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Performance Evaluation of Wastewater Treatment Plants in the Medical Device Manufacturing Industry

Ady Syah Putra Arif [1], Aulia Ulfah Farahdiba [2]

[1] *Environmental Engineering, Faculty of Engineering and Science, UPN Veteran Jawa Timur University, Surabaya., Indonesia*

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CORRESPONDING AUTHOR

*E-mail: adysyahputraarif@gmail.com

A B S T R A C T

This study evaluates the performance and effectiveness of a Wastewater Treatment Plant (WWTP) at a medical device manufacturing facility with a capacity of 6 m3/day. Based on laboratory analysis, the parameters for BOD, COD, TSS, pH, ammonia, and total coliform in the effluent comply with the quality standards stipulated in the Regulation of the Minister of Environment No. 5 of 2014. However, oil and grease parameters showed 0% removal efficiency and failed to meet the standards due to the absence of a specific treatment unit, such as a grease trap. Technical evaluations revealed significant discrepancies in detention times across several primary units. The detention time in the equalisation tank reached 48 hours, far exceeding the design criterion of <2 hours, triggering anaerobic conditions and odour issues. In the aerobic biofilter units, pollutant degradation was suboptimal due to the lack of contact media for microorganism biofilm formation. Furthermore, the sedimentation unit experienced excessive detention time of 12 hours and operational disruptions due to turbulence from existing diffusers, hindering particle settling. This study recommends adding a grease trap, installing biofilter media (such as bioballs or honeycomb), and removing diffusers from the sedimentation tank to optimise treatment efficiency.

Contribution to Sustainable Development Goals (SDGs):
SDG 6: Clean Water and Sanitation
SDG 12: Responsible Consumption and Production

1. INTRODUCTION

1.1. Research Background

Health logistics, covering pharmaceuticals and medical devices, is a crucial subsystem within the National Health System that must be managed to support Indonesia's health development [1]. Strengthening the health logistics subsystem will directly increase production volume in the medical device manufacturing industry, given its fundamental role as the primary provider of medical devices to service facilities throughout Indonesia. The medical device manufacturing industry produces a range of medical devices across several categories, including medical disposables and consumables, antiseptics and dialysis, diagnostics and equipment, walking aids and rehabilitation care, biotechnology and laboratory, and hospital furniture. To ensure the availability of these products, manufacturers are required to maintain a responsive manufacturing operational rate, in line with market needs and demand dynamics.

Production activities in every industry inevitably generate waste, as is the case in medical device manufacturing. The generated waste has the potential to pollute the surrounding environment if not properly treated before disposal. Therefore, the treatment process must be carried out to the fullest extent and in accordance with applicable regulations, given that industrial waste has become a serious issue in the era of industrialisation. Production waste, whether in the form of liquid, solid, or gas waste, poses a real threat to ecosystems and public health around industrial areas [2]

1.2. Literature Review

Ref [3] argues that liquid waste is the unused residue from a process, whether it be industrial, household, livestock, agricultural, or other waste. In this industry, liquid waste is generated from product sterilization processes, laboratory activities, and domestic waste. Given that waste treatment is highly dependent on the characteristics of the effluent produced, treatment must be implemented appropriately. Wastewater that is not properly treated and still contains pollutants can result in widespread contamination of the ecosystem, including open water sources (seas, rivers, and lakes), as well as t air and soil systems [4]. This contamination has direct and indirect negative impacts on human health, the survival of living creatures, and nature conservation.

The wastewater quality standards for the medical device manufacturing industry in Indonesia refer to the Minister of Environment Regulation No. 5 of 2014, which requires industrial-scale wastewater treatment. This management can be carried out by designing a wastewater treatment plant (IPAL). IPAL functions to reduce pollutant concentrations to meet the established quality standards [5]. To determine whether the IPAL is functioning optimally, identification is needed to evaluate the suitability of the design criteria and the IPAL's performance in removing pollutant parameters, ensuring compliance with the established quality standards. This evaluation is expected to form the basis for controlling environmental impacts and complying with applicable regulations.

1.3. Research Objective

This study aims to evaluate the performance and effectiveness of a wastewater treatment plant (WWTP) at a medical device manufacturing industry in Indonesia.

