_3), phosphate (PO_4^{3-}), oil and fat, pH potassium permanganate ($KMnO_4$), total coliform and temperature. Sampling was carried out for two consecutive days with measurements taken at processing times of 1, 3, 6, and 9 hours. The measurement data are presented in Tables 2–6.

Secondary data

Secondary data was obtained from technical and administrative documents belonging to the

Figure 1. Research area Manuju and Parangloe sub-districts Gowa Regency

Table 1. Location of anaerobic-aerobic WWTP and MBBR in Kebun Melati Reservoir

No	Code	Location	Coordinates	System
1	IPAL 1	West of the Reservoir	S: 06°11'52.944" E: 106°49'4.2492"	Anaerobic-Aerobic
2	IPAL 2	South of IPAL 1	S: 06°11'54.5424" E: 106°49'3.9432"	MBBR (Moving bed biofilm reactor)

Table 2. Measurement results of day 1 by MBBR method with Kladness media

Parameters	Unit	Inlet	1 Hour	Efficiency (%)	3 Hour	Efficiency (%)	6 Hour	Efficiency (%)	9 Hour	Efficiency (%)
pH	-	7.79	7.55	-	7.67	-	7.79	-	7.85	-
BOD_5	mg/l	51	15	70.59	8	84.31	5.4	89.41	4.8	90.59
COD	mg/l	173	50	71.10	27	84.39	18	89.60	16	90.75
Oil & grease	mg/l	1.8	1.8	-	1.8	-	1.8	-	1.8	-
Amonia (NH_3)	mg/l	34	0.75	97.79	0.45	98.68	0.27	99.21	0.21	99.38
Phospate (PO_4)	mg/l	8.55	5.23	38.83	6.35	25.73	7.67	10.29	5.53	35.32
Permanganate ($KMNO_4$)	mg/l	67.3	12.5	81.43	8.76	86.98	8.6	87.22	6.26	90.70
TSS	mg/l	42	16	61.90	16	61.90	2	95.24	8	80.95
Temperatur	°C	24	24.3	-	24	-	24.4	-	24.3	-
Total coliform	Total/ 100 ml	159	1	99.37	35	77.99	2	98.74	42	73.58

Table 3. Measurement results on day 2 of the MBBR method with cladness media

Parameters	Unit	Inlet	1 Hour	Efficiency (%)	3 Hour	Efficiency (%)	6 Hour	Efficiency (%)	9 Hour	Efficiency (%)
pH	-	7.3	7.61	-	7.68	-	7.71	-	7.71	-
BOD_5	mg/l	107	16	85.05	14	86.92	9.6	91.03	9	91.59
COD	mg/l	365	55	84.93	47	87.12	32	91.23	30	91.78
Oil & grease	mg/l	2.5	1.8	28.00	1.8	28.00	1.8	28.00	1.8	28.00
Amonia (NH_3)	mg/l	27	0.76	97.19	0.49	98.19	0.48	98.22	0.45	98.33
Phospate (PO_4)	mg/l	8.81	5.08	42.34	5.42	38.48	5.13	41.77	5.41	38.59
Permanganate ($KMNO_4$)	mg/l	86	7.98	90.72	8.45	90.17	7.04	91.81	4.69	94.55
TSS	mg/l	252	10	96.03	6	97.62	2	99.21	8	96.83
Temperature	°C	24	24.4	-	24.6	-	24.8	-	24.7	-
Total coliform	Total /100 ml	104	25	75.96	1	99.04	11	89.42	2	98.08

Table 4. Measurement results of day 1 by anaerobic-aerobic method using wasp nest + Kaldness

Parameters	Unit	Inlet	1 Hour	Efficiency (%)	3 Hour	Efficiency (%)	6 Hour	Efficiency (%)	9 Hour	Efficiency (%)
pH	-	7.27	7.08	-	7.32	-	7.35	-	7.42	-
BOD_5	mg/l	61	20	67.21	9.6	84.26	5.6	90.82	3	95.08
COD	mg/l	209	69	66.99	32	84.69	19	90.91	10	95.22
Oil & grease	mg/l	1.8	1.8	-	1.8	-	1.8	-	1.8	-
Amonia (NH_3)	mg/l	32	0.31	99.03	0.26	99.19	0.25	99.22	0.2	99.38
Phospate (PO_4)	mg/l	8.48	7.8	8.02	7.33	13.56	7.28	14.15	7.75	8.61
Permanganate ($KMNO_4$)	mg/l	51.6	8.45	83.62	5.16	90.00	4.61	91.07	6.41	87.58
TSS	mg/l	62	16	74.19	2	96.77	2	96.77	2	96.77
Temperature	°C	23.8	23.5	-	24.4	-	24.4	-	24.3	-
Total coliform	Total/ 100 ml	139	1	99.28	1	99.28	1	99.28	1	99.28

