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Optimization Planning of Cartridge Replacement Time at Water Treatment Plant of PT Surabaya Industrial Estate Rungkut (Sier)

Imro'atus Nur Mufidah Dimyati Putri

Institut Teknologi Sepuluh Nopember, Surabaya

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*Correspondence: Imro'atus Nur Mufidah Dimyati Putri
Email: imroatusnurmufidah@gmail.com

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Abstract: This study aims to optimize the cartridge replacement process in the wastewater recycling system at PT Surabaya Industrial Estate Rungkut (SIER), ensure compliance with clean water quality standards in accordance with Ministry of Health Regulation No. 2 of 2023 and Occupational Health and Safety (OHS) standards, and implement professional engineering ethics. The method involves evaluating the current pretreatment process, identifying the causes of high cartridge replacement frequency, and proposing technical improvements. Water quality parameters such as Fe, Mn, Al, and oil and grease were analyzed to determine their impact on membrane performance. The study also includes recommendations for adjusting coagulant and flocculant doses based on influent characteristics, applying agitators to achieve uniform mixing and effective floc formation, monitoring critical parameters consistently, and scheduling maintenance based on actual system conditions. The results indicate that optimizing the pretreatment process significantly reduces membrane fouling and cartridge replacement frequency, leading to lower operational costs. Furthermore, maintaining water quality within regulatory standards is achievable without compromising system efficiency. This approach contributes to sustainable operations, enhances workplace safety, and supports the development of engineering competencies in water treatment management.

Keywords: Cartridge, Operational Efficiency, Pre-treatment, Water Treatment

Introduction

Clean water is a primary necessity required across various sectors, including households, social institutions, industries, and others. This demand is inherently linked to the availability of raw water sources such as groundwater, seawater, river water, and natural springs. The distribution of clean water is generally managed by Regional Drinking Water Companies (PDAM) through both piped and non-piped systems. In 2024, PDAM Surabaya reported that clean water distribution reached 256,741,880 m³, serving a total of 630,491 customers (Surabaya City Statistics Agency, 2025). Historical data indicates that the industrial sector consumes approximately 0.93% of the total distributed water, suggesting that industrial water usage in 2024 was around 2,387,699 m³. Clean water is essential for households, institutions, and industries, and its distribution relies on both piped and non-piped networks managed by utilities around groundwater, surface water, or seawater sources (Pardo Picazo & Tekinerdogan, 2023).

The availability of clean water from natural sources is progressively declining, while the demand for water remains constant or increases. Without further treatment or recycling of used water, the availability of clean water will continue to diminish, potentially affecting both industrial sustainability and public welfare. Therefore, wastewater treatment for clean water recovery represents a critical strategy to ensure that used water can be processed to meet quality standards comparable to natural clean water. Implementing such treatment systems allows for the reuse of water in various applications, thereby reducing dependency on natural water sources. Natural clean water sources are rapidly declining while demand continues to rise, making wastewater treatment and reuse essential to sustain both industrial operations and public health (Aleksić & Šušteršič, 2022).

PT. Surabaya Industrial Estate Rungkut (SIER) has been one of the largest industrial estates in Indonesia since its establishment in 1974, with locations in Surabaya, Sidoarjo, and Pasuruan, East Java. As an integrated industrial zone, SIER provides various services, including wastewater treatment and the provision of clean water through recycled wastewater treatment processes to support tenants' sanitation needs while also contributing to water resource conservation efforts (SIER, 2019a). SIER implements a clean water treatment system utilizing ultrafiltration and reverse osmosis technologies to produce high-quality water that meets quality standards. The current intake capacity of the system is 2,500 m^3/day, with plans to double this capacity in the future, producing up to 1,200 m^3/day of clean water (Akhmad, 2023).

Enhancing operational cost efficiency remains a primary focus in utility management at PT. Surabaya Industrial Estate Rungkut (SIER), particularly in the clean water treatment (recycled water) process. Through strict monitoring of chemical usage, energy consumption, and equipment performance, the company seeks to identify and implement cost-saving strategies without compromising water treatment quality. One of the major contributors to high operational costs is the frequent replacement of cartridges, which occurs two to three times per week. Given the relatively high unit price of cartridges, this frequency results in a substantial cumulative cost burden. This situation suggests potential inefficiencies in the system, either in terms of process water quality or operational design. Therefore, optimization of cartridge replacement, as part of a comprehensive cost-efficiency analysis, is conducted regularly to ensure that every stage of the water treatment process operates optimally and contributes to the overall reduction of operational costs. This strategy aligns with studies emphasizing the importance of optimizing filtration systems to lower treatment costs without compromising water quality (Kobya, 2021).

