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Performance of Removal Efficiency in the Main Wastewater Treatment Plant for Physical, Chemical (Fe, Zn, Bod), and Biological Parameters at the Steam Power Plant (Pltu) Paiton Units 3, 7 & 8

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Abstract

Wastewater treatment in Wastewater Treatment Plant (WWTP) plays a vital role in protecting environmental quality. This study aims to evaluate the treatment efficiency of various pollutant parameters such as Total Suspended Solids (TSS), Iron (Fe), Zinc (Zn), Biochemical Oxygen Demand (BOD), and Total Coliform, based on data collected during the period 2023-2024. The results of the analysis showed fluctuations in pollutant levels in the influent and effluent of WWTP, with TSS removal efficiency reaching 95.83% in August 2023, and Total Coliform showing the highest efficiency of 99.88% in the same month. Although most parameters showed significant reductions, there were months where the removal efficiency decreased, even showing negative values. These findings indicate anomalies in the treatment process that need to be addressed, especially in certain parameters. The analysis of variance (ANOVA) conducted showed no significant difference between pollutant levels, indicating consistency in the treatment results carried out by the WWTP. The importance of regular monitoring and evaluation of the wastewater treatment system to ensure that the wastewater from the WWTP process that is discharged does not pollute the environment. Efforts to improve treatment technology and implement better waste management practices are needed to achieve environmental sustainability effectively.

Introduction

Electrical energy is vital in all human activities to improve life's welfare and prosperity. The electrical energy produced must go through a long and quite complex process (Armaroli & Balzani, 2011; Gür, 2018). Electrical energy greatly facilitates the fulfillment of human needs, considering the nature of electrical energy, which is easily distributed and converted into other forms of energy, such as light energy, mechanical energy, heat energy, and so on. The demand for electrical energy increases every year in line with economic and population growth in Indonesia (Erdiwansyah et al., 2021; McNeil et al., 2019; Batih & Sorapipatana, 2016; Pambudi et al., 2023; Hasan et al., 2012).

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The Indonesian government continues to strive to increase economic growth with the aim of improving the welfare of the community (Wibowo, 2023) . Indonesia's per capita electricity consumption, according to the Ministry of Energy and Mineral Resources (ESDM), throughout 2024 was at 1,411 kWh/capita. This figure increased 5.53% compared to per capita electricity consumption throughout 2023 of 1,337 kWh/capita (ESDM, 2024).

PT. Paiton Energy is the first private power producer company in Indonesia, which was established in the Paiton power plant complex in 1994. PT. Paiton Energy operates and maintains Paiton Unit 7 & 8 PLTU with a capacity of 2 x 615 Net MW, or a total of 1230 Net MW. In 2010, the government appointed PT Paiton Energy to oversee the expansion project of the PLTU in Paiton, which involved constructing PLTU Unit 3 with a capacity of 1 x 815 Net MW, increasing the total capacity of managed Coal PLTU to 2045 Net MW.

Paiton Energy is committed to ensuring the continuous availability of electricity and distributing it throughout Indonesia, especially within the framework of the Java-Bali Power Plant interconnection. During power generation operations, coal-fired power plants (PLTUs) produce liquid waste that has the potential to pollute the environment if not managed effectively. This liquid waste can contain various hazardous and toxic substances (B3), such as heavy metals, organic compounds, and other chemicals, which can damage aquatic ecosystems and threaten human health (Kurniawan, et al., 2017; Das et al. 2023; Sall et al., 2020; Baby et al., 2010).

Efficient wastewater management is becoming increasingly important with increasing awareness of environmental issues and increasingly stringent regulations (Metz, F., & Ingold, 214; Qadir et al., 2010). Inadequate management can lead to groundwater and surface water pollution, negatively impacting the quality of water used for various purposes, including drinking water and irrigation (Akhdiyat et al., 2025; Verlicchi & Grillini, 2020; Khatri & Tyagi, 2015; Raghav et al., 2018). Furthermore, wastewater pollution can also disrupt the balance of aquatic ecosystems, causing the death of aquatic biota and reducing biodiversity.