DKI Jakarta Provincial Water Resources Office and the Central Jakarta Water Resources Office, including:

- MBBR and Anaerobic-Aerobic WWTP unit design and specifications (e.g. capacity, hydraulic residence time, biofilm media type)

Table 5. Measurement results of day 2 by anaerobic-aerobic method using wasp nest + Kaldness

Parameters	Unit	Inlet	1 Hour	Efficiency (%)	3 Hour	Efficiency (%)	6 Hour	Efficiency (%)	9 Hour	Efficiency (%)
pH	-	7.28	7.51	-	7.42	-	7.5	-	7.52	-
BOD_5	mg/l	100	15	85.00	12	88.00	9	91.00	8.4	91.60
COD	mg/l	334	50	85.03	41	87.72	30	91.02	28	91.62
Oil & Grease	mg/l	1.8	1.8	-	1.8	-	1.8	-	1.8	-
Amonia (NH_3)	mg/l	27	0.51	98.11	0.46	98.30	0.37	98.63	0.31	98.85
Phospate (PO_4)	mg/l	10.8	10.8	-	7.08	34.44	7.6	29.63	7.46	30.93
Permanganate ($KMNO_4$)	mg/l	82.9	10.5	87.33	4.85	94.15	9.39	88.67	10.2	87.70
TSS	mg/l	258	2	99.22	2	99.22	10	96.12	2	99.22
Temperaturr	°C	24.4	24.4	-	24.2	-	24	-	24.4	-
Total Coliform	Total/ 100 ml	520	1	99.81	1	99.81	16	96.92	1	99.81

Table 6. Average concentration of wastewater quality parameters at the inlet and outlet of anaerobic-aerobic and MBBR WWTPs at Kebun Melati Reservoir

Parameter	Unit	Inlet (average)	Outlet anaerob-aerob	Outlet MBBR
BOD	mg/L	120	6.0	5.9
COD	mg/L	250	11.9	11.9
TSS	mg/L	400	3.1	3.1
Ammonia	mg/L	15	0.093	0.093
Phosphate	mg/L	1.4	1.28	0.86
Oil and grease	mg/L	10	8.2	7.2

Note:*) Referring to Permen LHK No. 68 of 2016, **) Referring to DKI Jakarta Governor Regulation No. 69 of 2013 (Appendix W). The maximum efficiency value is calculated based on laboratory test data after 9 hours of residence time (HRT).

- Daily maintenance and monitoring records of the WWTP system
- Location map and coordinate data of sampling points

These secondary data are used to understand the operational context and support interpretation of laboratory results, rather than as the primary source of water quality measurements.

Processing

This research was carried out through the following technical stages:

1. Preliminary preparation:

a) Prepare laboratory equipment such as reactor tubes, spectrophotometer, pH meter, oven, analytical balance, and other test equipment.
b) Prepare materials such as chemical reagents for wastewater parameter analysis, as well as biofilm media (Kaldnes and wasp nest) for the reactor system.
c) Conditioned the anaerobic and aerobic reactor systems, including aeration settings, wastewater flow, and ambient temperature.

2. Wastewater sampling:

a) Samples were taken at the inlet and outlet points of two WWTP systems: Anaerobic-Aerobic and MBBR, using standardized procedures.
b) The coordinates of the sampling locations were recorded to ensure replication.
c) Samples were stored in sterile containers and kept at low temperature before analysis.

3. Wastewater Treatment Process

a) Anaerobic-Aerobic System:
   - Wastewater is flowed into an anaerobic reactor that operates without oxygen supply. Microorganisms degrade the organic matter fermentatively.
   - The water is then flowed into an aerobic reactor, where aeration is provided to support the growth of aerobic microorganisms that continue the degradation process.

b) MBBR system:

- Wastewater goes through the stages of bar screen, equalizing tank, anoxic tank, then enters the MBBR tank with moving media (Kaldnes).
- After the biological aeration process, the water enters the sedimentation tank to separate the biomass apart from the biofilm media.

4. Laboratory analysis:
a) The outlet samples were analyzed for water quality parameters: BOD, COD, TSS, ammonia, phosphate, oil & grease, pH, $KMnO_4$, and total coliform.
b) The analysis method refers to the Indonesian National Standard (SNI) and Minister of Environment and Forestry Regulation No. 68 of 2016 and DKI Jakarta Governor Regulation No. 69 of 2013.

5. Analysis data
a) Data from the laboratory was analyzed descriptively quantitatively.
b) Effectiveness was calculated by the formula of percentage concentration reduction:

$$Efektivitas\ (\%) = \frac{C_{inlet} - C_{outlet}}{C_{inlet}} \times 100\% \quad (1)$$

where: *C_inlet* – concentration of pollutant parameters in wastewater before treatment; *C_outlet* – concentration of pollutant parameters after treatment.

