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Infrastructure For The Treatment Of Pharmaceutical Industry Waste As A Prevention Of Environmental Pollution

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Abstract—
The pharmaceutical industry's activities produce medications that are invaluable to human health. However, the production of these medications results in liquid wastae that poses a threat to the sustainability of living organisms. Consequently, it is imperative to treat this waste to prevent environmental contamination. This study is an experimental implementation of a design for pharmaceutical industry waste treatment infrastructure. Waste from the industry undergoes treatment through engineered wastewater treatment plant (WWTP) process flows and the addition of specific formulas, subsequently collected in ponds. The treated pharmaceutical waste is then laboratory-tested to determine the quality of the pharmaceutical industry's wastewater. Specific wastewater measurements, such as temperature, Total Suspended Solids, pH, COD, and BOD, are aligned with the liquid quality standards set by the Indonesian Ministry of Environment Regulation Number 5 of 2014 concerning Quality Standards for Wastewater in Pharmaceutical Activities. The results demonstrate that the engineered WWTP process flow infrastructure for pharmaceutical industry waste from this experimental study effectively treats the waste and meets the established wastewater quality standards for pharmaceuticals in Indonesia. It is hoped that this design for pharmaceutical industry waste treatment infrastructure can be implemented comprehensively within pharmaceutical industries across Indonesia and on an international scale.

Keywords*— waste treatment, WWTP process, industrial waste, pharmaceutical industry, environmental pollution.*

I. INTRODUCTION

The pharmaceutical industry plays a pivotal role in producing essential medications for human health [1]. Yet, this beneficial production process does not come without environmental implications [2]. One significant, often overlooked, repercussion is the generation of aqueous waste from pharmaceutical industrial activities [3]. If not adequately managed, this waste poses substantial threats to the livelihood of aquatic organisms and the balance of ecosystems [4]. Despite the profound benefits conferred by the medications produced, the industry's responsibility towards the environment is undeniable.
Amid increasing environmental awareness and stringent regulatory demands, especially as stipulated in the Minister of Environmental Regulation No. 5 of 2014 [5], the pharmaceutical industry faces an imperative need to innovate and implement effective

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wastewater treatment infrastructures [6]. This necessity transcends regulatory and ethical standpoints, extending into the domain of long-term business sustainability. Consequently, research into the design and deployment of pharmaceutical wastewater treatment infrastructure has become both timely and pressing.

Pharmaceutical wastewater poses multifaceted risks to ecosystems [7]. Numerous chemicals employed in pharmaceutical production can be toxic to aquatic organisms [8]. Contaminants, such as antibiotics, hormones, and other chemicals, can alter the physiology and behavior of aquatic species [9]. They can change species compositions in ecosystems, affect food chains, and result in biodiversity loss [10]. Antibiotic-containing waste can lead to environmental bacterial strains becoming resistant, subsequently affecting human and animal health by propagating hard-to-treat bacterial strains [11]. Certain wastewater chemicals can affect aquatic plant growth, subsequently disrupting ecosystems and the food supply for other species [12]. Many pharmaceuticals can disrupt organisms' endocrine systems, impacting reproduction, growth, and behavior [13].

Some pharmaceutical waste components might be bioaccumulative, meaning they accumulate within organism tissues over time, raising the risk of toxic effects in the food chain [14]. Pharmaceutical wastewater might also contain nutrients like phosphorus and nitrogen, which, when released into waters, can stimulate algal overgrowth, leading to aquatic organism deaths due to oxygen deficiency [4], [15]. Poorly managed pharmaceutical wastewater can pollute drinking water sources, impacting both human health and dependent ecosystems [16]. Components in pharmaceutical wastewater may interact with other pollutants, creating new compounds with unknown potential hazards [17]. The effects of pharmaceutical wastewater might not be immediately apparent and may manifest over prolonged periods, presenting long-term challenges for ecosystem balance [18].

Against the backdrop of these challenges posed by pharmaceutical wastewater, this research becomes paramount. Specifically focusing on pharmaceutical waste generated from the production of drugs like asam mefenamat mersifarma 500 mg, asimat 500 mg, miniaspi (acetylsalicylic acid) 80 mg, glidanil (glibenclamide) 5 mg, kutoin (phenytoin) 100 mg, versilon 6 mg, mersibion 5000, and aldomer 5 mg.