In addition to efficiency aspects, compliance with water quality standards and occupational safety regulations is a primary priority within the Utility Management Unit of SIER. The company adheres to standards outlined in Ministry of Health Regulation No. 2 of 2023, which governs clean water quality. This ensures that the implemented water treatment system complies with prevailing legal requirements while safeguarding the health and safety of both tenants and the surrounding environment. All utility management and water treatment activities are carried out with strict adherence to occupational health and safety (OHS) procedures, including routine employee training, the implementation of risk mitigation systems, and periodic reviews of on-site safety protocols. Thus, SIER not only emphasizes efficiency and technological innovation but also prioritizes the well-being and safety of all personnel involved in company operations.

Based on this background, engineering practices within the SIER Utility Management Unit are oriented toward the supervision, evaluation, and development of sustainable water treatment management strategies. This integrative approach is expected to enhance operational efficiency, optimize cost management, and ensure continuous compliance with applicable regulatory and OHS standards. Ultimately, these efforts aim to support the long-term sustainability of company operations and generate positive outcomes for all stakeholders involved.

Methodology

This study commenced with a preparatory phase encompassing problem identification, literature review, field observation, as well as the establishment of problem boundaries and assumptions. The problem identification focused on the low efficiency of the clean water treatment process at SIER, attributed to contamination in the intake water, short cartridge lifespan, and limited reservoir capacity. A literature review was conducted to explore relevant theories and regulations concerning water treatment processes, including clean water quality standards and occupational safety regulations, serving as both scientific and legal foundations. Comprehensive field observations were carried out at the water treatment unit and laboratory to gain an in-depth understanding of the actual processes and technical issues encountered. The scope of the study was limited to the optimization of cartridge and chemical usage, under the assumption that all future tenant water demands will rely solely on the SIER clean water supply system.

The subsequent phase involved data collection and processing, which was carried out through direct observations, reviews of technical documentation, internal and external laboratory testing, and discussions with relevant stakeholders. The collected data were analyzed to identify key factors contributing to the high frequency of cartridge replacement. The analysis included evaluations of water quality, chemical effectiveness, and maintenance procedure efficiency. Several technical strategies were examined, including optimization of the pre-treatment process, adjustment of chemical types and dosages, and routine monitoring of the treatment system’s performance.

The final stage of the methodology comprised the formulation of conclusions and recommendations based on the analytical results. The conclusions were used to develop an optimized cartridge replacement plan that emphasizes process and cost efficiency. The recommendations include improvements in the pre-treatment system, revisions to maintenance procedures, and more effective chemical management strategies.

Result and Discussion

Clean Water Treatment Process at PT. SIER

The clean water treatment process at PT. SIER involves the recycling of treated industrial wastewater from the SIER Wastewater Treatment Plant (WWTP). A portion of the effluent, which would otherwise be discharged into the river, is diverted and channeled into the clean water treatment system. The block diagram and process flow diagram (PFD) illustrating the clean water treatment process at SIER are presented in Figures 2 and 3, respectively.