Results are compared with quality standards to assess the system's compliance with applicable environmental standards.

Data analysis technique

In this study, data analysis techniques were carried out to evaluate the effectiveness of the MBBR and Anaerobic systems in treating wastewater. The analysis was carried out by comparing the quality of wastewater before and after going through the treatment process, based on predetermined parameters.

Data obtained from the measurement of BOD, COD, TSS, ammonia, oil and grease, pH, phosphate, potassium permanganate, and Total Coliform parameters will be analyzed quantitatively using descriptive statistical methods. The results of this data processing will be compared with the domestic wastewater quality standards stipulated in the Ministry of Environment and Forestry Regulation No. 68 of 2016 and DKI Jakarta Governor Regulation No. 69 of 2013.

The data analysis technique in this study aims to evaluate the effectiveness of MBBR and Anaerobic-Aerobic wastewater treatment systems in reducing pollutant levels in domestic wastewater. Data obtained from laboratory testing results will be analyzed quantitatively and compared with applicable quality standards. The following is the data we obtained in the field

Comparison with quality standard

The test results are compared with the domestic wastewater quality standards stipulated in the Minister of Environment and Forestry Regulation No. 68 Year 2016 as well as DKI Jakarta Governor Regulation No. 69 Year 2013. Parameters that do not meet the quality standards will be further analyzed to identify causal factors and possible improvements to the treatment system (Table 7).

RESULTS AND DISCUSSION

Wastewater treatment process

MBBR waste treatment process (WWTP)

The MBBR sewage treatment process (WWTP) at Kebun Melati starts from the electrical control panel that regulates the entire system, as well as the exhaust and intake fans in the blower room for air circulation. Blowers 1 and 2 deliver air to the system. Wastewater enters through a bar screen to filter out large objects, then through a scum skimmer that removes floating materials. The volume of incoming water is measured with a water meter, then chlorine is added for disinfection, and flowed into the treated water line. The wastewater then enters the equalizing tank, continued to the anoxic tank for decomposing organics without oxygen, then to the MBBR main tank which uses moving media to support microorganisms in the aeration process. Furthermore, the water enters the sedimentation tank to settle the biomass released from the biofilm media before finally flowing into the Kebun Melati Reservoir. This process is depicted in Figure 2.

The wastewater treatment process begins with initial filtration through a bar screen to filter out large objects. The wastewater then enters the equalizing tank to adjust the load and volume of water. After that, wastewater is processed in the

Table 7. Parameters and quality standards for domestic waste ai

Parameters	Unit	Quality Standard
Physics		
TSS*	mg/l	30
Debit	lt/org/Day	100
Chemistry		
BOD*	mg/l	30
COD*	mg/l	100
Ammonia*	mg/l	10
Oils & Fats*	mg/l	5
pH*	-	6–9
Phospat**	mg/l	5
$KMnO_4$**	mg/l	85
Biology		
Total coliform*	Total/100mL	3000

Note: * Minister of Environment and Forestry Regulation No.68 Year 2016, ** Jakarta Governor Regulation No.69 Year 2013 (Appendix Letter W).

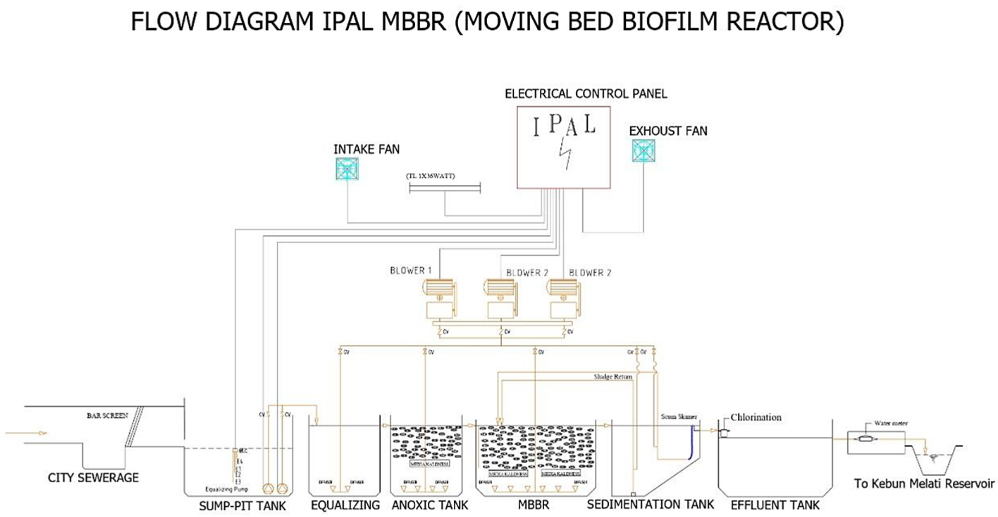

Figure 2. Process diagram of wastewater treatment with MBBR process IPAL Kebun Melati Reservoir

anoxic tank for decomposition of organic matter with deficit oxygen, then to the MBBR tank for biological processes with microorganisms. After the process, the wastewater is separated in a sedimentation tank to settle the biomass peeled off from the biofilm media, and finally chlorination is carried out before flowing into the Kebun Melati Reservoir.