The study's objective is to understand the risks and impacts of wastewater generated by the pharmaceutical industry on the environment and ecosystems. It aims to develop and design an efficient wastewater treatment infrastructure for the pharmaceutical sector, emphasizing waste treatment process engineering and specialized formula addition. Laboratory tests will be conducted on treated wastewater to determine its quality, comparing it against standards set by the Minister of Environmental Regulation No. 5 of 2014 [19], [20].

Anticipated benefits of this research include offering deep insights into the adverse impacts of pharmaceutical wastewater on the environment, thus enabling the industry and regulators to make better-informed decisions [21]. Through an effective wastewater treatment design, the pharmaceutical industry can minimize its environmental footprint while continually producing essential medicines for human health. Effective wastewater treatment would yield better water quality, reducing pollution risks to water sources and their subsequent impacts on aquatic ecosystems and human health [22].

This research's contribution is expected to provide recommendations, informed by the study's results, for revising or enhancing wastewater regulations for the pharmaceutical sector in Indonesia. It aims to catalyze the adoption of the developed wastewater treatment infrastructure design across the Indonesian pharmaceutical industry and, if feasible, at the international level [23]. The research outcomes can serve as references for policymakers in revising or establishing new standards concerning pharmaceutical industry wastewater treatment [24].

II. METHODOLOGY

A. Research Approach

In this study, a mixed-methods approach, combining both quantitative and qualitative methods, was adopted [25]. The quantitative approach was utilized to measure specific wastewater parameters at each processing stage, while the qualitative method was employed to evaluate and interpret water quality, as well as to identify types of bacteria and chemicals present [26].

B. Wastewater Treatment Infrastructure

- Screen Chamber: This is the initial unit designed to filter out coarse solid wastes such as paper, plastic, sanitary pads, among others, from the preliminary wastewater [25].
- Grease Trap: Utilized to segregate fats or oils and to sediment solid contaminants that are non-biodegradable [27].
- Isolation Tank for Penicillin Wastewater: Wastewater from penicillin is directed to this unit to break down the beta-lactam ring using a NaOH solution [28].
- Equalization Tank: All wastewater, including that which has been processed in the isolation tank, is channeled and homogenized here with a retention time between 12-24 hours [29].
- Neutralization Unit: This unit modulates the pH of wastewater to a range of 7-8 by introducing either HCI or NaOH as required [29].
- Chemical Sedimentation Unit and Break Tank: Sedimentation processes occur before the wastewater is temporarily stored in the break tank [29].
- Filtration: The wastewater undergoes a filtration process through a sand filter and carbon filter.

  Outlet/Fishpond Tank: This is the final unit where treated wastewater, compliant with quality standards, is discharged into water bodies [22].

C. Sample Collection and Laboratory Testing

- First Test (Pond No. 1 - Penicillin Isolation): Samples are drawn to gauge the water's pH, and interventions are conducted to reduce the pH until the beta-lactam ring is isolated.
- Second Test: Here, the primary aim is to identify types of bacteria and chemicals in the waste. Quantitative parameters measured include TSS, pH, COD, and BOD.

  Third Test (Outlet Pond): Before redirecting wastewater to water bodies, samples are taken to ensure the water quality meets established standards [30].

D. Data Analysis

- Quantitative Analysis: Data obtained from laboratory tests are analyzed to assess the efficacy of each wastewater treatment phase and to compare with the established standards.
- Qualitative Analysis: Laboratory data is interpreted to evaluate water quality and identify present bacteria types and chemicals.

Based on the outcomes from both quantitative and qualitative analyses, this research will provide recommendations on the efficacy of the wastewater treatment infrastructure and suggestions for improvements to attain optimal wastewater quality [31].

III. RESULTS AND DISCUSSION

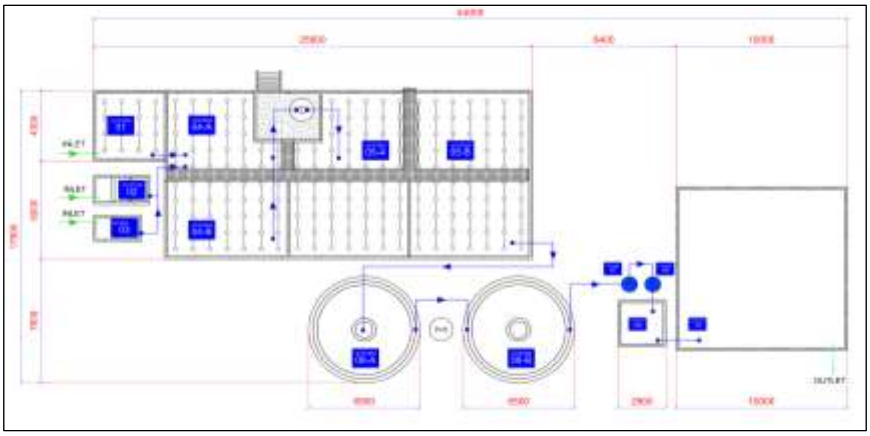
A. Wastewater Treatment Infrastructure Design