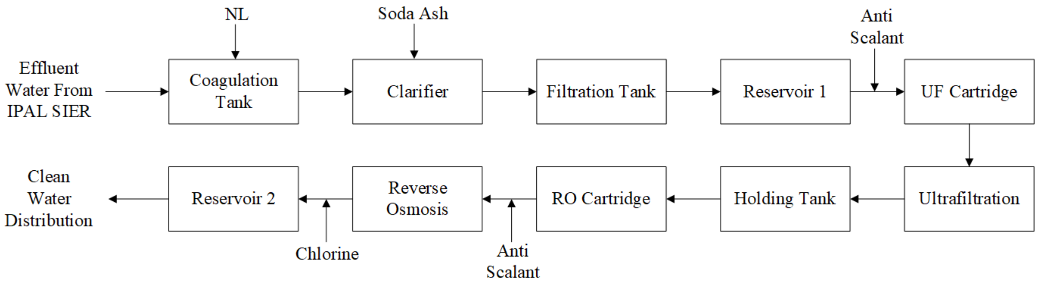

Figure 1. Block Diagram of the Clean Water Treatment Process at SIER

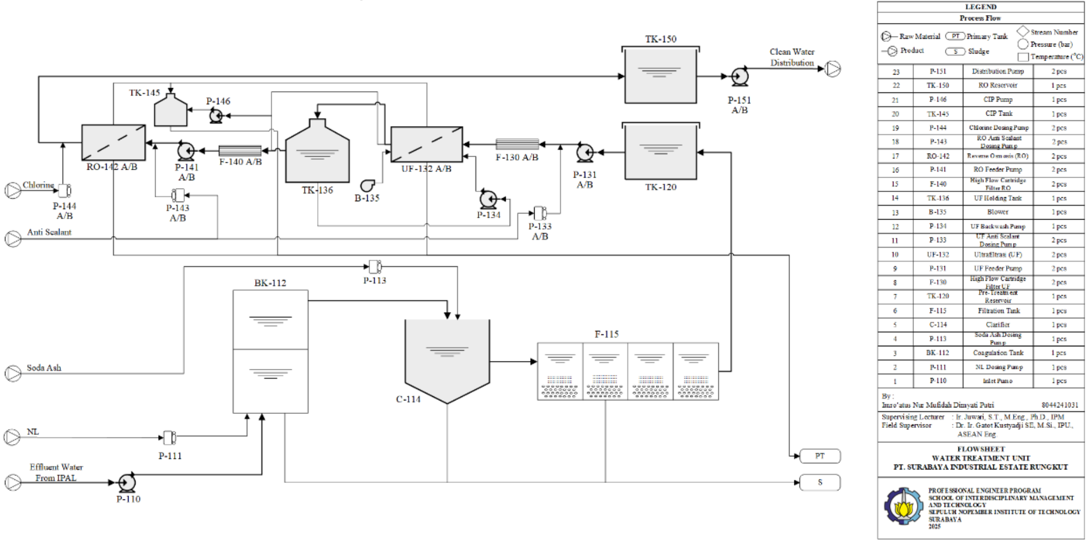

Figure 2. Process Flow Diagram (PFD) of the Clean Water Treatment at SIER

The clean water treatment process starts with raw water from the SIER WWTP effluent pumped by P-110 into the coagulation tank (BK-112), where poly amylum chloride (NL) is added via dosing pump P-111 to aggregate suspended particles. Sludge formed during coagulation is manually removed every three months, and the water continues into the clarifier (C-114), where inclined lamella plates aid in settling residual particles. Soda ash is added using pump P-113 to neutralize the acidic pH caused by the coagulant. Next, the water passes through four filter tanks (F-115) with silica sand and gravel media, then through a high flow cartridge filter (F-130 A/B) with anti-scalant dosing before entering two ultrafiltration (UF) units (UF-132 A/B). The UF system includes a periodic automatic backwash and stores filtered water in a holding tank (TK-136) before sending it through another cartridge filter (F-140 A/B) and into the reverse osmosis (RO) units (RO-142 A/B), with further anti-scalant dosing from pumps P-143 A/B. Post-RO, the water is chlorinated, stored in the RO tank (TK-150), and distributed via pumps P-151 A/B, with this study emphasizing the critical role of high flow cartridge filters (F-130 A/B and F-140 A/B) in removing impurities before UF and RO membrane filtration.

Current Conditions of the Clean Water Treatment Process at PT. SIER

The clean water treatment at PT. SIER follows the process units illustrated in the Process Flow Diagram (PFD) in Figure 4. To meet sanitation standards, water quality testing is conducted twice daily morning and afternoon on raw and treated water, assessing parameters such as turbidity, temperature, total dissolved solids (TDS), and pH. The results from these tests, taken from both the SIER WWTP effluent and processed clean water, are displayed in the graphs for May 2025 in Figure 4.

(a) (b)

(c) (d)

Figure 3. Graphs of Raw Water and Treated Water Test Results Based on (a) Turbidity, (b) Temperature, (c) TDS, and (d) pH in May 2025

In May 2025, the treated water quality generally met the standards set by Ministry of Health Regulation No. 2 of 2023, except on the afternoon of May 27, when elevated Total Dissolved Solids (TDS) levels likely from external industrial discharge caused a deviation. Routine maintenance and cleaning activities also led to several days of complete system downtime at the SIER Clean Water Treatment Unit. Key indicators such as TDS, turbidity, pressure, and flow variations guide decisions on maintenance, including Cleaning-In-Place (CIP) and cartridge filter replacement. Cartridge filters at this facility are replaced every 2–3 days more frequently than in other cases, where replacement intervals typically range from 8–10 days (Maulida, Zamrudy, & Mustofa, 2023) and may extend up to 24 days (Farhat et al., 2020). Additionally, sludge from the RO filtration process was analyzed for quality parameters, as detailed in Table 1.