2. MATERIALS AND METHODS

This study was conducted at the Wastewater Treatment Plant (WWTP) of a medical device manufacturing industry over approximately 4 months, from August to November 2025. Data collection involved both primary and secondary sources. Primary data included wastewater quality parameters (BOD, COD, TSS, oil and grease, ammonia, and total coliform) obtained from laboratory tests and source data from which the wastewater originated. Secondary data consisted of WWTP dimensions, design criteria, and technical calculations for each treatment unit. The wastewater generated by this industry is treated independently at an internal WWTP located within the factory premises. The treatment units include an equalisation tank, an aerobic biofilter, a sedimentation tank, and an indicator tank. The process flow begins at the wastewater source and proceeds through the equalisation tank, the aerobic biofilter, and the sedimentation units, eventually reaching the indicator tank.

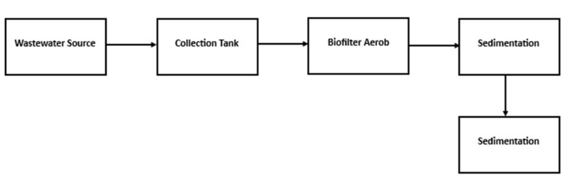

Fig. 1. Flowchart of the wastewater treatment unit

The task completion method involved evaluating the technical aspects of the building theoretically in accordance with design criteria that could affect the performance of the treatment units, and calculating the removal efficiency percentage for each treatment unit. The supporting data used are the building unit's existing conditions, including its dimensions (length, width, and depth). An evaluation is conducted if any units do not meet the design criteria. The assessment results in recommendations, including proposals for system optimisation and redesign, with the main objective of improving and maximising the performance of the Wastewater Treatment Plant (WWTP).

3. RESULT AND DISCUSSION

3.1. Wastewater Quality Parameters and Removal Efficiency Calculation

These industrial wastewater parameters are shown in Table 1. This data comes from third-party laboratory testing. Test samples were collected at the inlet and outlet of the Wastewater Treatment Plant (WWTP) to quantify parameters and assess removal efficiency. The calculation of the removal efficiency followed this, the percentage reduction in pollutant levels achieved by the IPAL. This efficiency calculation is an important indicator for evaluating the IPAL's overall performance and effectiveness.

Table 1. Wastewater parameter test results and removal efficiency

Parameter	Units	Test method	Inlet	Outlet	Persent removal
pH	pH	SNI 6989.11:2019	7.35	7.26	1.22%
BOD	mg/L	SM 23rd Ed. 5210 B. 2017	14	8	42.86%
COD	mg/L	SNI 6989. 73: 2019	32	23.4	26.88%
TSS	mg/L	SNI 6989. 3:2019	2.5	2.5	0%
Oil and Grease	mg/L	SNI 6989.10:2011	2.82	2.82	0%
Ammonia	mg/L	SNI 06-6989.30-2005	0.097	0.097	0%
Total Coliform	jml/100 mL	SM APHA 23rd Ed., 9221 B & C, 2017	340	270	20.59%

Based on the data from Table 1, the removal efficiency (n) is calculated as the difference between the inlet (Cin) and outlet (Cout) concentrations of wastewater parameters. The following equation is used to evaluate the WWTP's ability to reduce pollutant levels.

$$\text{Removal efficiency (n)} = \frac{C\ in - C\ out}{C\ in} \times 100\%$$

In addition, the pollutant concentration at the outlet point will be compared strictly with the Indonesian wastewater quality standards set out in Minister of Environment Regulation No. 5 of 2014. This comparison ensures that wastewater discharged from the IPAL meets the maximum permissible limits and complies with applicable regulations.

Table 2. Comparison of effluent results with the Minister of Environmental Regulation No. 5 of 2014.

Parameter	Units	Outlet	Quality Standart	Notes
pH	pH	7.26	6 – 9	Compliant
BOD	mg/L	8	50	Compliant
COD	mg/L	23.4	100	Compliant
TSS	mg/L	2.5	200	Compliant
Oil and Grease	mg/L	2.82	0.5	Not compliant
Ammonia	mg/L	0.097	5	Compliant
Total Coliform	jml/100 mL	270	10000	Compliant