In recent years, there have been significant advances in wastewater treatment technology. Gingerich et al., (2018) and Maiti et al. (2019) said that, Various treatment methods, such as biological, chemical, and physical processes, have been developed and implemented to remove pollutants from coal-fired power plant wastewater. Membrane technologies, such as reverse osmosis (RO) and nanofiltration (NF), are also gaining popularity due to their ability to produce high-quality water at relatively low cost (Bukhari, et al., 2020; Yang et al., 2019).

Integrated approaches combining various treatment methods are also increasingly being implemented to achieve optimal efficiency. The operation of a coal-fired power plant (PLTU) utilizes seawater as the primary raw material for electricity generation. Seawater is processed into freshwater and used for the production process. This production process will produce waste. According to Retnosari & Shovitri (2013), waste is waste or something unused, which can be in the form of liquid, gas, or solid, during the production process.

Waste resulting from production activities must go through a processing stage before being released into the environment (Pezeshki et al., 2023; Zhao & Yu, 2015). One effective effort is the construction of a Waste Water Treatment Plant (WWTP) that is appropriate to the pollutant load and characteristics of the wastewater (Sun et al., 2016; Zhou et al., 2019). Wastewater treatment at a coal-fired power plant (PLTU) has several treatment facilities, namely the WWTP and Sewage Water Treatment Plant (SWTP).

The WWTP is a wastewater treatment facility originating from the production process in the form of contaminated water from the turbine generator and boiler areas, namely from polisher

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and mixed-bed regeneration, boiler blowdown, water heater washing, boiler chemical cleaning, and laboratory waste (Sahlan & Razak, 2013). The SWTP is a facility for processing waste from domestic activities. Domestic Wastewater Treatment Systems (Sewage Water Treatment Plants) are designed to treat domestic wastewater to meet quality standards before being discharged into the environment.

One of the technologies used in this system is the Moving Bed Biofilm Reactor (MBBR), which utilizes a moving medium to support the growth of microbial biofilms that play a role in the degradation of organic contaminants (Liu et al., 2023; McQuarrie & Boltz, 2011). PT Paiton Energy has a main waste processing installation, WWTP. Analysis of the quality of incoming wastewater and processed wastewater at WWTP is very important, considering that wastewater to be discharged into the sea must meet quality standards in accordance with the Technical Approval for Fulfillment of Quality Standards for Wastewater Discharge into the Sea of PT Paiton Energy Number: S.429 / PPKL / PSPKPL / 1/5/2023. The parameters carried out at the compliance point at the WWTP outlet of PT Paiton Energy are TSS, pH, oil and fat, Cu, Fe, Zn, Cr, BOD, COD, total coliform, and phosphate. This study was conducted with the aim of analyzing the wastewater quality of PT Paiton Energy Pembangkitan Paiton WWTP based on the Technical Approval and to determine the removal efficiency of WWTP pollutants over the past 2 years.

Methods

This research was conducted at the Main Wastewater Treatment Plant (WWTP) of the Paiton Steam Power Plant (PLTU) Units 3, 7, and 8, PT Paiton Energy. Data collection was conducted from January 2023 to December 2024. The research location is shown in Figure 1.