Pharmaceutical industry waste encompasses not only organic and inorganic compounds but also various active pharmaceutical ingredients, antibacterial agents, and other compounds that can be toxic to the environment. The environmental impact of such waste, particularly when discarded without adequate treatment, can harm aquatic ecosystems, influence groundwater quality, and pose risks to human health and aquatic life [32].

Given the complexity and diversity of pharmaceutical waste, conventional waste treatment solutions may not suffice. This underlines the necessity to design a specialized wastewater treatment infrastructure capable of addressing the unique challenges posed by pharmaceutical waste and ensuring the discharged water meets stringent environmental standards [33].

In the pharmaceutical industry, there are five waste categories: 1) beta-lactam production waste; 2) non-beta-lactam production waste; 3) domestic waste; 4) septic tank waste; 5)

hazardous waste (B3) [34]. Out of these five waste categories, only the hazardous waste (B3) should not be processed using wastewater treatment plants [35].
In the context of the pharmaceutical industry, the need for a comprehensive wastewater treatment infrastructure is indispensable. The diverse waste from this sector demands a detailed and systematic solution. Through this research, a wastewater treatment infrastructure layout design has been produced to ensure that each treatment stage operates optimally and efficiently [31].
Based on monitoring results and observations from the pharmaceutical industry producing drugs such as Mersifarma Mefenamic Acid 500 mg, Asimat 500 mg, Miniaspi (acetylsalicylic acid) 80 mg, Glidanil (glibenclamide) 5 mg, Kutoin (phenytoin) 100 mg, Versilon 6 mg, Mersibion 5000, and Aldomer 5 mg, the wastewater treatment infrastructure design requires a screen chamber, grease trap, isolation tank for penicillin wastewater, equalization tank, neutralization unit, chemical sedimentation and break tank units, filtration, and an outlet/fishpond tank [32]. The implementation of the aforementioned requirements is illustrated in Figure 1.



Pharmaceutical industry wastewater treatment infrastructure layout The screen chamber serves as the initial entry point for wastewater, ensuring that large solid particles and other foreign objects do not interfere with subsequent processes. Without this step, there's an increased risk of equipment damage or blockages.

The grease trap addresses the need to segregate fat and oil contents. Excessive presence of fats can inhibit subsequent biological and chemical processes, making it crucial to separate them at an early stage.

The subsequent stages, ranging from the isolation of penicillin wastewater to the outlet/fishpond tank, combine a variety of treatment technologies and methodologies to ensure that specific contaminants are effectively targeted and removed [36].

The details of the layout design in Figure 1 are further elaborated upon in Figure 2.

