OPTIMIZATION OF GAMBIER INDUSTRY WASTEWATER TREATMENT PLANT (WWTP) PERFORMANCE: A SYSTEMATIC APPROACH FOR ENVIRONMENTAL SUSTAINABILITY

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***Abstract**. The gambier industry in West Sumatra, particularly in Payakumbuh, is Indonesia's largest producer of gambier, contributing approximately 80-90% of the national production. This high production rate results in increased waste generated during the production process. This article discusses the potential environmental pollution from wastewater from the gambier industry and efforts to address this issue. The study notes that coagulation-flocculation and adsorption methods have efficiently treated textile industry wastewater. The study discusses the Wastewater Treatment Plant (WWTP) conditions in the gambier processing industry before optimization and the steps taken to improve its performance. Additionally, the study analyzes wastewater characteristics before and after treatment. The results of this study indicate that adding aerators and pH-adjusting agents to the WWTP can improve wastewater treatment performance, resulting in effluent that meets the quality standards set by government regulations. Moreover, treating wastewater with adding Poly Aluminium Chloride (PAC) reduces COD and BOD, indicating the degradation of organic components in gambier waste. COD removal efficiency is 92.65%, and BOD removal efficiency is 58.01%. This optimization results in an improved quality of gambier industry wastewater, reducing its negative environmental impact. These efforts are crucial to meet environmental regulatory standards established by the Indonesian government.*
***Keywords:** wastewater; WWTP; gambier; COD; BOD.*

1. Introduction

West Sumatra, known as the largest producer of gambier, plays a pivotal role in contributing to this thriving industry. Approximately 80-90% of national production comes from West Sumatra (Irwan *et al.*, 2022). One of the prominent centers of this region's gambier industry is in Payakumbuh. However, the prodigious output of gambier processing in Payakumbuh, churning out an impressive 9,000 – 10,800 tons per year and generating gambier extract at an astounding capacity of 75,662 tons permonth or 907,944 tons per year is not without its challenges.

The accelerated production rates fuel economic growth and raise a mounting issue – the escalating volume of waste generated during the gambier production process. When viewed globally, this environmental concern aligns with the broader aspirations of the United Nations' Sustainable Development Goal (SDG) 6. SDG 6 underscores the need for clean water and sanitation, promoting responsible water management, and ensuring access to clean water for all, which are pertinent to the context of our study.

Received November 27, 2023; Accepted April 18, 2024; Published May 28, 2024
https://doi.org/10.55043/jaast.v8i2.253

Gambier extraction, primarily geared towards obtaining tannins for the dyeing industry, generates significant wastewater. In Payakumbuh, this process results in approximately 5,600 cubic meters per day of wastewater emanating from the extraction unit. Other processes, such as evaporation and distillation, further contribute to this wastewater stream. This effluent primarily consists of brown to blackish liquid with a high chemical oxygen demand (COD) and biological oxygen demand (BOD), making effective wastewater treatment imperative.

Wastewater treatment can be done through physical, chemical, and biological methods. Adsorption, ion exchange, and membrane processes are physical methods (Abdel-Karim *et al*., 2021; Mansor *et al*., 2020; Abdullahi *et al*., 2021). Chemical methods involve coagulation, flocculation, electro-coagulation, and oxidation (Padmaja *et al*., 2020). Most wastewater treatment processes containing organic matter are carried out by biological processes involving microorganisms through aerobic and anaerobic processes (Bhat & Gogate, 2021).

For instance, coagulation-flocculation and adsorption methods have demonstrated exceptional efficiency in treating textile wastewater, achieving an average removal rate of 97.5% for COD, 98% for TSS, 98.4% for color, 86.1% for TN, and 93.5% for turbidity (Badawi & Zaher, 2021). Furthermore, membrane separation processes have gained prominence for treating industrial wastewater, offering advantages over conventional methods, including enhanced reactivity for oxidizing organic contaminants (Keskin *et al*., 2021). Advanced oxidation processes (AOPs) can be seamlessly integrated with physical methods like flotation and coagulation, thus serving as a pre-treatment strategy for improving biochemical properties and eliminating organic pollutants from wastewater (Meng *et al*., 2018; Ma *et al*., 2021; Sabelfeld *et al*., 2022; Hu *et al*., 2020).