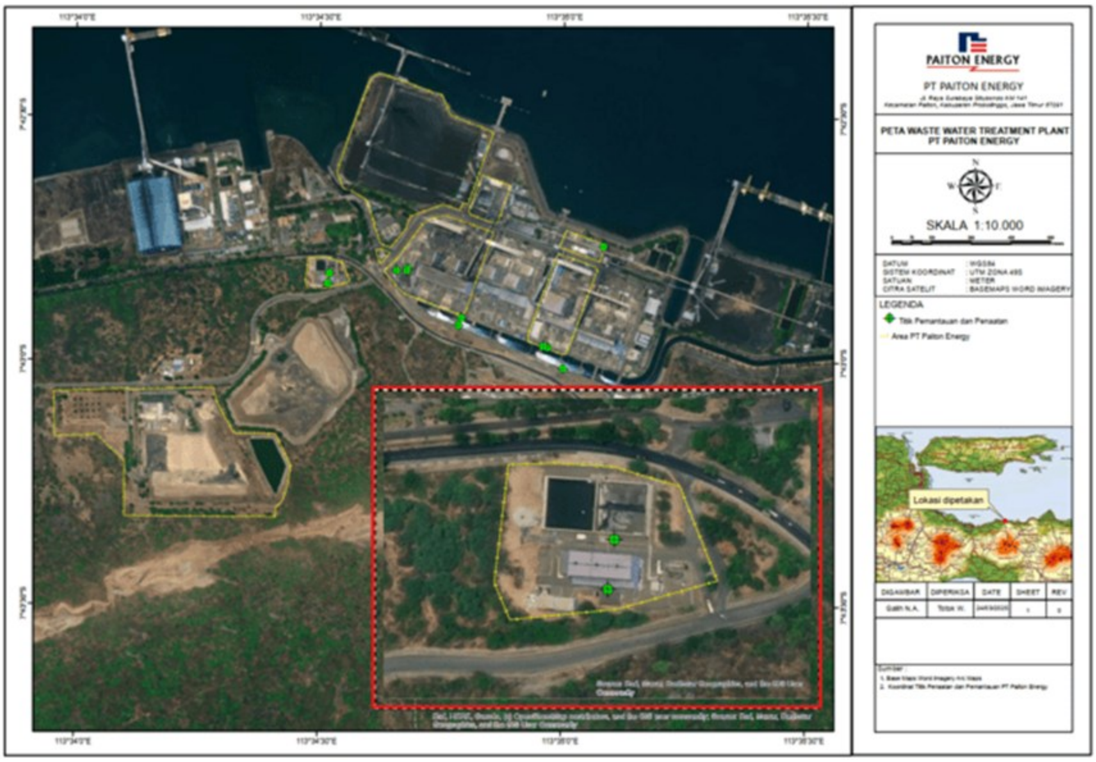

Figure 1. WWTP Research Location in PT Paiton Energy Area

The research design used is quantitative research with a literature study approach and secondary data collection in the form of wastewater quality data on the influent and effluent WWTP at PT Paiton Energy PLTU Unit 3 and Units 7 & 8 by the environmental laboratory

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of PT Envilab Indonesia, conducting wastewater data analysis based on the Decree of Technical Approval for Fulfillment of Wastewater Quality Standards discharged into the Sea of PT Paiton Energy number S.429 / PPKL / PPKPL / PKL.1 / 5/2023, including physical parameters (TSS), chemical (Fe, Zn, BOD), and biological (Total Coliform) of wastewater and calculating and Pollutant Removal Efficiency at the WWTP. Removal efficiency calculations are carried out to determine the amount of pollutants contained in the reduced wastewater. Removal efficiency is calculated using Formula 1.

Removal efficiency %= (X-Y)X ×100% ……………….. (Formula 1.)

Description:

X = Influent Concentration (mg/L)

Y = Effluent Concentration (mg/L)

Removal efficiency data analysis uses the single-factor ANOVA method with a confidence level of 95% or a value of $\alpha = 0.05$ to determine whether removal efficiency in each year is significantly different ($p < 0.05$) or not significant ($p > 0.05$).

Results and Discussion

Wastewater Quality

Monitoring of wastewater quality at the main wastewater treatment plant (WWTP) of the Paiton Steam Power Plant (PLTU) Units 3, 7, and 8, PT Paiton Energy is carried out at least once a month in accordance with the Decree on Technical Approval for Fulfillment of Wastewater Quality Standards discharged into the Sea of PT Paiton Energy number S.429/PPKL/PPKPL/PKL.1/5/2023. Monitoring and measurement of wastewater pollutant parameter content was carried out by an external party, PT Envilab Indonesia Environmental Laboratory, which has a valid KAN certification and registration letter from the Ministry of Environment. Sampling was carried out on waste before entering the WWTP treatment (Influent WWTP) and the output of the WWTP treatment (Effluent WWTP). The wastewater quality parameters measured included pH, TSS, oil & fat, Cu, Fe, Zn, PO_4, total Cr, BOD, COD, and total coliform. This study focused on observing key wastewater parameters, namely physical parameters (TSS), chemical parameters (Fe, Zn, BOD), and biological parameters (Total Coliform)

