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PERFORMANCE OF WASTEWATER TREATMENT PLANT (WWTP) TO TREAT PHOSPHATE (PO4) OF PT PETROKIMIA IN GRESIK CITY 2025

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ABSTRACT

Background: Wastewater management in the fertilizer industry, particularly at PT Petrokimia Gresik, poses considerable challenges due to the presence of complex chemical pollutants. By 2024, secondary data shows a sharp increase in the concentration of phosphate (PO_4) pollutants by 147.7%. These figures raise concerns about the effectiveness of the existing Wastewater Treatment Plant (WWTP) system. **Research Objective:** This study aims to evaluate the performance of the Wastewater Treatment Plant at PT Petrokimia Gresik in 2025, specifically focusing on phosphate (PO_4) removal efficiency across different treatment units. **Methods:** This study used a quantitative research approach using observation, documentation, and grab sampling techniques in accordance with SNI 8990:2021. The analysis focused on the main water quality parameter, PO_4 from the PT Petrokimia Gresik WWTP. Data were evaluated based on removal efficiency, residence time, and potential reuse of wastewater. **Results:** The findings showed that the phosphate removal efficiency was low, indicating inefficiency in the treatment process. Although the residence time remains within acceptable limits, it has not led to a significant reduction in pollutant levels. **Conclusion:** The current WWTP system has not been effective in meeting quality standards, especially regarding PO_4. Comprehensive reutilization of effluent is ongoing, but improvements in design and treatment technology are needed to enhance performance.

Key words: Wastewater Treatment Plant, Phosphate, Fertilizer Industry

BACKGROUND

PT Petrokimia Gresik plays an important role as one of the leading fertilizer producers in Indonesia that supports the agricultural sector through large-scale fertilizer production. However, the production process generates a significant amount of liquid waste containing harmful chemical substances such as ammonia, phosphate, and various organic compounds. If not treated properly, these substances pose a serious risk to environmental sustainability. A thorough understanding of the characteristics of this industrial wastewater is essential to ensure effective and efficient treatment. Recent studies emphasize the importance of integrating chemical treatment processes with phosphate recovery technologies, including zero-liquid discharge systems that allow reclamation of phosphate in a safe and reusable form for industrial applications (Zueva et al., 2020).

Since 2020, PT Petrokimia Gresik has operated a communal Wastewater Treatment Plant (WWTP) based on Ammonia Phosphate Fluoride Recovery (APFR) technology. This centralized system treats waste from three different production units, namely Factory 1, Factory 2, and Factory 3.

Each contributes wastewater with different characteristics. By consolidating the treatment into one system, the WWTP facilitates more efficient effluent handling, which includes neutralization, coagulation, flocculation, and advanced processing. Communal design enhances monitoring and control efforts, enabling compliance with regulatory standards on effluent quality.

A major problem faced by the company is the incomplete recycling of liquid waste, which contains non-biodegradable inorganic compounds such as ammonia, phosphates and complex organics. This requires sophisticated treatment technologies to ensure the effluent meets regulated discharge standards. Inefficient treatment can lead to environmental contamination, especially in adjacent water bodies.

Wastewater discharged from PT Petrokimia Gresik is treated using an IPAL system designed to meet the quality benchmarks set by WDP 175/2017. The treatment process utilizes sedimentation, filtration, and membrane technologies, and is periodically upgraded to improve efficiency. Despite these efforts, secondary data from 2024 shows inefficiencies in wastewater treatment. For example, phosphate levels showed a dramatic increase from 1,479.26 mg/L at the inlet to 3,664.2 mg/L at the outlet.

The average wastewater inflow rate into the WWTP was 140 m^3/hr, far below the plant's designed capacity of 300 m^3/hr which indicates sufficient retention time for treatment. The increase in pollutant levels at the outlet indicates a lack of effectiveness in some stages of treatment. This finding supports Widyadhana and Sururi's (2024) assertion that optimizing unit design and sizing is critical to improving WWTP performance.