Anaerobic-aerobic sewage treatment process (WWTP)

The WWTP process at Kebun Melati starts from the electrical control panel that regulates the entire system, as well as the exhaust and intake fans for air circulation in the blower room. Blowers 1 and 2 deliver air to the system. Wastewater enters through a bar screen to filter out large objects, then to a scum skimmer to remove floating materials. The volume of incoming water is measured with a meter, then chlorine is added for disinfection and flowed into the treated water channel. Wastewater then enters the equalizing tank, pumped to the anaerobic tank for decomposition of organics without oxygen, then to the aeration tank for decomposition with oxygen. Next, it enters the sedimentation tank to settle the biomass resulting from the biological process, then to the effluent tank, and finally is re-contacted with chlorine before being discharged into the Kebun Melati Reservoir. This process is shown in Figure 3. The process begins with the initial screening of wastewater using a bar screen, then the water goes through a series of biological processes in anaerobic and aerobic/aeration tanks. After that, the water undergoes a sedimentation process to settle biomass and then a disinfection process using chlorine. The treated water is then flowed and channeled to the Kebun Melati Reservoir.

a) Ph – the pH values of the MBBR and Anaerobic-Aerobic systems were within the neutral range (7.08–7.85), indicating optimal conditions for biological processes. On the first day, the pH of the MBBR system ranged from 7.55–7.85, while the Anaerobic-Aerobic system showed a pH of 7.08–7.42. This pH fluctuation is most likely influenced by nitrification and denitrification activities (Aniriani et al., 2022) (Figures 4 and 5).

b) BOD_5 – the decrease in BOD_5 is very significant, from 51–107 mg/L to 3–9 mg/L. The Anaerobic-Aerobic system achieved an efficiency of up to 95.08%, higher than MBBR (91.59%). This shows that the process of decomposing organic matter by microorganisms is effective (Said and Santoso, 2015) (Figure 6).

c) COD – COD decreased dramatically from 173–365 mg/L to 10–30 mg/L. The efficiency of the Anaerobic-Aerobic system reached 95.22%, while MBBR 91.78%. This effectiveness shows the successful decomposition of complex organic compounds (Cahyani et al., 2024) (Figures 7 and 8).

d) TSS – TSS experienced an extreme decrease,

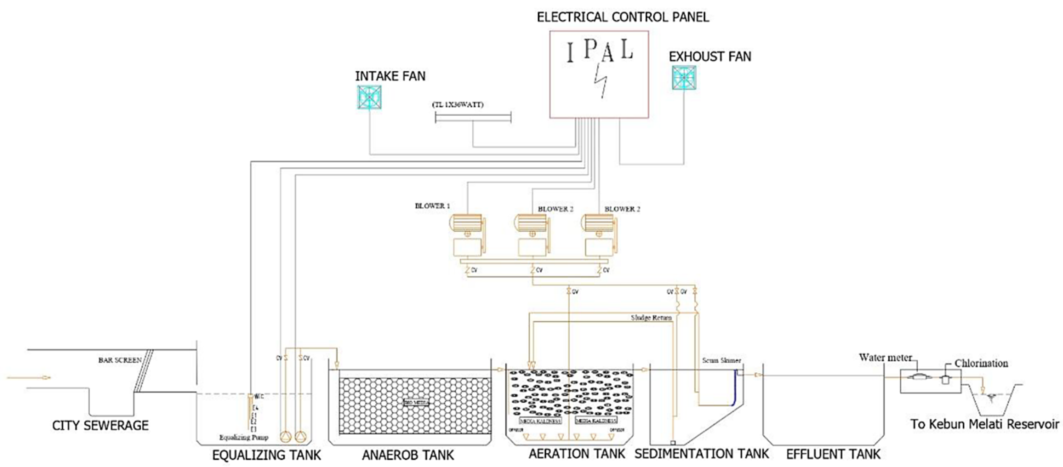

Figure 3. Process diagram of wastewater treatment with anaerobic-aerobic process of Melati Reservoir WWTP