Wastewater generated from the gambier industry contains several pollutants such as pH, Total Suspended Solid (TSS), Total Dissolved Solid (TDS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Ammonia (NH_3), Nitrate (NO_2), Nitrite (NO_3), Detergent, Oil, and Total Coliform. These parameters will cause pollution to the environment if not treated properly. Several studies have investigated the characteristics of wastewater from the gambier industries. The process to remove color in wastewater from the gambier industry was done according to the process where aluminum chloride, aluminum sulfate, ferric chloride, and ferric sulfate were used as a coagulant (Badawi & Zaher, 2021). Meanwhile, membrane technology is one of the best methods for achieving efficiency and purity of wastewater for obtaining the desired water quality for water reuse (Keskin *et al*., 2021). Another researcher investigated Multi-Soil-Layering (MSL) bioreactors for reducing pollutant parameters in textile dyeing wastewater (Sy *et al*., 2019). A separation and desalination procedure for farmland saline-alkaline water is proposed;

a separation and desalination device based on this process is also described and tested by earlier researchers. This approach aims to address issues related to soil salination, desalination of water sources, and other challenges faced by dry areas. According to the previous results, the water connected to the pretreatment device met the requirements for the composite nanofiltration (NF)-reverse osmosis (RO) membrane system to function, (Yang *et al*., 2021; Li *et al*., 2020).

The existing condition of the Wastewater Treatment Plant (WWTP) in the gambier processing industry before optimization consisted of Primary Treatment (Cooling and Evaporation Unit, Collection Unit, and Stabilization and Settling Unit), Secondary Treatment for biological treatment (Trickling Filter Unit and Aerobic Decomposer Unit), and Tertiary Treatment (Liquid and Solid Separation Unit). Based on the on-site survey, it was found that all units in the WWTP of the gambier processing industry were constructed in a closed (anaerobic) design, resulting in hot effluent temperatures (42 - 46°C), low DO values (<2), low pH (3.3 - 4.0), high COD (169.99 mg/L), and high BOD (312 mg/L). Furthermore, it was found that the aerator in the WWTP was not functioning, and no materials to neutralize the pH were added. This condition caused the decomposition process of organic compounds not to proceed as designed. It did not meet the quality standards of the Minister of Environment and Forestry Regulation No. 5 of 2014.

Given these challenges and shortcomings, optimizing the WWTP in the gambier processing industry in Payakumbuh becomes an imperative undertaking. This study is embarked upon to evaluate and optimize the performance of gambier wastewater treatment through a systematic trial-and-error approach, using a prototype WWTP to compare pollutant levels before and after treatment. This endeavor is not only of regional significance but also resonates with the global call for sustainable environmental practices outlined in the United Nations' SDG 6.

2. Materials and Methods

The wastewater samples were collected from a Gambier industry in Payakumbuh, West Sumatra, Indonesia. For optimizing design, the lab-scale wastewater treatment plant was used as a prototype to simulate the performance of the applied treatment to process gambier wastewater designed by the software AutoCAD 2021 as shown in Figure 1. The prototype size is 10% from WWTP in the Gambier Industry. Then, the design prototype was reconstructed with glass material as shown in Figure 2.

The characteristics of the sample before optimization can be seen in Table 1. Table 1 shows that the influent and effluent wastewater values of the Gambier Industry for several parameters still need to meet the quality standards that the government has set.