Further analysis of the 2024 data showed a mismatch with regulatory standards for PO_4 levels. Instead of decreasing, phosphate levels increased after treatment, indicating inefficiency in pollutant removal. PT Petrokimia Gresik currently discharges some of its effluent directly into nearby rivers without reuse, increasing pollutant loads and threatening local ecosystems. These findings highlight the urgent need for a comprehensive evaluation of the existing treatment system.

Waste reuse has the potential to improve resource efficiency and reduce the volume of environmental discharges. Such practices should be in line with Government Regulation No. 22/2021 on water quality management. Phosphate recovery in the form of calcium phosphate offers multiple benefits in industrial wastewater management, especially in treating acid mine drainage (Nepfumbada et al., 2023).

Previous studies have assessed the performance of WWTPs using sampling and analysis of water quality parameters. Bestari (2020) found inefficiencies in several units within PT Petrokimia Gresik's WWTP, while Iswarani (2018) showed that aeration-assisted settling improved phosphate removal. A report from the Ministry of Industry (2021) also supports the use of green technology to improve treatment efficiency and drive sustainability in the fertilizer sector.

To ensure long-term sustainability and regulatory compliance, PT Petrokimia Gresik must continuously evaluate and improve its wastewater treatment operations. As environmental regulations become increasingly stringent, technological improvements and operational adjustments will be critical to maintaining competitiveness and ecological responsibility. Valorization of wastewater offers not only operational efficiency but also environmental benefits.

With this context, this study aims to evaluate the performance of WWTP at PT Petrokimia Gresik in 2025.

RESEARCH METHODS

This study used an observational research design with a quantitative approach, with a focus on evaluating wastewater quality at the PT Petrokimia Gresik Wastewater Treatment Plant (WWTP). Data collection using grab sampling method, guided by Indonesian National Standard (SNI) 8990:2021 for physical and chemical testing of wastewater. This research aims to analyze phosphate (PO_4) wastewater parameters and explore its potential for reuse in industrial processes. The research was conducted at PT Petrokimia Gresik located in Gresik, East Java from January to June 2025. Sampling was conducted at several points in the WWTP, including the Collecting Pond (CP), Reactor Tanks I & II, Coagulation Tank, Flocculation Tank, Purification Tank, Processed Water Tank, and Thickener Tank. Laboratory analysis was used to determine phosphate concentration. The research variables included independent variables (WWTP components) and dependent variables (wastewater quality parameters).

Operational definitions are given for each parameter, including measurement methods and units. Additional variables such as removal efficiency, hydraulic detention time, and appropriate chemical dosage were also considered to evaluate WWTP performance and compliance with the standards outlined in WDP 175/2017 and Government Regulation No. 22/2021. Data sources include primary data obtained through field observations, sampling, and measurements and secondary data derived from company documentation and previous monthly reports. Data collection tools consist of standardized instruments such as submerged sample bottles, measuring cylinders, and supporting materials (labels, gloves, notebooks). The data collection process involved three core techniques: structured observation, photo and document-based documentation, and laboratory-scale measurements. Each parameter was sampled and analyzed three times to observe variations and ensure accuracy. The results were presented in the form of tables, figures and descriptive analysis. Quantitative analysis was conducted using two main formulas: the removal efficiency formula, which calculates the percentage reduction of pollutants from inlet to outlet, and the hydraulic detention time formula, which estimates the time wastewater spends in each reactor tank. These calculations are essential for assessing the effectiveness of the treatment process.

RESULTS AND DISCUSSION

Liquid Flow of Waste Treatment

The wastewater treatment process at PT Petrokimia Gresik shows the company's strong commitment to sustainable industrial development and environmental protection. With the rapid development of the fertilizer industry, the company has built an integrated, systematic, and environmentally sound wastewater management system. Liquid waste generated from several production units is directed to the central wastewater treatment plant (WWTP) through designated channels. The process begins with Primary Treatment, which consists of several stages, namely pH neutralization, coagulation-flocculation, and sedimentation, all of which are carried out in accordance with strict environmental quality standards. These stages are essential to meet regulatory requirements and reflect the company's innovation in supporting green industry principles.