Table 1. Sludge Test Results from the Reverse Osmosis Process

Parameter	Unit	Analytical Result
Total Dissolved Solids	mg/L	833
Dissolved Iron (Fe)	mg/L	18.02
Dissolved Manganese (Mn)	mg/L	12.02
Aluminium (Al)	mg/L	26.01
Permanganate Index ($KMnO_4$)	mg/L	114

The test results in Table 1 show that high levels of total dissolved solids (TDS) and dissolved manganese remained in the water despite undergoing multiple pre-treatment processes coagulation, clarification, filtration, ultrafiltration, and cartridge filtration leading to severe membrane fouling that required direct high-pressure cleaning of the reverse osmosis (RO) membranes even after acid-base Cleaning-in-Place (CIP). To investigate further, water samples collected at each pre-treatment stage on the morning and afternoon of June 11, 2025, were analyzed for turbidity, temperature, TDS, and pH, as shown in Table 2.

Table 2. Test Results for Turbidity, Temperature, TDS, and pH at Each Pre-Treatment Stage

Parameter	Waktu	Bak Koagulan	*Clarifier*	Bak Filtrasi	Ultrafiltrasi
Kekeruhan (NTU)	Pagi	2,57	1,27	1,03	0,94
	Siang	1,24	1,04	0,58	0,37
Temperatur (°C)	Pagi	29,7	29,4	29,7	29,6
	Siang	30,1	29,8	30,1	29,9
TDS (ppm)	Pagi	1181	1163	1126	1108
	Siang	1138	1125	1133	1095
pH	Pagi	7,56	7,82	7,93	7,85
	Siang	7,33	7,35	7,41	7,45

The current pre-treatment process has proven ineffective in significantly reducing turbidity and TDS levels, leading to severe membrane fouling and frequent cartridge filter replacements that increase the operational burden on the RO membrane filtration system. This excessive replacement frequency results in high operational costs, prompting the use of temporary cost-saving measures such as washing used cartridge filters with NaOH and reusing them, although their effectiveness typically lasts only two days. Therefore, a comprehensive evaluation is urgently needed to develop improved pre-treatment strategies capable of efficiently removing organic and inorganic contaminants, thereby extending filter service life and reducing overall expenses.

Optimization Planning for the Clean Water Treatment Process at PT. SIER

Based on the actual conditions observed in the Clean Water Treatment Unit at PT. SIER, optimization efforts are required in several aspects, including operational processes, the use of supporting materials, and maintenance practices. These improvements aim to extend the service life of cartridge filters, thereby reducing operational costs, and ideally, also prolonging the lifespan of both UF and RO membranes without compromising the quality of the treated water. The following are several proposed optimization plans for the clean water treatment process, formulated in response to the current challenges encountered in the field.

Pre-Treatment to Reduce Dissolved Iron (Fe), Manganese (Mn), Aluminium (Al), and Oil and Grease

The influent used in PT. SIER's clean water treatment, sourced from WWTP effluent, contains high levels of dissolved iron (Fe), manganese (Mn), aluminium (Al) and oil and grease, which damage cartridge filters and raise operational costs due to frequent replacements. Despite efforts to reduce TSS and TDS, Fe, Mn, Al and oil removal remains inadequate, worsened by inconsistent Mn monitoring, as evidenced by a recent RO system failure caused by undetected high Mn levels. Various studies propose Fe, Mn, Al removal solutions including phytoremediation using *Trapa natans L.* (Kumar & Chopra, 2018), constructed wetlands with *Phragmites australis* and *Typha latifolia* (Morari et al, 2015), ZnCl-treated *Ocimum basilicum* leaves (Alamrani et al, 2021), pine bark powder (Abujazar et al, 2022), geopolymer adsorbents (Pachana et al, 2022), and sulfuric acid-modified activated carbon with over 99.56% efficiency (Mahmoud et al, 2016). For oil and grease, techniques like dissolved air flotation (Show, 2008) (Ertz et al, 1977), electroflotation with stable anodes (Chen, 2004) (Beer, 1972), cork granule adsorption (Pintor et al, 2015), and biological treatments using *Trichosporon fermentans* and *Candida rugosa* (Yu et al, 2018) (Gonçalves et al, 2012) offer removal efficiencies up to 89.9%. While physicochemical methods typically yield higher removal rates, biological approaches are advantageous for treating high-load influents due to shorter processing times (Ahmad et al, 2020).