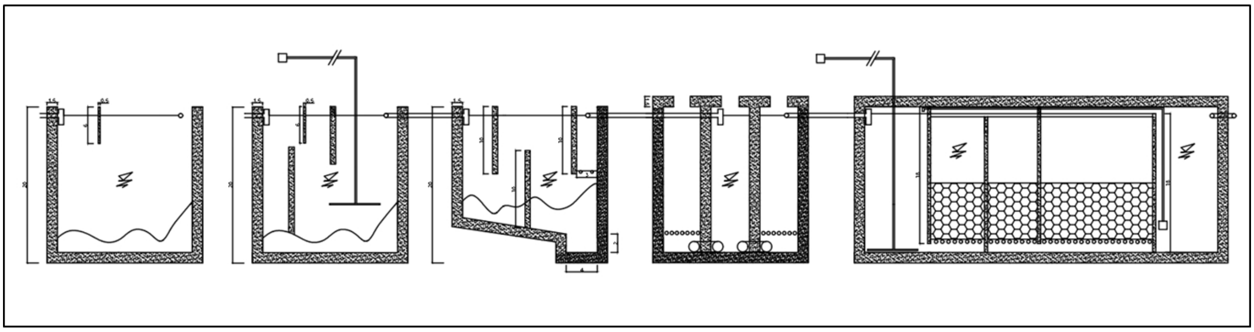

Figure 1. Prototype Design of Wastewater Treatment Plant

Figure 2. Prototype of Wastewater Treatment Plant

Table 1. Characteristics of The Gambier Industry Wastewater in Payakumbuh

Parameters	**Units**	**Analysis** *Influent*	***Effluent***	**Standard***
Colour	-	Yellow		No Colour
Temperature	˚C	60-65	50	38 - 40
TSS	mg/L	<10	12	50
TDS	mg/L	100	108	2000
pH	-	3.56	3.90	6.0 – 9.0
COD	mg/L	266.7	222.2	150
BOD	mg/L	82.30	80.30	50 - 150
Oil & Grease	mg/L	< 2	< 2	10 max
Nitrite as N	mg/L	0.110	0.064	1 max
Nitrate as N	mg/L	10.5	6.1	20 max
Ammoniac	mg/L	0.27	0.08	8 max
Total coliform	*Colony*/100 mL	< 160000	1500	10000 max

* Indonesian Government regulation LHK No. 5 Year 2014 (Menteri Lingkungan Hidup, 2014)

Two aerator units were added to the Stabilization and Settling Unit (A2) and Trickling Filter Unit (A3) for optimization of wastewater treatment Gambier Industry. After optimization, the aerator was added to the Collection Unit (A1), Stabilization and Settling Unit (A2), Trickling Filter Unit (A3), and Aerobic Decomposer Unit (A4). The process of wastewater from the Gambier Industry is carried out by using a prototype that has been optimized, continuously. Wastewater flowed at a flow rate of 37 mL/minute. Then, $CaCO_3$ 0.1% was added to the Cooling and

Evaporation Unit (1 and 2). The addition of $CaCO_3$ 0.1% functions to neutralize the pH which was acidic (3.56 – 3.90). Poly Aluminium Chloride (PAC) and biofilm were added to the Trickling Filter Unit (A3) and Aerobic Decomposer Unit (A4). Biofilm media and aerators function enhance the efficiency of wastewater treatment by increasing the surface area available for microbial growth and breaking down organic matter so existing microorganisms can break down organic substances in wastewater and precipitate components that have not been previously processed. Poly Aluminum Chloride (PAC) was added to facilitate the flocculation process, enabling the formation of flocs that can settle or adhere to the biofilm media. Effluent from the Liquid and Solid Separation Unit (A5) was analyzed based on pH value, COD, BOD, and Organic Matter Group.

pH value was Analyzed by pH meter Hana Instrument HI98107. First, the pH meter was prepared, and the wastewater sample to be tested was inserted into the beaker glass. Then, the pH meter was dipped into the unit to be tested. After that, the pH value displayed on the screen COD and BOD analyses were carried out based on the Indonesian national standards (SNI 6989.72, 2009a; SNI 6889.2, 2009b). Organic Matter Group analysis was done by Spectrophotometer Fourier Transform Infrared (FTIR) (Merk PerkinElmer Frontier) at Padang State University.

3. Results and Discussion

3.1. Potential Liquid Waste in Water Distribution Gambier Industry

Raw water for the production activities of the gambier industry is sourced from dug wells with a depth of more than 20m. The gambier industry requires raw water with a production demand capacity of around 63 m^3/day. The raw water will be used for the boiler unit, which has a capacity of 48 m^3/day, and for the cooling tower, which has a capacity of 10 m^3/day. Gambier leaves contain a moisture content of 78.4 m^3/day as raw material for production. In the production process, the boiler and cooling tower are included in the utility unit, with a total incoming water capacity of 58 m^3/day. In addition to the water from the utility unit, the water contained in gambier leaves will also enter the production activities, so the total water for gambier extract production activities is 136.4 m^3/day.