Tabel 1.Baku Mutu Air Limbah Proses Utama / Wastewater Treatment Plant (WWTP)

No	Parameter	Unit	Highest Levelor Maximum Level
1	pH	-	6,0 – 9,0
2	TSS	mg/L	100
3	Oils and Fats	mg/L	10
4	Total Chromium (Cr)	mg/L	0,5
5	Copper (Cu)	mg/L	1
6	Iron (Fe)	mg/L	3
7	Zinc (Zn)	mg/L	1
8	Phosphate (PO4)	mg/L	10
9	BOD	mg/L	30
10	COD	mg/L	100
11	Total Coliform	Amount/100 mL	3.000

Source: Technical Approval Decree for Fulfillment of Wastewater Quality Standards Discharged into the Sea by PT Paiton Energy Number S.429/PPKL/PPKPL/PKL.1/5/2023

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The Wastewater Treatment Plant (WWTP) processes all wastewater originating from the Sanitary Wastewater Treatment Plant, Turbine Area Chemical Sump, Wastewater Retention Basin unit 3, Wastewater Retention Basin units 7 & 8, Coal Pile Runoff Pond, Ash Disposal Runoff Pond, Water Treatment Plant Neutralization Pit, and Wastewater Treatment Plant Building Sump Pit. The WWTP treatment process uses sedimentation, filtration, and pH adjustment methods. The WWTP processing process diagram is shown in Figure 2 below:

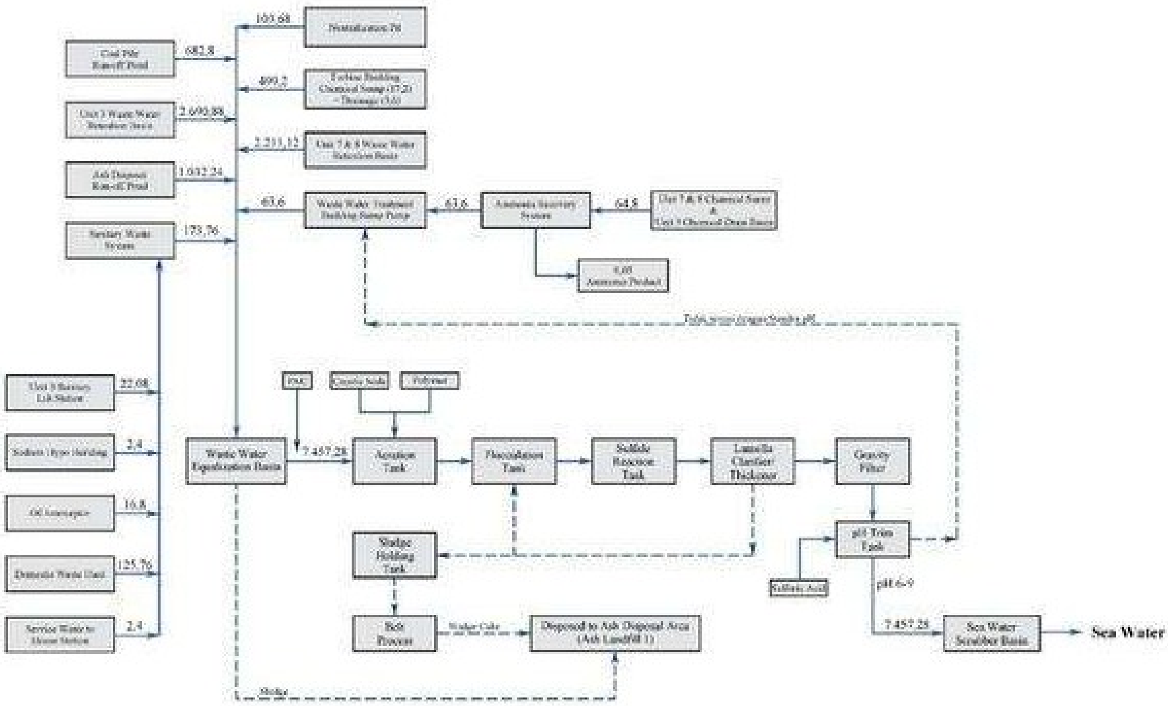

Figure 1. Main Process Wastewater Treatment / WWTP Diagram of PT Paiton Energy

Description: (1) Waste balance using maximum discharge (m3/day); (2) Units 7 & 8 capacity 2 x 615 MW (net) @ 100% rated load