Adjustment of Coagulant Dosage

The Clean Water Treatment Unit at PT. SIER employs polyaluminum chloride (PAC) Terrased NL 65P NL from Behn Meyer, a 20% w/w aluminum chloride polymer, preferred over aluminum sulfate for its superior floc formation and sedimentation efficiency (Aziz, Effendy, & Basuki, 2017). Currently, the PAC is diluted at a 1:20 ratio, but the resulting weak floc formation and residual aluminum suggest suboptimal dosage. Research indicates that optimal PAC dosages for water with 164–181 mg/L TSS, 1450–1520 mg/L COD, and 179–88% BOD_5 removal fall around 1000 mg/L, achieving 52.66% COD and 97.16% suspended solids removal (Thaldiri, Hanafiah, & Halim, 2017). Additionally, 20 ppm PAC effectively reduced turbidity by over 94% under various initial turbidity and pH conditions (Bakri et al, 2019) (Komala et al, 2024). Therefore, due to fluctuating influent characteristics, regular water quality monitoring and daily jar tests with varying PAC dosages are necessary to establish the most effective and economical NL dosing strategy.

Use of Agitator for Rapid Mixing in the Coagulation Process

In the Clean Water Treatment Unit at PT. SIER, the current method of injecting NL coagulant via dosing pumps directly into the inlet channel lacks mechanical mixing, resulting in uneven coagulant distribution and suboptimal coagulation performance. This inadequacy allows some water portions to bypass the reaction process and flow directly to the sedimentation tank without effective impurity removal. To overcome this, the implementation of a mechanical agitator is proposed, designed to match the tank configuration and operate at controlled speeds to prevent vortex formation and water splashing. Pitched-blade turbine agitators, commonly set at a 45° angle, are preferred in conventional systems due to their efficient axial and radial flow, which promotes effective mixing and enhances solids suspension and particle sweeping (Geankoplis, 1993). Thus, integrating an agitator is expected to significantly improve the coagulation process efficiency by ensuring homogenous chemical distribution. Examples of suitable agitator models include the PRO-DO-MIX types 3PM-0134 HURRICANE and 3PM-0030 EVOLUTION, as well as the MILTON ROY Mixing model 31T. These models generally feature three-blade configurations with dimensions adapted to the volume and geometry of the coagulation tank.

To determine the appropriate design and blade dimensions, calculations should be carried out using geometric proportions for standard agitation systems, as detailed in *Transport Processes and Unit Operations* by Geankoplis (1993). These calculations ensure optimal mixing efficiency while minimizing energy consumption and mechanical stress on the system.

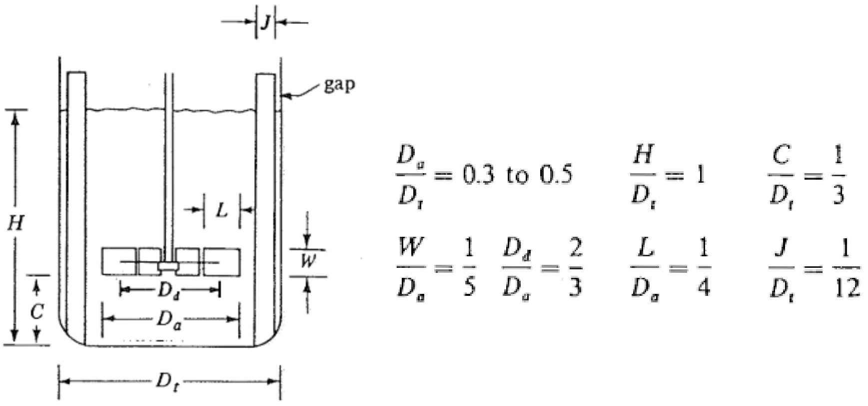

Figure 4. Dimensions of the Mixing Tank and Turbine Agitator

The measurement of blade height (W) and blade diameter (Da) is based on the tank diameter (Dt). Considering the current existing condition, in which the cross-sectional width of the coagulation tank is only 1.15 meters, the appropriate blade diameter (Da) for the agitator installation in the coagulation tank is:

$$\frac{D_a}{D_t} = 0,5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$D_a = 0,5 D_t$$

$$D_a = 0,5\ (1,15) = 0,58\ m$$

The measurement of blade height (W) and blade diameter (Da) is based on the tank diameter (Dt).