The Primary Treatment process begins when wastewater enters the Collection Pond (acidic- caustic), then flows into the Reactor Tank, which homogenizes wastewater from various production sources. It then proceeds to the Second Reactor Tank, which serves as a temporary holding and monitoring station, especially for extreme pH levels caused by acidic or alkaline substances used in production. The third stage is the Coagulation Tank, where fine suspended particles such as residual raw materials, organic matter, and colloids are destabilized and aggregated into larger clumps by using 12 sacks (50 kg) of alum, dissolved in 6,000 liters of water, and injected into the system at a flow rate of 250 liters/hour. This is followed by rapid mixing at high speed (150- 300 RPM) for 1-3 minutes to ensure uniform distribution of the coagulant.

Next, the wastewater enters the Flocculation Tank, where slow mixing (20-50 RPM) for 15- 30 minutes allows unstable particles to form larger, more stable flocs (0.1-5 mm). An anionic polymer (0.8 kg/hr), diluted with 600-1200 liters of water at a concentration of 0.3%, is added to strengthen floc formation. The treated water then flows to the Purification Tank, where gravity settling separates the flocs from the clear filtrate. The Treated Water Tank collects the clarified water, which is reused in the ammonia scrubber and for NPK fertilizer production. This tank helps regulate water quality and ensures that key parameters and chemical residues meet reuse or discharge standards. Finally, the remaining sludge is directed to the Thickener Tank, which reduces the volume of sludge by 70-85%, stabilizes the characteristics, and allows recycling of process water reducing freshwater consumption by 80%.

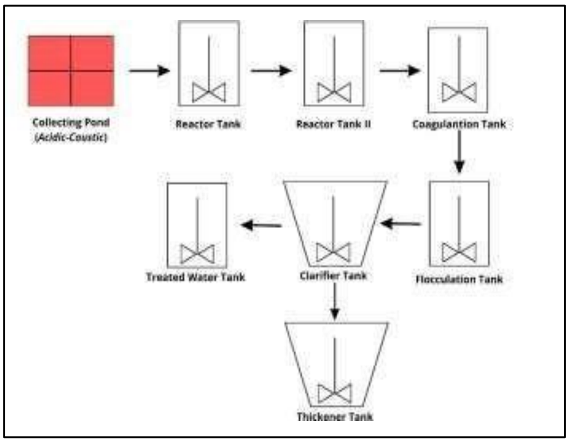

Figure 1. Primary Treatment Flow at PT Petrokimia Gresik
Source: Secondary Data, 2025

Characteristics of PT Petrokimia Gresik Liquid Effluent

The phosphate parameter (PO_4) is the main indicator in evaluating the quality and level of wastewater pollution at PT Petrokimia Gresik. Laboratory scale testing was carried out at two main points in the treatment process, namely the Collection Pond (acidic-caustic) and the Reactor Tank. Sampling and measurement were carried out for three separate days on May 21, May 27, and June 5, 2025 to observe fluctuations in phosphate levels and determine possible correlations with production activities.

Tabel 1.
Laboratory Test Results of Liquid Waste Characteristics at PT Petrokimia Gresik

Unit	Parameter	Sample			Average (mg/L)
		1	2	3	
Collecting Pond	PO_4	5,117	7,850	5,300	6,089
Reactor Tank		5,000	6,450	9,840	7,097
Clarifier Tank		8,100	7,000	1,000	5,367
Treated Water Tank		7,955	1,138	1,000	3,364.33

Primary Data Source 2025

In the Collecting Pond, phosphate levels showed significant variations. The highest concentration reached 7,850 mg/L, indicating a sharp increase in phosphate effluent likely related to the surge in fertilizer production. The sampling average PO_4 level was 6,089 mg/L, exceeding the typical discharge limit and indicating a considerable phosphate load in the untreated wastewater.