Equalization Basin Located in the WWTP unit area, the equalization basin aims to accommodate and homogenize wastewater to facilitate further processing. The wastewater homogenization process is equipped with a surface aerator. The Equalization Basin is capable of accommodating wastewater generated during 24-hour PLTU operation. This condition is an effort to anticipate damage or emergencies in the WWTP. Wastewater from the equalization basin is then pumped to the aeration tank to adjust the pH between 9.0 and 11.0 by adding caustic soda (NaOH) to optimize the flocculation and coagulation processes and optimize process homogeneity by blowing air using a blower (aeration). Next, the wastewater flows to the Flocculation Tank and is added with polymer. This process completes the flocculation reaction into coagulation.

There is a recirculation process of sludge from the Lamella Clarifier if needed as seed floc to assist the flocculation stage of the coagulated wastewater (Kurniawan et al., 2020; The et al., 2016). After the process in the Flocculation Tank, the wastewater is flowed to the Sulfide Reaction Tank. Wastewater is dosed with sodium bisulfite to precipitate heavy metals in the wastewater. The wastewater is then channeled to the Lamella Clarifier tank. In this tank, a gravitational sedimentation reaction occurs, and separation from water occurs. The heavier sludge will settle at the bottom of the tank, while the clean wastewater will move to the gravity filter through a splitter box to divide the flow evenly. In this gravity filter, the remaining dissolved particles or suspended substances are filtered. The filtered results will enter the

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Gravity Filter's water storage compartment and then flow to the pH Trim Tank. The filtered water from the Gravity Filter is collected in the pH Trim Tank to be adjusted by adding Sulphuric Acid (H_2SO_4), ensuring that the pH of the WWTP effluent meets the established quality standards.

The pH of the WWTP effluent is monitored online using an instrument connected to the outlet valve. The pH set point is set at 8.8 for high alarm and 6.2 for low alarm. If the pH of the output water is outside the setpoint range, the outlet valve will automatically close, and the output water will be processed back to the equalization basin via the wastewater treatment building sump pit. The sedimentation sludge from the gravity filter will be flowed and collected into the sludge holding tank. Inside this tank, there is a stirrer that rotates slowly to ensure the flocculation process is running perfectly and consistently. Once the volume is sufficient, the -6- sludge will be dehydrated to around 80-85% using a belt press. The sludge from the Beltpress will form a cake and be disposed of in Ash Landfill 1.

Table 2. Results of Measurement of Wastewater Pollutant Levels in WWTP Influent and Effluent