$$\frac{W}{D_a} = \frac{1}{5} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$W = \frac{D_a}{5}$$

$$W = \frac{0{,}58}{5} = 0{,}12\ m$$

Such a condition is not feasible, as manufacturers such as PRO-DO-MIX only provide agitators with a minimum impeller diameter of 0.9 meters. One viable approach to meet the required specifications is to redesign the existing tank layout by dismantling the first partition wall in the coagulation tank. This modification would expand the available area for agitator installation, increasing the effective diameter of the coagulation tank to 2.45 meters. Based on this new configuration, the recalculated values for blade diameter (Da) and blade height (W) are as follows:

$$\frac{D_a}{D_t} = 0{,}5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$D_a = 0{,}5D_t$$

$$D_a = 0{,}5\ (2{,}45) = 1{,}23\ m$$

The appropriate blade height (W) for the agitator,

$$\frac{W}{D_a} = \frac{1}{5} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$W = \frac{D_a}{5}$$

$$W = \frac{1{,}23}{5} = 0{,}25\ m$$

The liquid height (H) used for mixing calculations is determined based on the following equation:

$$\frac{H}{D_t} = 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$H = D_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where the tank diameter (Dt) can be derived from the reduction of Equations (1) and (2), resulting in the following expression:

$$D_t = \frac{D_a}{2} = 10W \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

By substituting Equation (4) into Equation (5), Equation (6) is obtained as follows:

$$H = 10W \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$H = 10\ (0{,}25) = 2{,}5\ m$$

Based on post-reconstruction calculations, the liquid height is 2.5 meters with an impeller diameter of 1.23 meters and blade height of 0.25 meters; however, a 3-meter central partition wall requires elevating the tank base to optimize agitator performance, or alternatively, accepting slight suboptimal mixing due to design deviation. Mixing speeds generally range from 100 to 350 rpm (Abu Bakar & Halim, 2013; Ramadhan, Maleiva, & Nugraheni, 2024), but speeds exceeding 300 rpm risk floc breakup and reduced coagulation efficiency. Hence, further experimental testing is needed to determine the optimal mixing speed in real-world conditions and with the specific coagulant dosage used in PT. SIER's Clean Water Treatment Unit (Zhao et al, 2014).

Application of Flocculants and Clariflocculator with Slow Mixing

The current water treatment system at PT. SIER is hindered by inefficient floc particle removal due to reliance solely on gravity sedimentation without slow mixing or flocculant addition, leading to accumulation in downstream units. To improve performance, chemical flocculants like polyacrylamide (PAM), particularly cationic variants such as Organopol 5415, have shown excellent results in turbidity removal (Ahmad et al., 2008), while the PAC (70 mg/L) and anionic PAM (2 mg/L) combination achieved 98% TSS and 70% COD reduction (Bakar & Halim, 2013). Clariflocculators offer a superior alternative, outperforming pulsator-based systems with just 5 mg/L PAC by maintaining a more stable floc layer (Maldhure et al., 2022). Slow mixing at 20–50 rpm for 10–20 minutes allows for gentle floc formation, supported by pitched-blade turbines with a 45° angle (Lin, Pan & Huang, 2013; Thaldiri et al., 2017; Geankoplis, 1993). Equipment like PRO-DO-MIX's 2PM-0650 PREMIUM and MIXEL's FLOCMIX match calculated tank specifications (4 m × 4 m, 3.6 m height, 71.28 m^3 volume), confirming their suitability for optimal flocculation.

Maintenance of Clean Water Treatment Process Equipment

The Clean Water Treatment Unit at PT. SIER employs HDPE pipes for inlet and distribution, and galvanized iron pipes for other process lines connected to units such as clarifiers, filters, and coagulation tanks. Structural components include concrete tanks and SS41 steel plates with epoxy coatings, though corrosion still occurs, notably in the UF product tank, causing contamination and increased cartridge filter replacements. Maintenance is performed every 2 to 6 months, triggered by indicators like turbidity, TDS, and membrane pressure drops, and includes tank draining, CIP, and membrane replacement every four years. To ensure hygienic and food-grade water standards, daily inspections and backup systems are critical (Perhab, 1936), although cleaning delays exacerbate contamination risks. To enhance system efficiency and minimize downtime, implementing acid-based cleaners or dedicated drainage systems is recommended (Ludwig & Sampson, 1996).