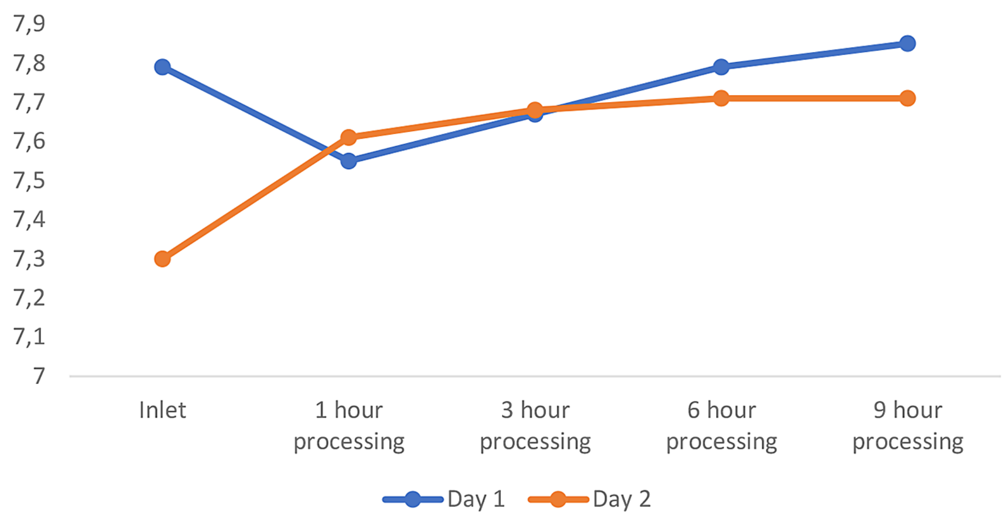

Figure 4. Results of pH measurement

Figure 5. Sampling at the inlet and outlet of the WWTP

from 42–258 mg/L to 2–10 mg/L. The efficiency reached 99.22%, which was obtained through the settling of suspended particles and degradation by aerobic microorganisms. The highest efficiency was achieved at 6 hours residence time (Said and Santoso, 2015) (Figures 9 and 10).

e) Ammonia (NH_3) – the Anaerobic-Aerobic system showed ammonia reduction efficiency of up to 99.38%, while MBBR reached 99.33%. This decrease reflects the efficiency of the nitrification process that takes place under aerobic conditions (Widayat et al., 2018) (Figure 11).

f) Phosphate (PO_4^{3-}) – both systems showed limited phosphate reduction (efficiency of only 8.61–38.83%). The phosphate reduction was due to the activity of microorganisms producing phosphatase enzymes, but no chemical separation system was used (Alexander, 1997; Rajasa, 2010) (Figure 12).

g) Oils and fats – the efficiency of oil and grease reduction was very low (< 28%) due to the absence of a grease trap unit. The initial content of up to 2.5 mg/L did not change much during the process, indicating the need for an additional physical separation unit (Lestari and Rohaeni, 2020) (Table 8).

Scientific discussion and recommendations for system optimization

Although the MBBR and Anaerobic-Aerobic systems demonstrated high efficiency in removing BOD, COD, TSS, and ammonia, their performance in removing phosphate and oil-fat was significantly lower. Phosphate reduction efficiencies ranged between 8.61% and 38.83%, while oil-fat removal was below 28%. These values fall short of the domestic wastewater quality standards established in Permen LHK No. 68 of 2016 and suggest the limitations of biological processes alone in treating these parameters.

Phosphate in wastewater typically exists in dissolved inorganic forms (e.g., orthophosphate), which are not easily assimilated by microorganisms without specific chemical or physical interventions. According to Alexander (1997) and Rajasa (2010), while microorganisms produce phosphatase enzymes that can convert organic