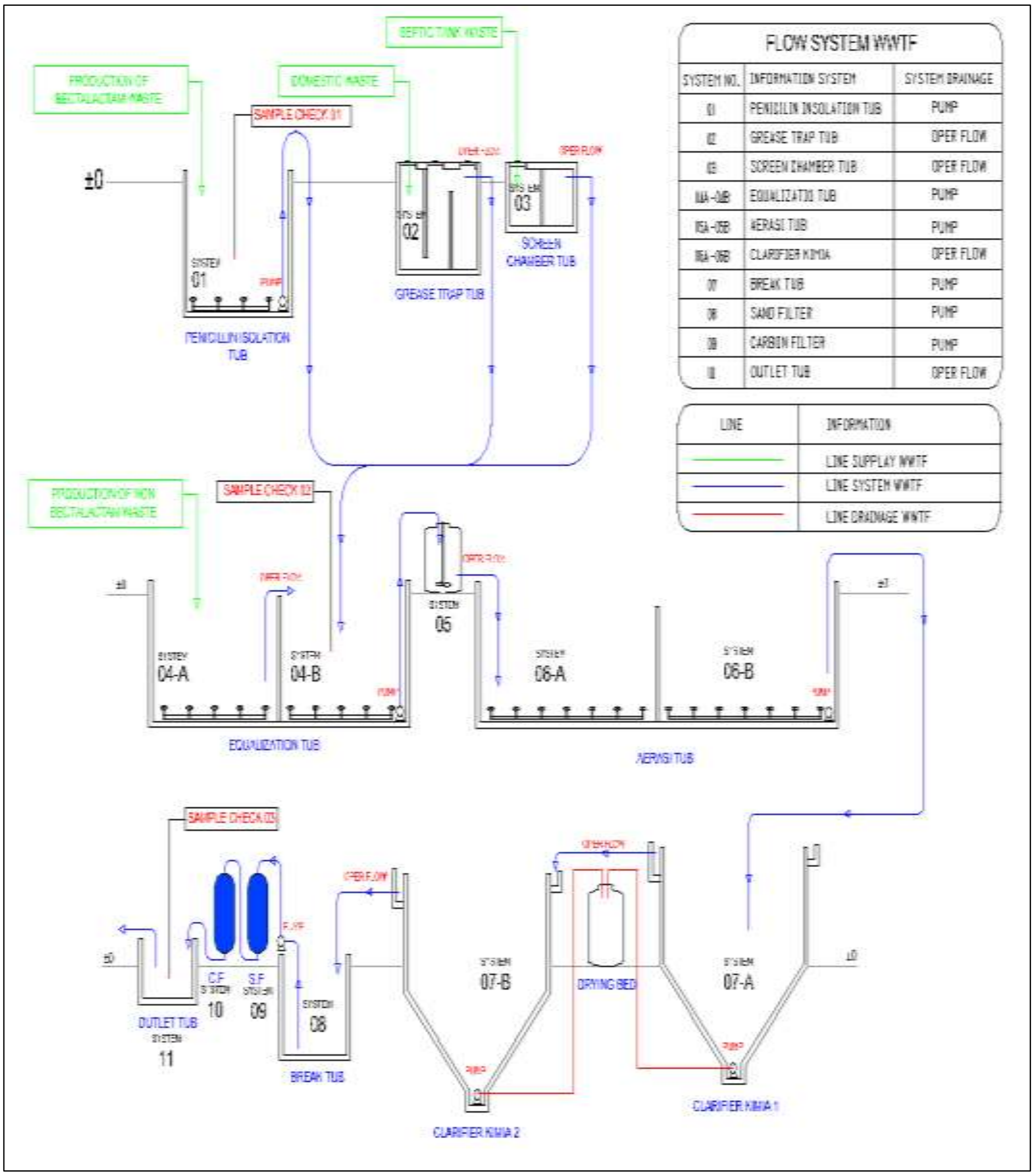


Fig. 1. Scematic diagram of wwtp waste

Through a comprehensive treatment process, this infrastructure design reflects a systematic approach focused on end-product quality and operational sustainability [37]. Each component of this design functions harmoniously with others, creating a balanced and effective system. The wastewater treatment process flow is illustrated in Figure 3.