Period		WWTP Influent Pollutant Levels					WWTP Effluent Pollutant Levels				
		TSS	Iron (Fe)	Zinc (Zn)	BOD	Total Coliform	TSS	Iron (Fe)	Zinc (Zn)	BOD	Total Coliform
		(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
2023 Semester-II	Jul-23	6	0,06	0,066	8	1.700	3	0,10	0,077	3	120
	Aug-23	24	0,10	0,096	7	8.000	1	0,11	0,057	11	10
	Sep-23	12	0,02	0,068	13	2.500	4	0,02	0,053	12	1.500
	Oct-23	49	0,05	0,120	40	6.995	8	0,03	0,098	29	95
	Nov-23	7	0,02	0,450	5	497	5	0,02	0,300	4	597
	Dec-23	20	0,05	0,140	7	7.490	9	0,06	0,088	2	2.090
2024 Semester-I	Jan-24	5	0,03	0,028	14	3.400	5	0,02	0,025	4	200
	Feb-24	20	0,02	0,170	24	1.000	7	0,02	0,110	23	200
	Mar-24	21	0,19	0,070	33	129	15	0,19	0,051	18	1.179
	Apr-24	12	0,19	0,120	8	499	8	0,19	0,100	5	99
	May-24	20	0,19	0,220	18	499	11	0,19	0,140	16	49
	Jun-24	13	0,22	0,810	19	2.100	5	0,19	0,051	8	1.200
2024 Semester-II	Jul-24	13	0,19	0,051	25	1.100	6	0,19	0,051	14	500
	Aug-24	20	0,31	0,051	23	1.000	10	0,19	0,051	12	100
	Sep-24	64	0,31	0,051	28	1.800	11	0,19	0,051	14	300
	Oct-24	7	0,19	0,060	10	2.500	60	0,19	0,050	9	1.900
	Nov-24	22	0,24	0,330	29	10.900	8	0,19	0,051	11	2.700
	Dec-24	21	0,19	0,051	18	20.700	7	0,19	0,051	7	1.200

The results of the measurement of key wastewater parameters, namely physical parameters (TSS), chemical parameters (Fe, Zn, BOD), and biological parameters (Total Coliform), are shown in Table 2. In general, the values fulfill the quality standards that have been set in the Decree on Technical Approval for Fulfillment of Wastewater Quality Standards discharged

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into the Sea by PT Paiton Energy number S.429/PPKL/PPKPL/PKL.1/5/2023. This data indicates that the performance of wastewater treatment can still run normally.

Removal Efficiency

Removal efficiency percentage indicates the extent to which a substance can be removed/processed. Based on the results of data analysis on wastewater quality, the percentage of removal efficiency is obtained from the comparison of the reduction in the parameters contained in the influent and effluent with the levels of parameters in the WWTP influent. The calculated removal efficiency percentage includes physical parameters (TSS), chemical (Fe, Zn, BOD), and biological parameters (total coliform). The results of the calculation of the removal efficiency percentage are shown in Table 3.

Tabel 3. Removal Efficiency Kadar Pencemar Air Limbah WWTP

Periode		**Removal Efficiency (%)**				
		TSS	**Iron (Fe)**	**Zinc (Zn)**	**BOD**	**Total Coliform**
		(1)	**(2)**	**(3)**	**(4)**	**(5)**
2023 Semester-II	Jul-23	50,00%	-66,67%	-16,67%	62,50%	92,94%
	Aug-23	95,83%	-10,00%	40,63%	-57,14%	99,88%
	Sep-23	66,67%	0,00%	22,06%	7,69%	40,00%
	Oct-23	83,67%	40,00%	18,33%	27,50%	98,64%
	Nov-23	28,57%	0,00%	33,33%	20,00%	-20,12%
	Dec-23	55,00%	-20,00%	37,14%	71,43%	72,10%
2024 Semester-I	Jan-24	0,00%	33,33%	10,71%	71,43%	94,12%
	Feb-24	65,00%	0,00%	35,29%	4,17%	80,00%
	Mar-24	28,57%	0,00%	27,14%	45,45%	-813,95%
	Apr-24	33,33%	0,00%	16,67%	37,50%	80,16%
	May-24	45,00%	0,00%	36,36%	11,11%	90,18%
	Jun-24	61,54%	13,64%	93,70%	57,89%	42,86%
2024 Semester-II	Jul-24	53,85%	0,00%	0,00%	44,00%	54,55%
	Aug-24	50,00%	38,71%	0,00%	47,83%	90,00%
	Sep-24	82,81%	38,71%	0,00%	50,00%	83,33%
	Oct-24	-757,14%	0,00%	16,67%	10,00%	24,00%
	Nov-24	63,64%	20,83%	84,55%	62,07%	75,23%
	Dec-24	66,67%	0,00%	0,00%	61,11%	94,20%

The removal efficiency percentage of wastewater treatment at the WWTP for several parameters shows inefficient calculation results. This is indicated by a removal efficiency value of <0%. In the second semester of 2023, the efficiency of the iron (Fe) parameter fluctuated greatly from -66.67% to 40.0%. In addition, the Zinc (Zn), BOD, and Total Coliform parameters also experienced a decrease in July, August, and November by -16.67%, -57.14%, and -20.12%, respectively. In the first semester of 2024, the removal efficiency of

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wastewater treatment at the WWTP was quite efficient, with only a decrease of -813.95% in March for the Total Coliform parameter. In the second semester of 2024, the removal efficiency of wastewater treatment at the WWTP was quite efficient, with only a decrease of -757.14% in October for the TSS parameter.

