



# Beyond Conventional Wastewater Treatment: Integrated Lagoon Biogas System for Tapioca Effluent Management

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## Abstract

**Purpose:** This study examines the wastewater treatment system operated by a tapioca starch manufacturer in Central Lampung, Indonesia, and evaluates whether the treated effluent complies with the national quality standard for tapioca industry wastewater.

**Research Methodology:** A descriptive case-study approach was used during a one-month field internship. Primary data were obtained through direct observation of the anaerobic, facultative, and aerobic lagoon units, interviews with plant operators, and secondary laboratory test results for pH, biochemical oxygen demand, chemical oxygen demand, free cyanide, temperature, turbidity, and total suspended solids for January and February 2025. Results were compared against Regulation of the Minister of Environment Number 5 of 2014.

**Results:** All regulated parameters in both months remained below the national ceilings, with biochemical oxygen demand of 38 and 48 mg/L, chemical oxygen demand of 81 and 99 mg/L, and total suspended solids of 71.83 and 44.25 mg/L, equal to 25–32%, 27–33%, and 44–72% of the respective limits.

**Conclusions:** The seven-lagoon biological train, supported by upstream biogas digestion, produced compliant effluent during the monitoring period.

**Limitations:** The study covers only two monthly sampling events at a single facility, restricting statistical generalization.

**Contributions:** The findings offer a replicable operational benchmark for small and medium tapioca processors seeking low-cost, energy-recovering wastewater management.

**Keywords:** *Biological Treatment, Effluent Quality, Lagoon System, Tapioca Industry, Wastewater Management*

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## 1. Introduction

The tapioca starch industry illustrates the tension between agro-industrial growth and environmental protection in Indonesia. Cassava is inexpensive and widely cultivated, but the wet extraction process that separates starch from the root consumes large volumes of water and returns almost all of it as high-strength effluent ([Yosep, Mulkhan, Hasanudin, & Iryani, 2024](#)). Untreated tapioca wastewater is characterized by elevated Total Suspended Solids (TSS), high Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), low pH, and free cyanide released by the hydrolysis of cyanogenic glycosides during washing and grating, at concentrations that can approach 200 mg/L in

concentrated process streams ([Siller & Winter, 1998](#)). Discharged without adequate treatment, this combination of organic loading and cyanide toxicity depletes dissolved oxygen and endangers aquatic life and the downstream communities that depend on receiving rivers ([Nizzy & Kannan, 2022](#)).

To control these risks, Regulation of the Minister of Environment Number 5 of 2014 sets maximum effluent concentrations of BOD, COD, TSS, cyanide, and pH for tapioca starch operations. Technologies proven for this waste stream range from high-rate anaerobic reactors, such as upflow anaerobic sludge blanket (UASB) reactors achieving more than 95% COD conversion ([Annachhatre & Amatya, 2000](#)), and two-phase multi-staged UASB systems ([Thepubon, Choeisai, Choeisai, & Syutsubo, 2023](#)), and fixed-film sequencing batch reactors that remove cyanide and COD simultaneously ([Potivichayanon, Toensakes, Supromin, & Seaung, 2020](#)), to constructed wetlands ([Kurniadie, Wijaya, Widayat, Umiyati, & Iskandar, 2018](#)) and anaerobic ponds coupled with biogas recovery ([Wattanasilp, Songprakorp, Nopharatana, & Khompatraporn, 2021](#)). Many Indonesian processors nevertheless continue to rely on open-lagoon trains because land is available and operating costs are far lower than those of engineered high-rate digesters ([Profile, 2015](#)).

Most of this evidence, however, comes from laboratory- or pilot-scale reactors and single unit processes, or, where full-scale Indonesian installations have been studied, from the perspective of energy recovery and methane emission rather than effluent compliance ([Pratiwi, Iryani, Haryanto, Bakri, & Hasanudin, 2026](#)). Comparatively little published work documents the effluent quality of a complete, full-scale, multi-stage lagoon train that integrates biogas recovery, measured at the regulatory compliance point under routine production conditions. This gap matters because real installations are exposed to fluctuating influent loads, rainfall, and maintenance constraints that laboratory studies cannot replicate. The present case study of PT XYZ, a tapioca starch producer in Central Lampung, adds to existing knowledge in three ways. First, it describes the configuration and operation of a seven-lagoon train with upstream biogas digestion at an operating factory. Second, it evaluates accredited-laboratory effluent data against both the national standard and the stricter limits listed on the laboratory certificates. Third, it quantifies the compliance margin, month-to-month variation, and indicative removal performance rather than reporting compliance status alone.