Production activities consist of evaporation, extraction, and distillation processes. Production activities will produce 58 m3/day 58 m^3/day of water, which will be collected into the condensate (F7). Water from the condensate will be reused by the boiler (F8). Wastewater is generated from the extraction process, with the amount of wastewater generated being 78.4 m^3/day (F9). Wastewater will be released within a period of 4 times in 24 hours (F10, F11, F12, and F13). About every 6 hours, wastewater amounting to 19.6 m^3/day will be treated in the WWTP (F14, F15, F16, and F17). The distribution of water usage in the gambier industry can be seen in Figure 3.

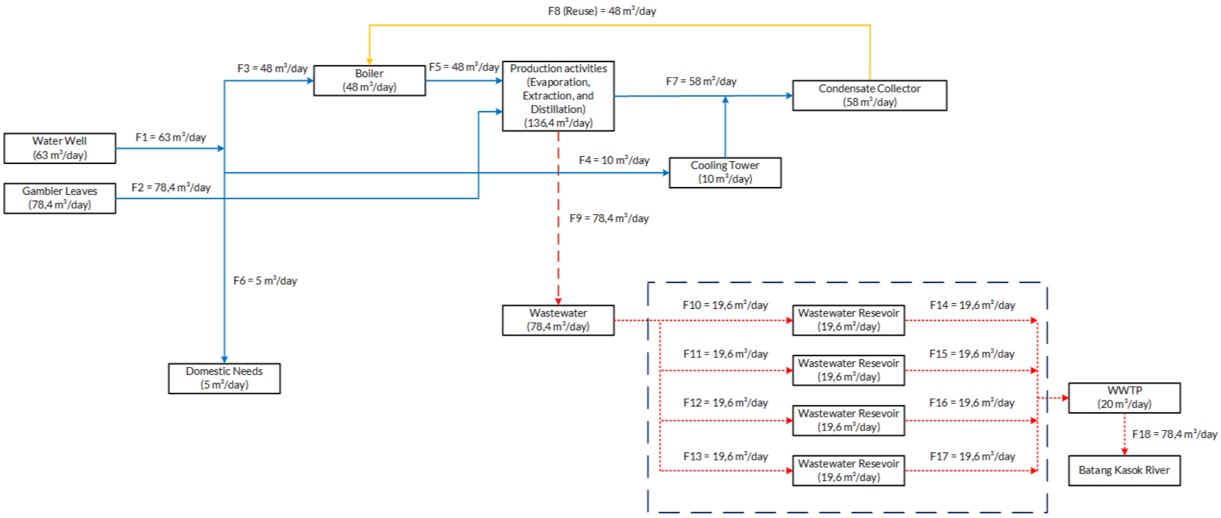

Figure 3. Distribution of Water Consumption in Gambier Industry

3.2. Optimization of Wastewater Treatment Plant (WWTP) Performance of Gambier Processing Industry

The performance of the Gambier Industry Wastewater Treatment Plant (WWTP) prototype initially did not meet the quality standards set by PERMEN LHK No.5 of 2014, where the effluent pH, COD, and BOD values were still relatively high. Aerators were placed in the Collection Unit (A1) and Aerobic Decomposition Unit (A4), respectively, as shown in Figure 4.

Figure 4. WWTP Prototype Lab Scale (Ratio 1:10) Before Optimization

Aerators were added to the Collection Unit (A1), Stabilization and Settling Unit (A2), Trickling Filter Unit (A3), and Aerobic Decomposer Unit (A4) to optimize the performance of the Gambier Industry Wastewater Treatment Plant (WWTP) as shown in Figure 5.