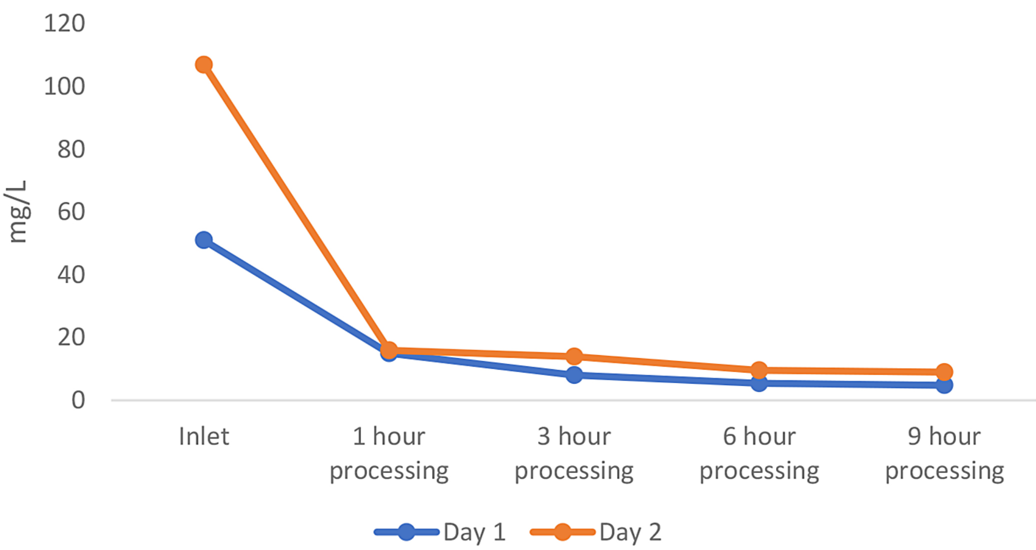

Figure 6. BOD measurement results

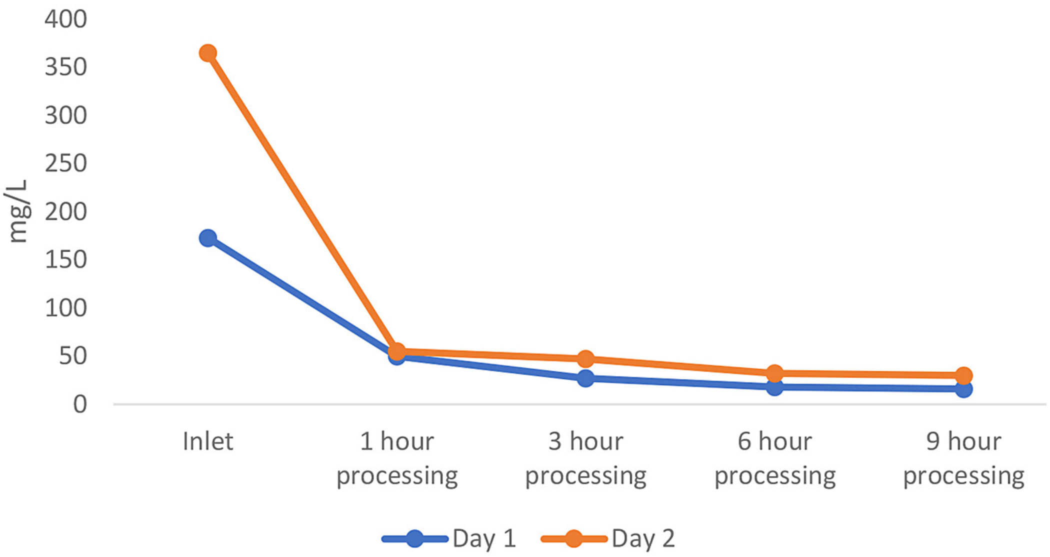

Figure 7. COD measurement

Figure 8. COD sampling process at the outlet

phosphorus compounds, the absence of a chemical precipitation process (e.g., using alum or ferric chloride) limits the effectiveness of biological phosphate removal.

Similarly, the low efficiency in oil and grease reduction is due to the absence of a dedicated grease trap or physical separation unit. Lestari and Rohaeni (2020) emphasize that effective oil-fat removal requires physical skimming or flotation techniques, which are not present in either treatment system observed at Kebun Melati Reservoir.

Based on these findings, the following scientifically supported recommendations are proposed:

1. For phosphate removal, integration of a

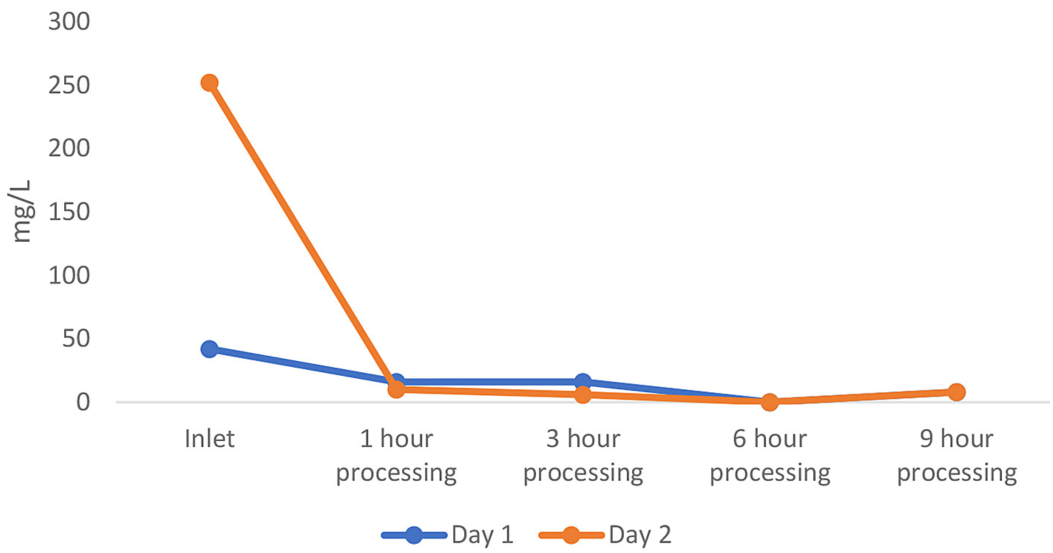

Figure 9. TSS reduction graph from inlet to outlet

Figure 10. Sedimentation tank

chemical precipitation stage after biological treatment is recommended. Coagulants such as aluminum sulfate ($Al_2(SO_4)_3$) or ferric chloride ($FeCl_3$) have been proven to bind phosphate and remove it via sedimentation.