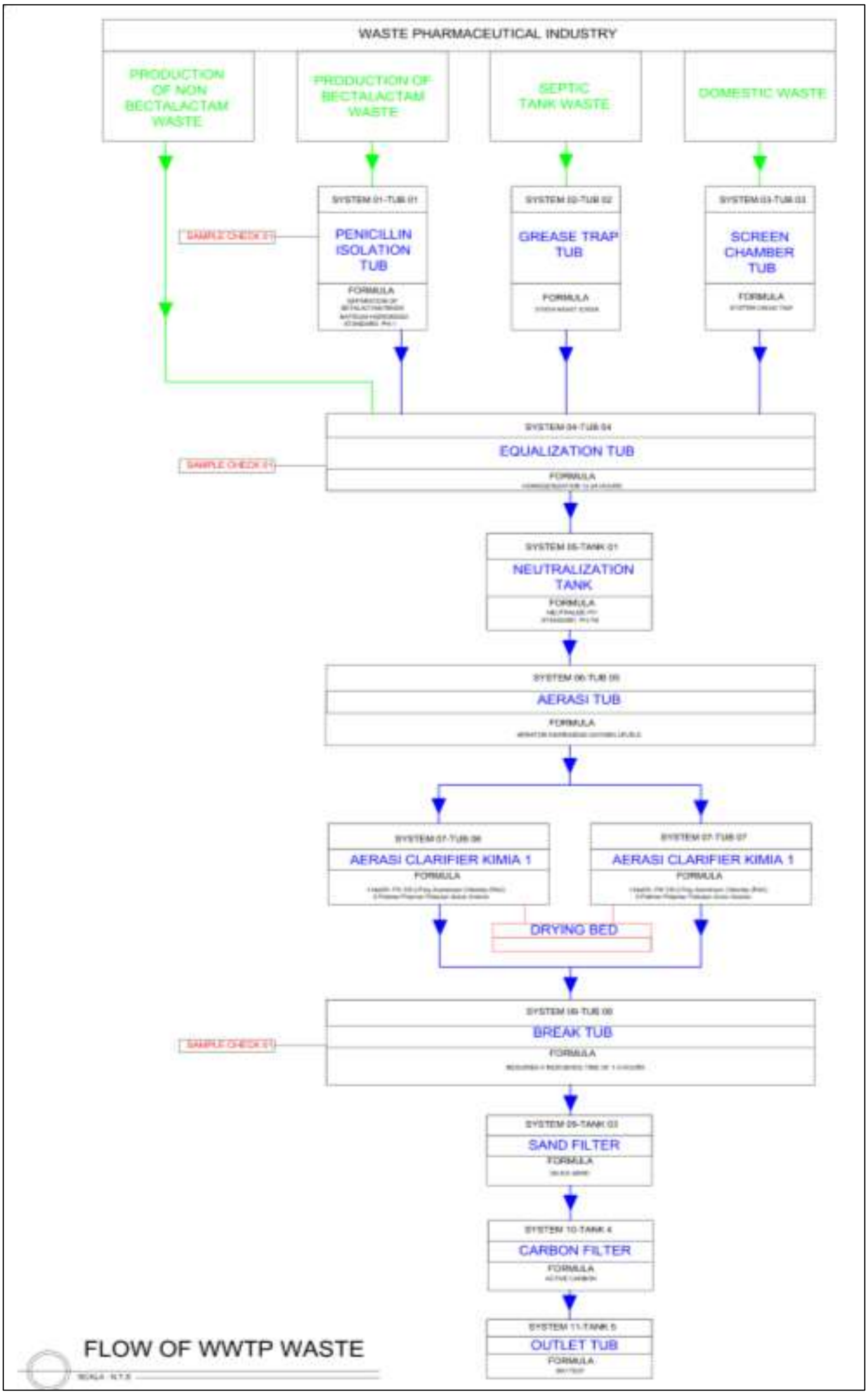


Fig. 2. Flow of WWTP waste

The flow of the waste treatment process through WWTP in this study is shown in Figure 3 as follows:

- The initial treatment utilizes the penicillin isolation tank (containing beta-lactam). The wastewater is directed to the beta-lactam ring destruction tank (isolation tank) using a NaOH solution until the pH reaches 1. Subsequently, it is channeled/combined with non-beta-lactam wastewater in the equalization tank [38].

- The secondary treatment features the screen chamber/the first stage of domestic wastewater treatment. The chamber uses a basket-type screen, functioning as a filter for coarse solid wastes such as tissue paper, plastics, sanitary pads, etc., present in the initial wastewater, before entering the equalization tank. The grease trap is the primary treatment stage for wastewater from septic tanks/canteens. This trap or fat separator is designed to separate fats or oils originating from kitchen activities and to sediment impurities like sand, soil, or non-biodegradable solids [39].
- After the aforementioned three processes, wastewater from non-beta-lactam production and domestic sources are directed to the equalization tank along with the beta-lactam wastewater, which has previously been treated in the isolation tank. Here, all types of wastewater are homogenized with a retention time between 12-24 hours.
- After complete homogenization in the equalization tank, the wastewater is directed to the neutralization tank to adjust the pH before moving on to subsequent processes. The desired pH standard for the subsequent processes is between 7-8. HCI is added if the pH exceeds the set standard, and NaOH is added if the pH is below the standard. The neutralization unit requires a processing time of 5-7 minutes.
- Post-processing in the coagulation and flocculation unit, the wastewater is then directed to the chemical sedimentation tank for settling. Here, a separation occurs between water and sludge. The water will undergo the next process using Poly Aluminium Chloride (PAC) and Anionic Flocculant Polymer, whereas the resulting chemical sedimented sludge is directed to the sludge treatment unit (drying bed).
- Subsequently, after sedimentation in the chemical sedimentation unit, wastewater is directed to the break tank. The process within this unit requires a retention time between 1-3 hours. The processed wastewater is temporarily stored here before undergoing filtration through a sand filter (silica sand) and a carbon filter (activated carbon). The filtration process demands a retention time of 10-15 minutes.
- After undergoing filtration, the processed wastewater is directed to the outlet/fishpond. This is the final unit in the treatment process, and once the wastewater meets the set quality standards, it is discharged into a water body.