Accordingly, this study addresses two research questions concerning the structure and operation of the wastewater treatment system at PT XYZ and the extent to which the treated effluent complied with the applicable quality standards for BOD, COD, TSS, cyanide, and pH during the January–February 2025 monitoring period.

## 2. Literature Review and Hypothesis/es Development

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### 2.1 Characteristics of Tapioca Starch Wastewater

Tapioca flour is produced by extracting starch granules from cassava roots, a process that is distinct from producing cassava flour, since the latter is simply the ground and dried whole root while tapioca starch is the purified starch fraction ([Mamat, Ronie, Aziz, Ridhwan, Kobun, Pindi, & Putra, 2025](#); [Chisenga, Workneh, Bultosa, & Alimi, 2019](#)). Extracting one ton of cassava root into starch requires approximately six to nine cubic meters of process water, and nearly all of that water eventually becomes wastewater; a survey of eight Thai tapioca starch plants found an average wastewater generation of about 19 m<sup>3</sup> per ton of starch ([Chavalparit & Ongwandee, 2009](#)). The resulting effluent is consistently described as pale yellowish, initially smelling of fresh cassava before developing a pungent odor as microbial activity proceeds, with TSS of 1.500–5.000 mg/L, COD of 4.000–30.000 mg/L, BOD of 3.000–6.000 mg/L, and pH as low as 4–5.5 once the wastewater has aged ([Yosep, Mulkhan, Hasanudin, & Iryani, 2024](#)).

Reported organic strength varies widely between studies, largely because of differences in the process stream sampled and the degree of starch recovery. [Potivichayanon, Toensakes, Supromin, and Seaung \(2020\)](#) reported COD from roughly 16 to more than 140 g/L in cassava industrial wastewater, [Annachhatre and Amatya \(2000\)](#) treated settled tapioca supernatant of 12.000–24.000 mg/L [Yosep et](#)

[al. \(2024\)](#) reported 4.000–30.000 mg/L for small and medium enterprises in Lampung. Read together, these figures indicate that raw tapioca effluent typically exceeds the national COD ceiling by one to two orders of magnitude. Cyanide is the second defining hazard because cyanogenic glycosides in the root and peel are hydrolyzed by endogenous enzymes during washing, peeling, and grating. [Siller and Winter \(1998\)](#) reported free cyanide of up to about 200 mg/L in cassava starch wastewater. Because cyanide is acutely toxic to fish even at trace concentrations, regulatory standards require its monitoring alongside conventional organic-loading parameters ([Nizzy & Kannan, 2022](#)).

## 2.2 Regulatory Standards for Industrial Wastewater in Indonesia

Indonesian environmental law addresses wastewater at both the general and sector-specific level. Government Regulation Number 82 of 2001 concerning water quality management and water pollution control, since superseded by Government Regulation Number 22 of 2021, defined *air limbah*, or wastewater, as residual liquid produced by any business or activity, whether domestic or industrial in origin. Building on this general framework, Regulation of the Minister of Environment Number 5 of 2014 establishes sector-specific *baku mutu*, or quality standards, for numerous industries, including tapioca starch processing. For tapioca operations, the regulation sets maximum permissible concentrations of 150 mg/L for BOD, 300 mg/L for COD, 100 mg/L for TSS, 0.3 mg/L for cyanide, and a pH range of 6–9, together with a maximum wastewater discharge of 30 m<sup>3</sup> per ton of tapioca produced. Region-specific ceilings, such as Lampung Governor Regulation Number 7 of 2010 on regional wastewater quality standards, and the conditions of individual discharge permits may impose additional or stricter limits that a facility must simultaneously satisfy before discharge to a public water body ([Ruscitasari, Marzuqoh, & Mutia, 2025](#)).