This negative efficiency value indicates that the pollutant content increased after treatment. One of the causes of the WWTP's inefficiency in waste processing is the presence of blockages/rust in the pipelines at each stage of the WWTP process. In addition, there is a fluctuating load capacity at the WWTP due to the rainy season, resulting in a tremendous influent flow carrying a relatively high pollutant content. These obstacles can still be handled by preventive maintenance in the form of periodic cleaning, such as cleaning the tank, draining, shortening the countdown timer for the backwash gravity filter, and effective process flow regulation. This fact is evident from the results of measurements of key wastewater parameters: physical parameters (TSS), chemical parameters (Fe, Zn, BOD), and biological parameters (Total Coliform) shown in Table 2, the values of which meet the established quality standards. After obtaining the calculation results for the removal efficiency value for each parameter per year, the data was analyzed using a single-factor ANOVA to determine the level of influence of removal efficiency each year. The purpose of this analysis is to identify important independent variables and how they influence them (Petter et al., 2013; Dohoo et al., 1997; Kim & Soergel, 2005; Kusurkar et al., 2011). The criteria for real differences or significant differences used for the removal efficiency analysis are at the 95% confidence level ($p < 0.05$). Real differences occur when the p-value is < 0.05, and when the p-value is > 0.05, the differences between the variants are insignificant.

Table 4. ANOVA Removal Efficiency Calculation Results

No	Parameter	Source of Variation	SS	df	MS	F	P-value	F crit	Information
1	TSS	Between Groups	6,375	2	3,187	0,842	0,450	3,682	Not Significant
		Within Groups	56,754	15	3,784				
		Total	63,129	17					
2	Besi (Fe)	Between Groups	0,208	2	0,104	1,777	0,203	3,682	Not Significant
		Within Groups	0,876	15	0,058				
		Total	1,084	17					
3	Seng (Zn)	Between Groups	0,125	2	0,062	0,757	0,486	3,682	Not Significant
		Within Groups	1,235	15	0,082				
		Total	1,360	17					
4	BOD	Between Groups	0,177	2	0,088	0,838	0,452	3,682	Not Significant
		Within Groups	1,583	15	0,106				
		Total	1,760	17					
5	Total Coliform	Between Groups	7,648	2	3,824	0,846	0,449	3,682	Not Significant
		Within	67,842	15	4,523				

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		Groups							
		Total	75,491	17					

Based on the results of the ANOVA calculation, for the physical parameters (TSS), chemical parameters (Fe, Zn, BOD), and biological parameters (Total Coliform), the difference in removal efficiency per semester was not significant. This is indicated by the results of the p-value calculation, which is > 0.05 with p-values of 0.450, 0.203, 0.486, 0.452, and 0.449, respectively.

Conclusion

The quality of wastewater produced by the main wastewater treatment plant (WWTP) at the Paiton Steam Power Plant (PLTU) for Units 3, 7, and 8 of PT Paiton Energy is being discussed. The quality of wastewater at the WWTP has met the required quality standards according to the Decree on Technical Approval for Fulfillment of Wastewater Quality Standards discharged into the Sea of PT Paiton Energy number S.429/PPKL/PPKPL/PKL.1/5/2023.

Suggestion

Removal efficiency values can be both positive and negative. Process optimization is necessary by increasing regular maintenance and ensuring that each stage of the WWTP treatment system is running smoothly and optimally. Wastewater treatment is crucial for maintaining environmental quality and meeting established standards. Maintenance and improvement of the treatment system are essential to ensure operational sustainability.

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