2. For oil and grease, the addition of a grease trap unit or dissolved air flotation (DAF) system before the biological treatment stage is necessary to physically separate fats and oils, improving the overall treatment efficiency.

These recommendations are grounded in both the data from this study and existing environmental engineering literature, and thus represent scientifically validated improvements that can be

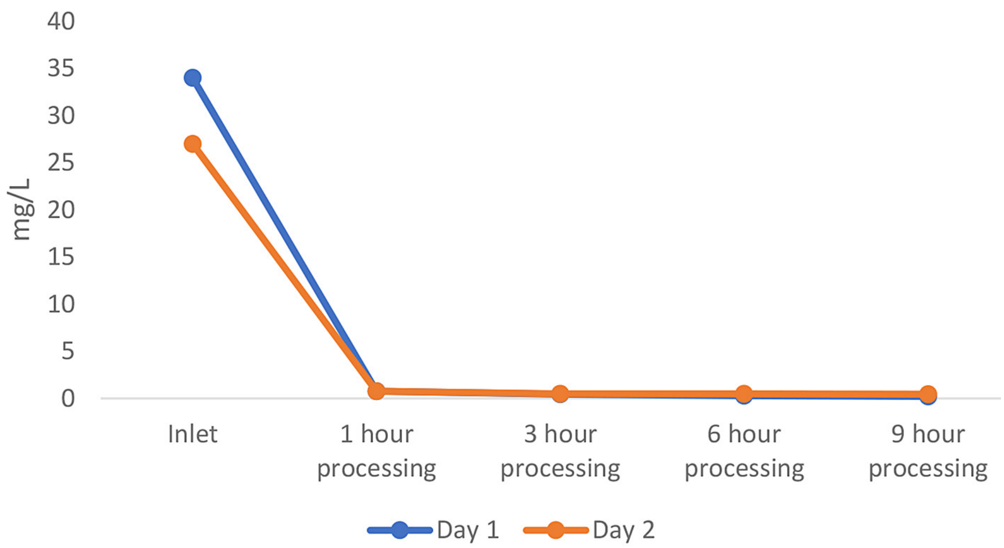

Figure 11. Ammonia concentration during residence time 1–9 hours

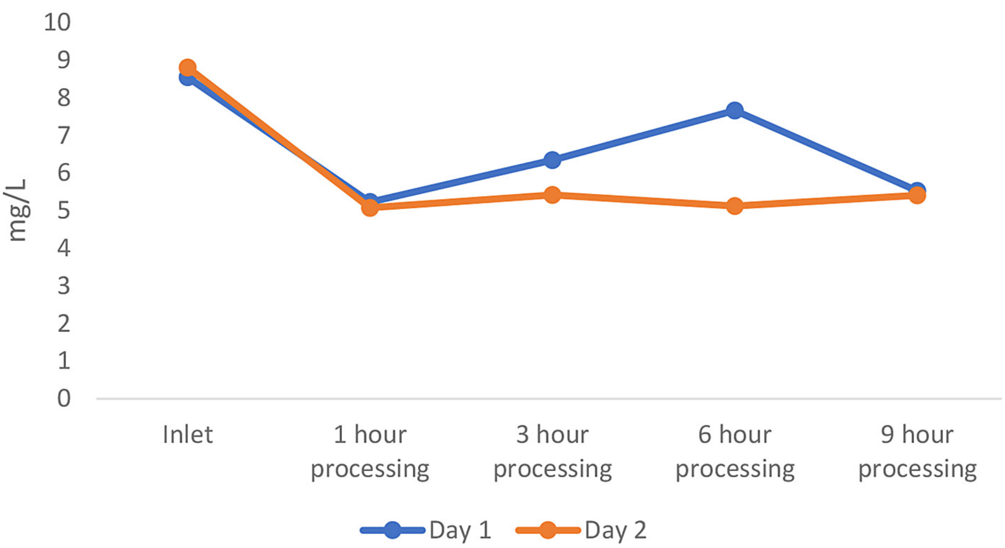

Figure 12. Comparison of phosphate reduction efficiency in two systems

Table 8. Oil and fat measurement results

Oil and grease	Unit	Day 1	Day 2
Inlet	mg/L	< 1.8	2.5
1 hour processing	mg/L	< 1.8	< 1.8
3 hour processing	mg/L	< 1.8	< 1.8
6 hour processing	mg/L	<1,8	<1,8
9 hour processing	mg/L	<1,8	<1,8