Evaluation of Regulatory Compliance, Occupational Health and Safety, and Engineering Professionalism and Ethics at PT. SIER

The current clean water treatment process at SIER complies with the water quality standards established in the Indonesian Ministry of Health Regulation No. 2 of 2023, particularly for key parameters such as turbidity, temperature, total dissolved solids (TDS), and pH, which are monitored daily. However, testing of other parameters is still limited, conducted only once every six months through external laboratories. Therefore, budgeting for routine monthly testing is necessary to maintain water quality and to support process improvements if abnormal parameter values are detected. Moreover, SIER is in the process of obtaining halal certification (SJPH) from the Indonesian Ulema Council (MUI) to ensure that its clean water product complies with halal standards. The disposal of liquid and solid waste generated from the water treatment process is also conducted in accordance with applicable regulations, where wastewater is channeled to the SIER WWTP, and sludge is collected in the B3 Waste Temporary Storage Area (TPS Limbah B3) before being transported by a third party, PT. PPLI, in compliance with Government Regulation No. 22 of 2021. Additionally, a portion of the sludge is reused as fuel by PT. Solusi Bangun Indonesia.

The implementation of environmental and occupational health and safety (OHS) management systems at SIER demonstrates the company's commitment to sustainability and professionalism. The achievement of the PROPER Blue certification from the Ministry of Environment and Forestry (KLHK) for the 2021–2022 period and the ongoing application for ISO 14001:2015 certification indicate compliance with environmental management standards. In terms of OHS, SIER is certified under ISO 45001:2018 and adheres to national occupational safety regulations, with a SMK3L evaluation score of 82.7, categorized as good. The OHS Division actively conducts various programs such as training, audits, safety briefings, routine inspections, and awareness campaigns to ensure optimal implementation of safety protocols. Engineering professionalism and ethics are reflected through the involvement of competent personnel from various engineering disciplines who work collaboratively and are regularly trained to enhance their expertise. With continuous improvement and service enhancement, SIER aims to maintain its quality and reputation as a trusted clean water provider for industrial area tenants.

Conclusion

The primary cause of the high frequency of cartridge replacement was identified as the fluctuating quality of influent water. This finding underscores the need for an optimization plan that includes enhancing the pre-treatment process to reduce contaminants, adjusting coagulant dosages, employing an agitator system, and implementing more precise maintenance scheduling. These measures are expected to extend cartridge lifespan and reduce operational costs. All production processes and related activities within the SIER Clean Water Treatment Unit are carried out in accordance with regulations, specifically referring to Ministry of Health Regulation No. 2 of 2023 as the standard for clean water quality, and Law No. 1 of 1970 concerning Occupational Safety. Activities within the SIER Clean Water Treatment Unit uphold high standards of professionalism and engineering ethics in accordance with Law No. 11 of 2014 and the Code of Ethics of the Institution of Engineers Indonesia (PII). These principles are reflected in competence-based work, cross-disciplinary coordination, individual capacity building through training, and the implementation of effective occupational safety standards. Collectively, these efforts support improvements in the quality of clean water services and help maintain SIER’s reputation as a trusted industrial estate service provider.

The findings of this study underscore the critical role of optimized pre-treatment in extending cartridge filter lifespan and reducing operational costs at PT. SIER’s clean water treatment plant. This improvement not only supports compliance with clean water standards but also enhances sustainability and system reliability, contributing to the company's long-term industrial service excellence.

Future studies should explore real-time monitoring systems for dissolved metal concentrations, particularly manganese and iron, to prevent unexpected membrane fouling.

Pilot testing of advanced pre-treatment technologies such as hybrid adsorption-coagulation or biological filtration is also recommended to further improve water quality. Practically, SIER should redesign its coagulation tank to accommodate mechanical agitators and implement a more flexible chemical dosing system responsive to influent characteristics. Routine jar tests and predictive maintenance models can help refine chemical usage and replacement schedules. These strategies will contribute to operational resilience and greater water treatment efficiency.

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