B. Final Wastewater Sample Laboratory Testing

To measure the success of the pharmaceutical wastewater treatment infrastructure design, laboratory tests are essential to evaluate water quality parameters, including temperature, Total Suspended Solids (TSS), pH, COD, and BOD. This assessment adheres to the standards set by the Minister of Environment Regulation Number 5 of 2014 on Quality Standards for Wastewater in Pharmaceutical Activities.

During the wastewater treatment process, besides relying on infrastructure, specific chemical additives are necessary to neutralize harmful chemicals. The chemicals incorporated comprise NaOH, Poly Aluminium Chloride (PAC), and Anionic Flocculant Polymer.

NaOH functions as a pH reducer and a beta-lactam ring breaker. Poly Aluminium Chloride (PAC) serves as a separator between water and sludge, acting as a chemical coagulant. The Anionic Flocculant Polymer accelerates the formation of flocs from dissolved ions in the water.

Based on the Minister of Environment Regulation Number 5 of 2014 on Quality Standards for Wastewater in Pharmaceutical Activities [40], the standards are detailed in Table I.

TABLE I. QUALITY STANDARDS FOR WASTEWATER IN PHARMACEUTICAL ACTIVITIES

Parameter	**Formula Material Manufacturing Process (mg/L)**	**Formula (Mixed) (mg/L)**
BOD_5	100	75
COD	300	150

TSS	100	75
Total Nitrogen	30	-
Fenol	1,0	-
pH	6,0 – 9.0	6,0 – 9,0

BOD5 represents the amount of oxygen required by bacteria to oxidize nearly all dissolved organic substances and some suspended materials in water. The quality of wastewater is indicated by the types of dissolved substances. According to the standard, BOD5 should be <100 mg/L.

COD (Chemical Oxygen Demand) is a measurement of the oxygen equivalent of both organic and inorganic substances in a water sample that can be oxidized by strong oxidizing agents, such as bichromate. Based on the standard, the COD value should be <200 mg/L.
Potential of Hydrogen (pH) is a measure of acidity or alkalinity used to indicate the level of acidity or alkalinity of a solution. According to the standard, the pH value should range between 6.0 and 9.0.

After the pharmaceutical industry wastewater is treated, it is then subjected to laboratory testing, with the results presented in Table II.

TABLE II. QUALITY STANDARDS OF TREATED PHARMACEUTICAL ACTIVITY WASTEWATER

Test Description	Result	Formula Ingredients Manufacturing Process	Mixing Formulation	Unit
Physical Properties				
Temprature	25.3			°C
TSS	5	100	75	mg/L
Chemical Properties				
pH	7.08	6.0-9.0	6.0-9.0	pH unit
COD	8	300	150	mg/L
BOD_5	2	100	75	mg/L

Based on laboratory test results, it was demonstrated that the treatment of pharmaceutical industry wastewater using the infrastructure design proposed in this study, supplemented with chemicals such as NaOH, Poly Aluminum Chloride (PAC), and Anionic Flocculant Polymers, was effective in improving wastewater quality. This is evidenced by the pH value of 7.08, which lies between 6.0-9.0, indicating compliance with wastewater quality standards. The COD value of <150 and the BOD5 value of <100 both also signify adherence to the wastewater quality standards, as elaborated in Table II.
In summary, after treatment using the proposed infrastructure design and chemical additions from this study, the pharmaceutical industry wastewater met the standard quality criteria, ensuring that it does not contaminate the environment.

IV. CONCLUSION

Concerns about the environmental hazards posed by pharmaceutical industry waste have now been addressed through the development of a wastewater treatment infrastructure as designed in this study. This waste treatment design involves streamlining the wastewater treatment process and the addition of chemicals like NaOH, Poly Aluminium Chloride (PAC), and Anionic Flocculant Polymers to the waste. The treatment outcomes have significantly enhanced water quality, with TSS values at 5, pH at 7.08, BOD5 at 2, and COD at 8. Overall, these results meet the standard water quality criteria as specified by the Ministry of Environment Regulation Number 5 of 2014 concerning Wastewater Quality Standards for Pharmaceutical Activities. It is hoped that the findings of this study can be implemented in industries whose production generates hazardous liquid waste. Further, it is essential for policymakers to enforce these wastewater treatment standards for the industry. Continued research is necessary to determine the costs associated with the development of this industrial wastewater treatment infrastructure.

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