Within the Reactor Tank, phosphate levels also increased, peaking at 9,840 mg/L which was the highest value recorded across all units. This sharp increase is consistent with the observation of reddish colored wastewater, which is usually associated with high phosphate concentrations. The average PO_4 level in the reactor tanks was 7,097 mg/L, further emphasizing the need for effective phosphorus removal technology in the treatment system.

The consistently high phosphate concentrations in both treatment units indicate a critical challenge in the wastewater treatment process. These results highlight the need to optimize phosphorus removal strategies and closely monitor production cycles that cause PO_4 discharge spikes. In evaluating phosphate (PO_4) concentrations at different stages of wastewater treatment at PT Petrokimia Gresik, laboratory data showed dynamic fluctuations reflecting the performance of each treatment unit in reducing phosphate. The Clarifier tank showed significant variations in phosphate concentration over the three-day monitoring period. PO_4 levels peaked at 8,100 mg/L, then dropped to 7,000 mg/L, and dropped substantially to 1,000 mg/L. This pattern indicates that the Clarifier Tank plays an important role in the initial reduction of phosphate from the raw wastewater, which results in an average PO_4 level of 5,367 mg/L. This decrease indicates that the chemical and physical treatment in this unit effectively breaks down or precipitates phosphate compounds.

In the Treated Water Tank, which handles the post-clarified effluent, the phosphate concentration showed a significant downward trend. From a high of 7,955 mg/L, the level dropped drastically to 1,138 mg/L, and further decreased to 1,000 mg/L, with an overall average of 3,364.33 mg/L. These results confirm the effectiveness of tertiary treatment in polishing the effluent and further removing phosphate before reuse or discharge. The consistency observed in the final measurement reinforces the system's ability to maintain phosphate levels close to the regulatory threshold.

Other treatment units such as Reactor Tank II, Coagulation Tank, Flocculation Tank, and Thickener Tank do not include PO_4 in their scope of laboratory analysis; therefore, they are not included in this summary. The observed reduction in phosphate levels from the Clarifier Tank to the Treated Water Tank indicates that PT Petrokimia Gresik's wastewater treatment infrastructure demonstrates effective phosphate reduction performance and is aligned with environmental compliance objectives.

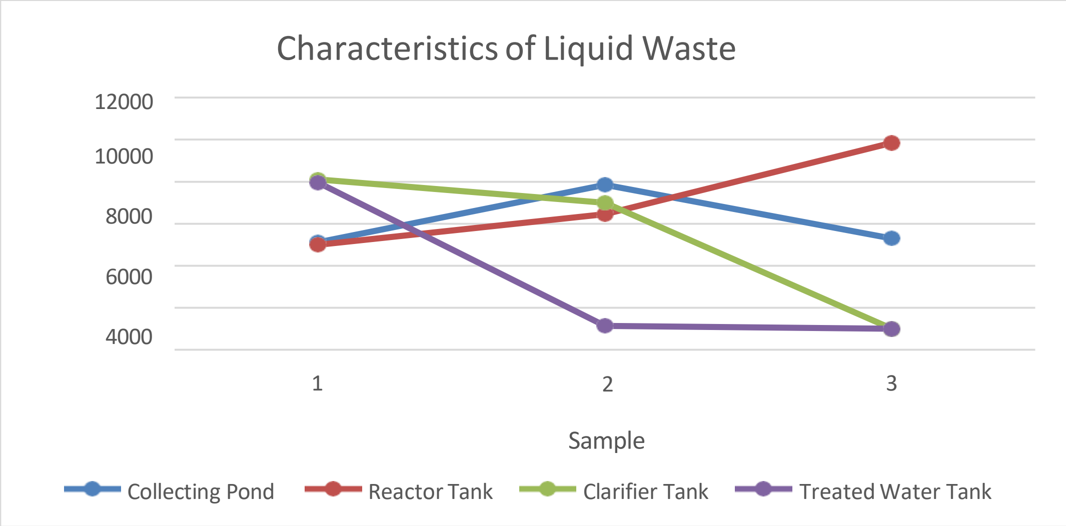

Figure 2. Measurement Graph of PO_4 in units (a) Collecting Pond, (b) Reactor Tank, (c) Clarifier Tank, and (d) Treated Water Tank