There was an increase in the performance of the Gambier Industry Wastewater Treatment Plant (WWTP) prototype when two aerator units were added to the Stabilization and Settling Unit (A2) and Trickling Filter Unit (A3). In addition, biofilters and quicklime were also added to optimize the performance of the Gambir Industry Wastewater Treatment Plant (WWTP). Biofilters were added to the Trickling Filter Unit (A3) and Aerobic Decomposition Unit (A4). In addition, quicklime to neutralize the influent pH was added to the Cooling and Evaporation Units (1 and 2). The improved performance of the Gambier Industry Wastewater Treatment Plant (WWTP) can be evidenced by the effluent pH, COD, and BOD values that follow the quality standards set by

PERMEN LHK No.5 of 2014.

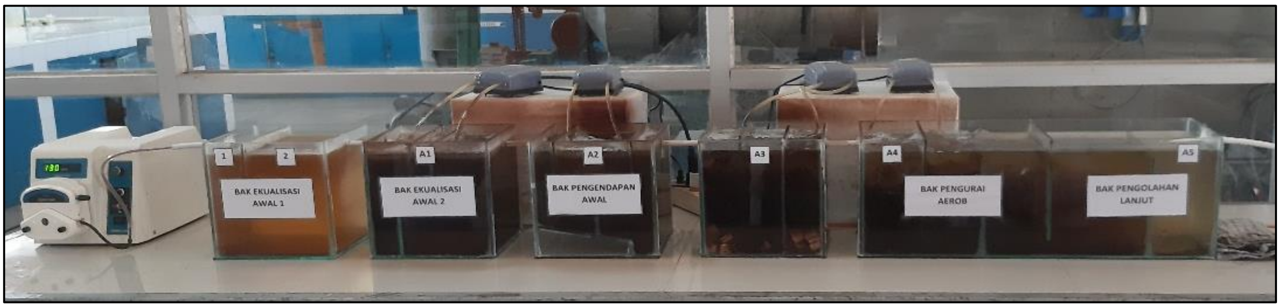

Figure 5. WWTP Prototype Lab Scale (Ratio 1:10) After Optimization

3.2.1. Effect of $CaCO_3$ Addition on pH Value

The addition of $CaCO_3$ to a solution can have several effects depending on the chemical properties of the solution and the presence of ions in the solution (Du *et al*., 2020; Wang *et al*., 2013). The effect of $CaCO_3$ addition on the *Gambier* industry wastewater pH value can be seen in Figure 6.