Based on the table data, the oil and grease parameters in the effluent do not yet meet the established quality standards. This is due to the absence of a dedicated treatment unit to reduce or eliminate oil and grease levels within the WWTP. Therefore, an additional treatment unit, such as a grease trap, is required to achieve the reduction targets. High concentrations of oil and grease can cause environmental damage by clogging drainage systems, as they adhere firmly to the inner walls of discharge pipes. Such blockages can cause wastewater to overflow into water bodies and attract pests due to unpleasant odors [6]

3.2. *Theoretical Evaluation of a Wastewater Treatment Plant Unit in the Medical Device Manufacturing Industry*

The Wastewater Treatment Plant (WWTP) in this industry has a capacity of 6 m³/day. The daily influent wastewater flow rate is 4.8 m³/day, determined from electromagnetic flowmeter readings. An electromagnetic flowmeter is a measuring instrument used to accurately measure the volumetric flow rate of conductive liquids within a pipe.

3.2.1. Collection Tank

An equalisation tank is a structure designed to collect and homogenise variations in flow rates and related parameters to achieve constant characteristics for subsequent processes 7]. The water level during peak conditions must remain below the inlet or the conveyance channel to prevent backflow. Once the flow exits the equalisation tank, the fluctuating hourly wastewater discharge is converted to an average flow rate.

The storage tank at the IPAL has a volume of 6 m, enabling it to accommodate wastewater generated from industrial processes and domestic waste. In Table 3, the storage tank unit does not meet the design criteria, as seen from the detention time criteria. The detention time design criteria are not met because the storage tank volume is not proportional to the incoming wastewater flow rate. The length of detention time in the storage tank shifts conditions from aerobic to anaerobic. This triggers various problems, including foul odours, lower wastewater quality standards, sedimentation and compaction, and the proliferation of anaerobic bacteria. Adjustments can be made by optimizing wastewater discharge or changing the water level.

Fig. 2. Collection Tank

Table 3. Design spesifications and current conditions collection tank

Design specifications	Design value	Existing condition	Units	Notes	Source
Length	-	3.2	m	-	-
Width	-	1.25	m	-	-
Depth	1.5 - 3	1.5	m	Compliant	Metcalf and Eddy, Wastewater Engineering Treatment and Reuse Fourth Edition
Detention time	< 2	48	Hour	Not compliant	

3.2.2. Biofilter Aerob

Ref. [8] defines biological treatment as a method of owastewater treatment that involves microorganisms. These microorganisms play a role in degrading and stabilising organic pollutants by utilising the organic matter in wastewater as a food source and converting it into simpler forms. Biofilter technology has been widely developed because it offers several advantages, including easy operation, relatively low sludge production, resistance to fluctuations in flow rate and pollutant load (concentration), high efficiency in removing pollutant loads from liquid waste, and the ability to remove suspended solids effectively [9]. One advantage of the biofilter method over other methods is its ability to reduce BOD and COD concentrations. Biofilters are also capable of lowering the concentrations of suspended solids, ammonia, and phosphorus 10]. The biofilter media used as attachment sites for microorganisms can be made of organic materials, such as ropes, nets, irregular granules, boards, and honeycombs. Biofilter media made from inorganic materials, such as crushed stone, gravel, marble, pottery, coal, and others.

In aerobic biofilters, wastewater is treated with oxygen, allowing aerobic microorganisms to break down and eliminate organic materials effectively. An increase in the amount of organic material in wastewater directly increases oxygen demand, leading tochanges in water quality [11].

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Fig. 3. Biofilter Aerob

Table 4. Design specifications and current conditions biofilter aerob tank 1

Design specifications	Design value	Existing condition	Units	Notes	Source
Length	-	1.33	m	-	-
Width	-	1.28	m	-	-
Depth	-	1.6	m	-	-
Detention time	2 - 6	3	Hour	Compliant	Said, 2017 Teknologi Pengolahan Air Limbah
Media	Bioball, Honeycomb, dan lain – lain.	-	-	Not compliant	-

Based on the data in Table 4, the absence of contact media in aerobic biofilter unit 1 significantly inhibits the unit's performance. The absence of this media automatically eliminates the specific surface area essential for microorganism biofilm formation. As a result, microbial activity responsible for degrading organic pollutants cannot function optimally because it lacks a surface to attach to and multiply effectively. The selection of appropriate biofilter media helps microorganisms access more organic material to be decomposed, so that the thatecomposition and oxidation processes proceed properly [12].
The existence of two aerobic biofilter tanks indicates that the previous existing conditions required a configuration with two identical units. The addition of units aims to achieve significant contaminant removal efficiency through load sharing and process refinement.