Performance of PT Petrokimia Gresik WWTP

The performance of the wastewater treatment plant (WWTP) at PT Petrokimia Gresik was evaluated by calculating the removal efficiency of key parameters compared to the established design criteria. The removal efficiency of phosphate (PO_4) in various treatment units shows significant insight into the effectiveness of the system and areas that need to be improved.

Table 2.

Calculation Results of PT Petrokimia Gresik WWTP Performance

Unit	Parameter	Standard Efficiency (%)	Inlet (mg/L)	Outlet (mg/L)	Removal Efficiency (%)	Performance
Collecting Pond	PO_4	10-20	5,117	4,264	16.7	Meets Standard
			7,850	3,925	50.0	Meets Standard
			5,300	4,200	20.75	Meets Standard
Reactor Tank			5,000	4,988	0.24	Below Standard
			6,450	3,548	45.0	Meets Standard
			9,840	8,200	16.7	Meets Standard
Clarifier Tank			8,100	7,430	8.3	Below Standard
			7,000	1,100	84.3	Meets Standard
			1,000	753	25.0	Meets Standard
Treated Water Tank			7,955	6,657	16.3	Meets Standard
			1,138	910	20.0	Meets Standard
			1,067	800	25.0	Meets Standard

Primary Data Source 2025

At the initial treatment stage, the Collection Pond. Removal efficiencies ranged from 16.7% to 50% and 20.75%, all meeting the Metcalf & Eddy (2003) standard range of 10-20%. This indicates consistent phosphate attenuation during the initial neutralization process, with the highest removal observed on 27 May at 50%.

The phosphate removal efficiency in the Reactor Tank showed more variability, with very low removal (0.24%), a sharp increase to 45%, and a decrease to 16.7%. Only the last two met the 10-20% standard. These inconsistencies reflect operational fluctuations in aeration and nutrient degradation.

The Clarifier tank showed variable phosphate removal efficiency. The removal was insufficient at 8.3%, but significantly improved to 84.3% and maintained acceptable performance at 25%, both meeting the standard.

In the final treatment stage, the phosphate removal efficiency ranged from 16.3% to 20% and 25%, which consistently met the standard. These results confirmed the ability of the Treated Water Tank to maintain phosphate concentrations within regulatory limits before reuse or discharge.

Discussion

Characteristics of Phosphate (PO_4) Load Analysis of Wastewater

The wastewater profile at PT Petrokimia Gresik reflects the characteristics of petrochemical effluents in general, with a very high phosphate (PO_4) concentration, averaging 6,184.22 mg/L, which significantly exceeds the limit permitted by the Minister of Environment Regulation No. 5 Year 2014. Such high phosphate levels pose an acute environmental threat, especially the risk of eutrophication in the receiving water bodies. Excess phosphate in the effluent catalyzes uncontrolled algae growth, which consequently depletes dissolved oxygen and disrupts aquatic ecosystems. These conditions underscore the urgency for robust phosphate-specific treatment interventions.

Given these concentrations, conventional treatment processes that rely on physical sedimentation are not sufficient. Advanced chemical precipitation using calcium hydroxide ($Ca(OH)_2$) has been widely documented as an effective way to form insoluble calcium phosphate compounds, which can be removed through sedimentation. Furthermore, coagulation-flocculation processes using polyaluminum chloride (PAC) and polymer aids have shown synergistic effects in binding phosphate ions and improving sedimentation efficiency.