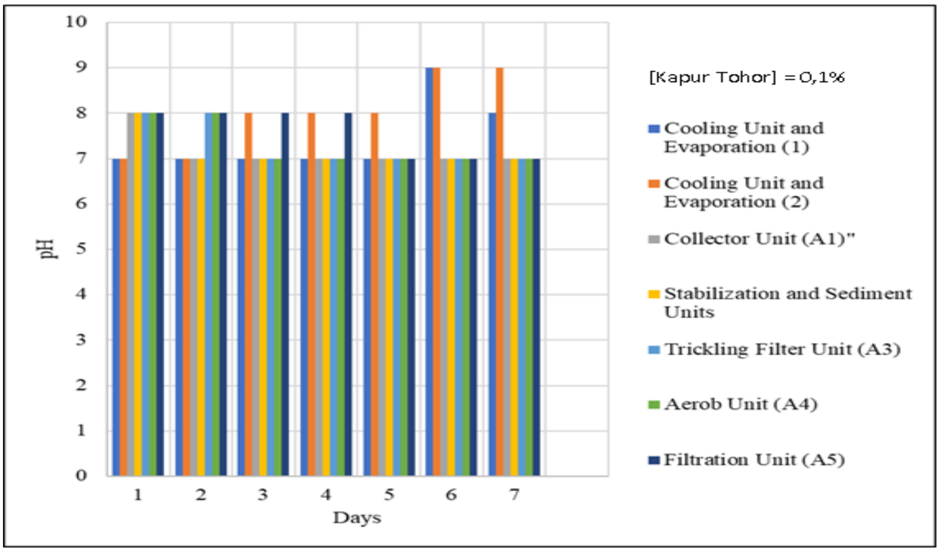

Figure 6. The Effect of $CaCO_3$ Addition on pH Value

The concentration of $CaCO_3$ added to the gambier processing industry wastewater was 0.1%. The results show that the pH of wastewater in the Cooling and Evaporation Unit (1), Cooling and Evaporation Unit (2), Collection Unit (A1), Stabilization and Sediment Unit (A2), Trickling Filter Unit (A3), Aerobic Unit (A4), and Liquid and Solid Separation Unit (A5) from day 1 to day 7 ranged from 7.0 to 9.0. The pH value of gambier wastewater before processing was 3.3 – 4.0. Meanwhile, the quality standards stipulated by the Minister of Environment and Forestry Regulation No. 5 of 2014 are 6.0 – 9.0. The pH parameter of the media environment greatly value that is too high (> 8.5) will inhibit the activity of microorganisms. In contrast, a pH value below 6.5 will cause the growth of fungi and competition with bacteria in the metabolism of organic matter (Sayekti *et al*., 2011; Tran *et al*., 2021; Jin & Kirk, 2018).

3.2.2. Effect of Poly Aluminium Chloride (PAC) Addition on COD

The concentration of PAC added to the Gambier wastewater treatment industry was 20 mg/L. The effect of PAC addition on COD is shown in Figure 7. The COD of gambier wastewater before being processed was 169.99 mg/L. In comparison, the COD of gambier wastewater after being processed in the Liquid and Solid Filtration Unit (A5) on the day first was 28.05 mg/L with a removal efficiency of 83.50%. Then, on the second day, the COD was 18.75 mg/L with a removal efficiency of 88.97%. Furthermore, COD on the third day was 22.32 mg/L with a removal efficiency of 86.87%, while the COD on the fourth, fifth, sixth, and seventh days was 35.71 mg/L; 43.75 mg/L; 12.5 mg/L; and 31.25 mg/L, with a sequential removal efficiency of 78.99%; 74.26%; 92.65%; and 81.62%. From the research that has been done, the highest removal efficiency was obtained on the sixth day, which was 92.65%.

In contrast, the lowest removal efficiency value was seen on the fifth day, 74.26%. The decrease in COD value before and after processing indicates the activity of microorganisms that degrade organic compounds (Fitri *et al*., 2016; Agustina & Yuniarto, 2022). The decrease in COD was due to the floc formed by organic compound ions bonding with positive coagulant ions. The molecules in the waste are formed into flocs, and the colloidal particles in the waste have the property of binding to other particles or compounds in the waste. Decreasing the number of particles decreases the oxygen needed to oxidize organic compounds, so the COD value after coagulation is also low (Badawi & Zaher, 2021; Meng *et al*., 2018). The COD of the gambier wastewater after treatment meets the quality standards stipulated by the Government Regulation, which is 150 mg/L.

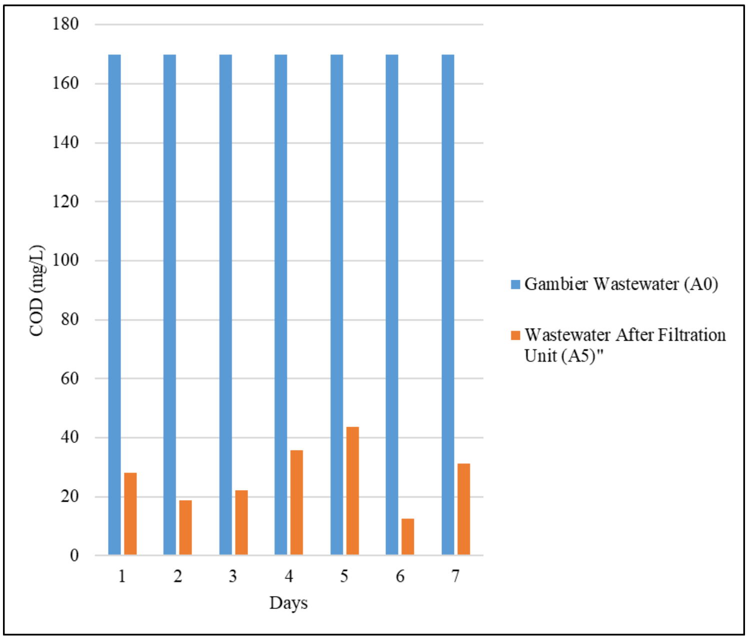

Figure 7. The effect of PAC addition on Gambier wastewater COD

3.2.3. Effect of Poly Aluminium Chloride (PAC) Addition on BOD

The PAC is a potential coagulant for treating textile dyeing effluents and helping to create a sustainable environment (Islam & Mostafa, 2020; Liu *et al*., 2021). The effect of PAC addition on Gambier wastewater BOD can be seen in Figure 8.