Table 5 shows conditions that are almost identical to those in Table 4. The difference is that the aerobic biofilter tank 2 has a partition that divides it into two compartments. This condition is ineffective because there is no media for microorganisms to attach to, and there is no oxygen support in the process mechanism. To maximise the biofilter unit's performance, media can be added to both tanks. In Apema's 2023 study, bioball media in biofilters reduced BOD by 88.72%, COD by 86%, and TSS by 78.95%. Meanwhile, honeycomb media reduced BOD by 86.35%, COD by 83.25%, and TSS by 77.1%. To optimise the biofilter, a diffuser should be added to increase oxygen transfer in the water. The availability of abundant oxygen is crucial for microorganisms to degrade pollutants in wastewater.

Table 5. Design spesifications and current conditions biofilter aerob tank 2

Design specifications	Design value	Existing condition	Units	Notes	Source
Length	-	1.33	m	-	-
Width	-	1.28	m	-	-
Depth	-	1.6	m	-	-
Detention time	2 - 6	3	Hour	Compliant	Said, 2017 Teknologi Pengolahan Air Limbah
Media	Bioball, Honeycomb, dan lain – lain.	-	-	Not compliant	-

3.2.3. Sedimentation

Sedimentation units are physical processes for separating suspended particles in water due to their own weight or the influence of gravitational force. This process is commonly referred to as sedimentation. It is generally used in drinking water treatment, raw water treatment, and advanced treatment [13]. Sedimentation units are useful for settling sludge or solids produced by previous processes. Generally, sedimentation structures have a sedimentation zone and a sludge zone. The sedimentation zone is where separation between solid particles and liquid occurs. Meanwhile, the sludge zone serves as a settling area for the solids generated in the sedimentation zone.

Fig. 4. Sedimentation

Table 6. Design spesifications and current conditions biofilter aerob tank 2

Design specifications	Design value	Existing condition	Units	Notes	Source
Length	-	1.33	m	-	-
Width	-	1.28	m	-	-
Depth	-	1.6	m	-	-
Detention time	1.5 - 3	12	jam	Not compliant	SNI 6774 – 2008 Tentang Tata Cara Perencanaan Unit Paket Instalasi Pengolahan Air
NRe	<2000	209.369	-	Compliant	
Nfr	>10^-5	0.0000187	-	Compliant	

The data in Table 6 shows a discrepancy between the detention time and the design criteria. This discrepancy is caused by the tank's disproportionate volume relative to the inflow. The consequence of this condition is a shift in the tank's environment from aerobic to anaerobic, due to the lack of water movement that inhibits the diffusion of dissolved oxygen (DO). This can be overcome by adjusting the inflow or adjusting the water level. Under current conditions, a diffuser is used to inject oxygen into the water. The turbulence generated prevents the particles from settling and even keeps them suspended or carried out, thus entering the next unit. The diffuser needs to be removed to avoid this condition.

4. CONCLUSION

The performance of Wastewater Treatment Plants (WWTPs) in the medical device manufacturing industry has met the quality standards set out in the Minister of Environment Regulation No. 5 of 2014 for most parameters, including BOD, COD, TSS, Ammonia, and Total Coliform (Table 2). However, there are significant discrepancies in technical and operational aspects that could potentially disrupt performance stability. The oil and grease parameters in the effluent do not meet the quality standards (0.5 mg/L), with a removal efficiency of 0%, indicating the need for additional units, such as grease traps, to treat oil and grease. Furthermore, theoretically, in the storage tank unit, a detention time discrepancy of 48 hours was found, exceeding the required criterion of less than 2 hours. This disproportionate volume triggered anaerobic conditions and foul odors. A similar condition occurred in the aerobic biofilter unit, where the absence of a contact medium for biofilm formation significantly hampered the performance of the microorganisms. Furthermore, the sedimentation unit experienced significant operational constraints due to an excessively long detention time of 12 hours, resulting from a tank volume that was not proportional to the inflow discharge. The presence of diffusers in the existing sedimentation unit worsened the situation, as the turbulence they generated kept particles suspended and carried out, making the removal of diffusers necessary to optimise the sedimentation process.

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