High PO_4 concentrations also contribute to the overall Chemical Oxygen Demand (COD), as some inorganic reducing agents affect COD readings. The average hydraulic retention time (HRT) of each unit becomes very important, as phosphate removal is time-sensitive and influenced by the duration of contact with the coagulant and pH stabilizer. Optimization of pH is critical, as studies by Ma et al. (2020) and Ilhan et al. (2023) showed that phosphate solubility and metal complexation behavior are pH-dependent. These findings highlight the importance of designing an integrated treatment system where chemical dosing, pH control, and reaction time are harmonized to achieve optimal phosphate reduction prior to effluent discharge.

WWTP Performance Overview

In the Collection Pond, the phosphate (PO_4) removal performance was inconsistent with efficiency below the standard even though the 6-hour retention time met SNI 8066:2020. The phosphate concentration remained high in the outflow due to the absence of coagulant and reliance on ineffective natural neutralization. As supported by Camelo et al. (2024), influent variability greatly affects the effectiveness of this stage without responsive treatment dosing.

In the Reactor Tank the phosphate removal efficiency varied between 0.24% and 45%, with only one test reaching the 20-50% standard. The retention time of 1.5 hours was too short for optimal settling. The system requires automatic dosing and pH-adjusted coagulant application. Studies show that real-time control of pH and nutrient balance is essential for effective phosphate reduction (Filho & Rossas, 2020).

In the Coagulation-Flocculation Tank, although not directly monitored for PO_4, this unit plays an important role with a retention time of 18 minutes. The combination of PAC and cationic polymers can achieve 75% efficiency (Gholami et al., 2020), but current performance shows suboptimal dosing. The study recommended 450 mg/L PAC and 1.5 mg/L polymer at pH 7-7.5 (Badawi et al., 2024).

The Clarifier Tank showed moderate efficiency with an increase from 8.3% to 25%. The 2- hour residence time was designed for sedimentation, not chemical removal. Scientific works (Bai et al., 2010; Macherzyński et al., 2023) state that coagulants such as $FeCl_3$ or $Al_2(SO_4)_3$ are needed to convert dissolved phosphate into sediment.

In the Treated Water Tank functioning as a final buffer with a residence time of 30 minutes, the efficiency increased from 16.3% to 25%. Residual phosphate levels are often above the threshold. To reach the standard and enable reuse, technologies such as multi-parameter optical sensors and zeta potential probes are recommended (Batista et al., 2023). Increasing the volume from 12 m^3 to 20 m^3 will provide better phosphate stabilization, as suggested, will provide longer residence time and better phosphate stabilization, ensuring compliance with environmental discharge regulations and improving the sustainability of water reuse initiatives at PT Petrokimia Gresik.

CONCLUSION

Based on the research findings, several conclusions can be drawn. First, the measurement results of PO_4 levels in various wastewater treatment units, namely the Holding Pond, Reactor Tank, Purification Tank, and Processed Water Tank, indicate that the removal efficiency is not optimal, especially for phosphate. This indicates that the treatment process has not fully met the set environmental quality standards. Secondly, the Flocculation Tank remained outside the optimum range for the treated effluent, necessitating a comprehensive review of the mixing regime and dosing strategy of the chemicals used in this unit.

In addition, the removal efficiency, hydraulic retention time and coagulant dosing accuracy have not consistently met the desired targets. Although the retention time in the reactor is adequate, the insufficient reduction in pollutant concentrations requires a critical reassessment of the WWTP system design and operational parameters. Lastly, the reuse of treated wastewater, especially with regard to phosphate and total solids that are still at high levels has been implemented in the fertilizer production process. This practice is in line with the guidelines set out in Government Regulation No. 22 of 2021, which supports the industrial sector's sustainable development goals. Collectively, these insights underscore the need for process optimization to achieve regulatory compliance and enhance environmental sustainability.

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