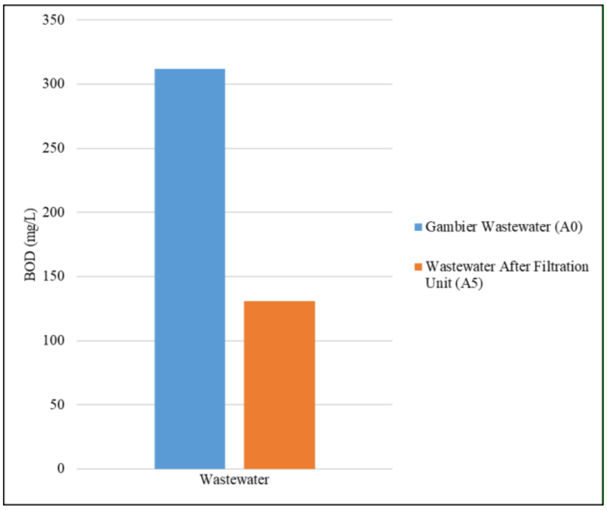

Figure 8. The effect of PAC addition on Gambier wastewater BOD

Based on Figure 8, the effect of PAC addition on BOD, it can be seen that the BOD of gambier industrial wastewater before processing was 312 mg/L. In comparison, the BOD of gambier industrial wastewater after processing was 131 mg/L with a removal efficiency of 58.01%. From the research that has been done, the processed Gambier wastewater BOD is under the quality standards stipulated by Government Regulation No. 5 of 2014, which is 50 – 150 mg/L.

BOD is a characteristic that indicates the amount of dissolved oxygen needed by microorganisms (usually bacteria) to decompose or decompose organic matter under aerobic conditions (Meng *et al*., 2018; Dasguptaang & Yildiz, 2016). BOD is a parameter that estimates the amount of oxygen that waters need to degrade the organic matter they contain and describes biodegradable organic matter in the water or waters concerned. From the BOD value, it can be seen whether the ability of the waters to degrade organic matter is still quite good or shallow. If it is low, it means that the self-purification ability of the waters has been dramatically reduced (Jobin & Namour, 2017; Purwati *et al*., 2019).

3.3. Organic Compounds Analysis

Characteristics of organic matter help evaluate and optimize wastewater treatment for treating wastewater in the gambier industry. The results showed a change in the functional groups of organic matter after the aerobic process, which could explain the degradation process so that it was directed at an easy containment process. The organic components analysis of the Gambier wastewater can be seen in Figure 9.