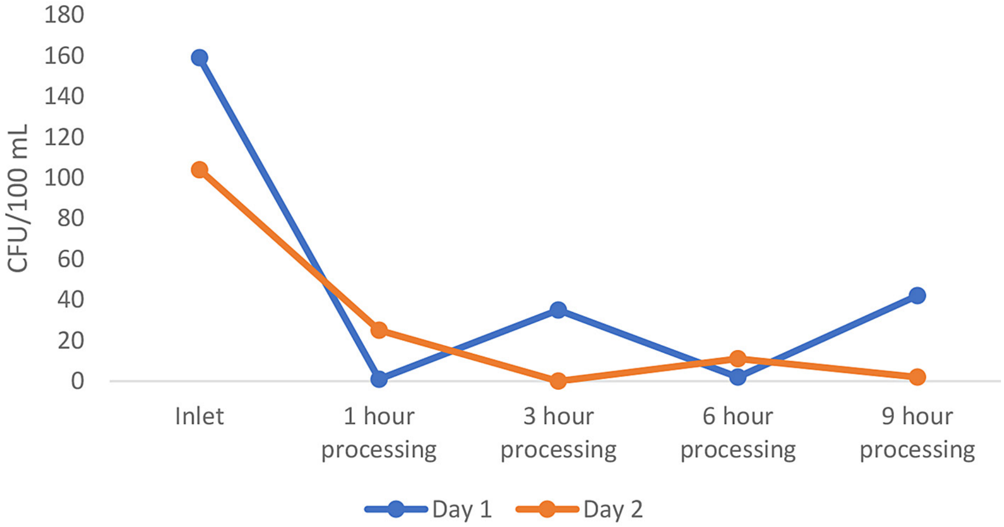

Figure 13. Total coliform measurement results

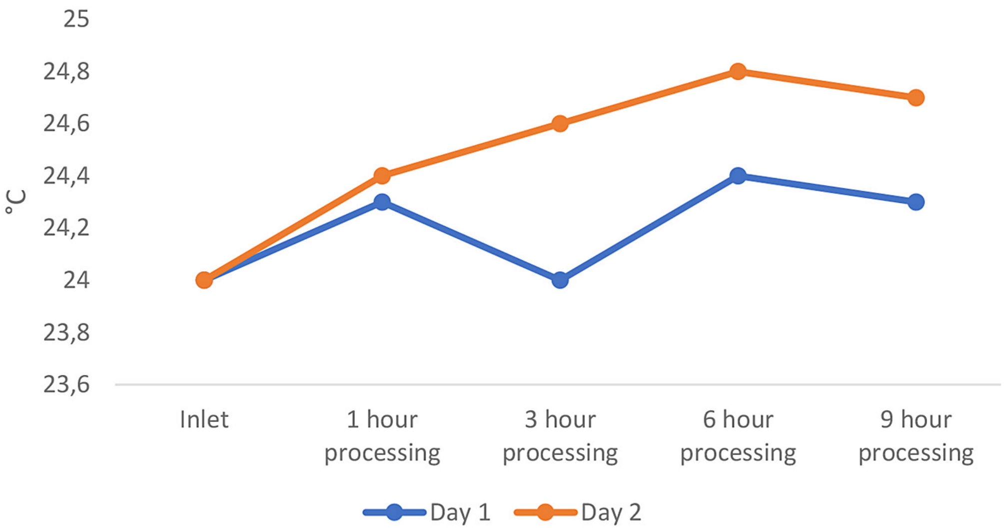

Figure 14. Temperature measurement results

implemented in urban WWTP systems with similar pollution loads.

h) Total coliform – the treatment system showed a coliform bacteria reduction efficiency of up to 99%, supported by chlorine disinfection and biological stabilization processes (Ranudi and Ratnawilis, 2018) (Figure 13).

i) Temperature – the treatment temperature is within the range of 23.4–24.5 °C which is suitable for the growth of mesophilic microorganisms. The biological process is stable because the ambient temperature does not experience extreme fluctuations (Figure 14).

CONCLUSIONS

Based on the results of field measurements and laboratory analysis, it can be concluded that the moving bed biofilm reactor (MBBR) and anaerobic-aerobic systems are effective in reducing BOD, COD, TSS, and ammonia concentrations in domestic wastewater at the Kebun Melati WWTP. Both systems showed efficiencies above 90% for these parameters, thus meeting most of the water quality standards according to Permen LHK No. 68 of 2016.

However, the effectiveness in reducing phosphate and oil-fat was still low, indicating the need for additional units or advanced treatment methods. This research confirms the importance of biofilm media characteristics, residence time, and aeration system in supporting the effectiveness of the treatment process.

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