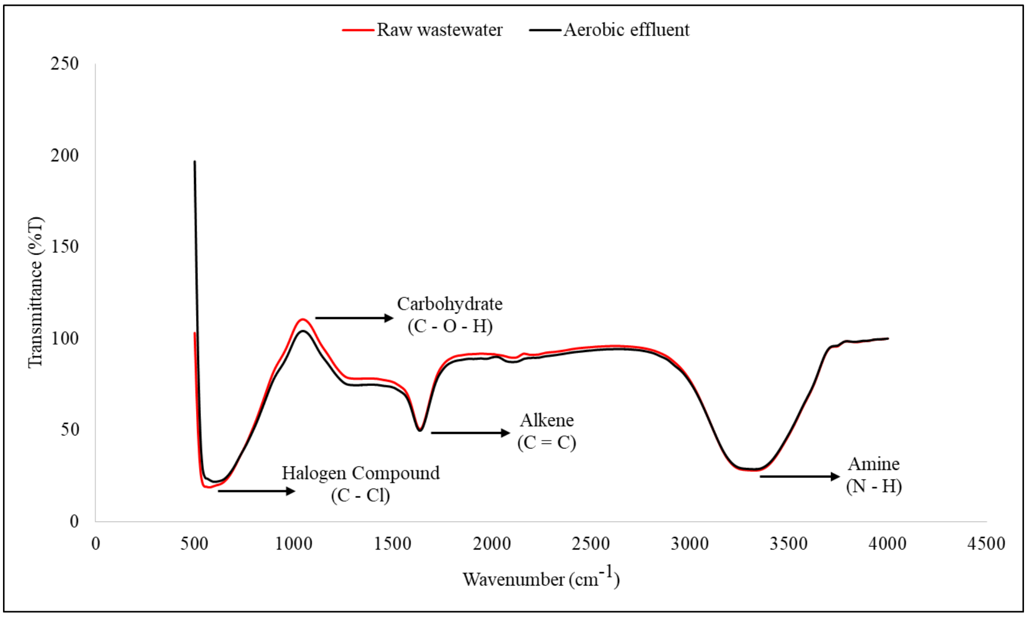

Figure 9. The organic components analysis of the Gambier wastewater

Figure 9 shows the FTIR spectra of the Gambier wastewater organic components. The organic components found in the Gambier industry wastewater are halogen compounds (C-Cl) with a wave number range of 550-850 cm^{-1}, carbohydrates (C-H–O) with a wave number range of 900–1200 cm^{-1}, alkenes (C=C) with a wave number range of 1600 – 1678 cm^{-1}, and amines (N–H) with a wave number range of 3300 – 3400 cm^{-1}.

The halogen compounds (C–Cl) detected in the FTIR spectra come from Poly Aluminum Chloride (PAC). This is evidenced by the increase in intensity (%T) of aerobic effluent compared to raw wastewater, which shows an increase in the concentration of a compound. Poly Aluminum Chloride (PAC) enhanced the formation of aerobic granules (Liu *et al*., 2016). Carbohydrates (C–H–O) come from catechin compounds (flavonoids), which are found in the raw materials for the gambier processing industry, namely the gambier plant and ethyl acetate which acts as a solvent. Aerobic effluent has a lower transmittance intensity (%T) of carbohydrates (C–H–O) compared to raw wastewater. Alkene double bonds (C=C) were detected in the spectra spanning wavenumbers 665 – 1678 cm^{-1}. This condition suggests the presence of various alkene compounds. These bonds may represent disubstituted, trisubstituted, vinylidene, and monosubstituted alkene configurations originating from natural and industrial processes. The presence of N-H bonds in the FTIR spectra indicates the occurrence of amines, which may derive from organic matter present in the gambier plant material. Amines are organic compounds containing nitrogen atoms bonded to hydrogen atoms, and their presence may influence the chemical characteristics of the wastewater.

Fourier Transform Infrared Spectroscopy (FTIR) is a widely used technique for identifying functional groups in materials (gas, liquid, and solid) using infrared radiation. Infrared spectroscopy measures the absorption of IR radiation created by each molecule in a molecule, and the results give a spectrum usually expressed as % transmittance versus wavenumber (cm^{-1}). Various materials containing covalent bonds absorb electromagnetic radiation in the IR region (Sharma *et al*., 2018).

4. Conclusions

The optimization of the performance of the Gambier Processing Industry Wastewater Treatment Plant (WWTP) involves several steps. Firstly, two aerator units are added to the Stabilization and Sedimentation Unit (A2) and the Trickling Filter Unit (A3). Next, biofilters are installed in the Trickling Filter Unit (A3) and the Aerobic Decomposition Unit (A4). Finally, quicklime is introduced into the Refrigeration and Evaporation Units (1 and 2). The study results show positive outcomes, with improved pH, COD, and BOD levels, which now meet quality standards. Additionally, the study analyzes the changes in the functional groups of organic matter after treatment, demonstrating how the degradation process was improved to facilitate containment. In summary, this article highlights the importance of addressing the environmental challenges associated with the Gambier industry in West Sumatra. The industry can significantly reduce its environmental footprint by systematically optimizing wastewater treatment processes while aligning with global sustainability goals, particularly SDG 6.

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