Empirical evaluations of tapioca wastewater treatment in Indonesia show that compliance depends strongly on system configuration. At a tapioca factory in Sumedang, West Java, a pre-treatment unit followed by a constructed wetland planted with *Phragmites karka* achieved BOD and COD removals of about 99% over nine months of monitoring, with mean effluent BOD<sub>5</sub> of 17 mg/L and COD of 22 mg/L ([Kurniadie et al., 2018](#)). Batch wetland trials using water hyacinth reported removal of up to 97.9% for BOD, 84.4% for COD, and 99.9% for cyanide, but only 45.6% for TSS ([Siswoyo, Faisal, Kumalasari, & Kasam, 2020](#)), suggesting that suspended solids are harder to control than dissolved organics in plant-based systems. In Thailand, most of the eight tapioca plants surveyed by [Chavalparit and Ongwandee \(2009\)](#) relied on anaerobic and facultative ponds in series, and the effluent of the final polishing ponds met national standards. By contrast, many small and medium tapioca enterprises in Lampung still face barriers to adopting resource-recovering wastewater practices ([Yosep et al., 2024](#)). Compared across these studies, the decisive factors appear to be retention time, staging of treatment units, and maintenance discipline rather than the choice of technology alone, while full-scale effluent data for Indonesian multi-stage lagoon trains remain scarce.

## 2.3 Biological Treatment Technologies: Anaerobic, Facultative, and Aerobic Lagoons

Biological treatment exploits the metabolic activity of microorganisms to convert dissolved and suspended organic matter into simpler, more stable end products, and it remains the dominant approach for agro-industrial wastewater because it is comparatively inexpensive to build and operate. Anaerobic lagoons, typically excavated to a depth sufficient to exclude sunlight and maintain an oxygen-free environment, rely on a four-stage microbial pathway of hydrolysis, acidogenesis, acetogenesis, and methanogenesis to break down complex organic polymers into methane and carbon dioxide ([Saini, Tewari, Dwivedi, & Sharma, 2023](#); [Yudhistira, Suprpto, & Sulmartiwi, 2023](#)). High-rate UASB reactors treating tapioca starch wastewater have achieved COD conversion above 95% at organic loading rates of 10–16 kg COD/m<sup>3</sup>·day ([Annachhatre & Amatya, 2000](#)), whereas a two-phase multi-staged UASB operated on undiluted tapioca wastewater at ambient temperature reached about 80% COD removal at 8 kg COD/m<sup>3</sup>·day ([Thepubon, Choeisai, Choeisai, & Syutsubo, 2023](#)); the difference illustrates how sensitive anaerobic performance is to suspended-solids removal and loading control. Anaerobic biomass can also degrade cyanide, as demonstrated by a methanogenic fixed-bed reactor treating cassava starch wastewater, which degraded cyanide concentrations of up to 150 mg

CN<sup>-</sup>/L at a hydraulic retention time of three days while maintaining effluent cyanide concentrations below 0.5 mg/L ([Siller & Winter, 1998](#)).

Facultative lagoons occupy an intermediate ecological niche. Shallower than anaerobic ponds, they permit sunlight to penetrate the upper water column, sustaining an aerobic surface layer dominated by algae and aerobic bacteria, while the lower layer remains anoxic and continues to host anaerobic decomposition. This dual-zone structure allows facultative lagoons to further reduce residual organic load left after anaerobic pretreatment, smoothing the transition toward fully aerobic polishing ([Hoffmann, Duarte, & Amí, 2020](#)). Aerobic lagoons, the final biological stage in most agro-industrial treatment trains, depend on mechanical or diffused aeration to maintain dissolved oxygen concentrations sufficient for aerobic bacteria to oxidize remaining organic matter into carbon dioxide and water, yielding an effluent that is markedly clearer, less odorous, and lower in BOD, COD, and TSS than the lagoon influent ([Remmas, 2022](#); [Putra, Mahadewi, Sundary, Hari, & Muhajir, 2025](#)).

Anaerobic treatment of tapioca wastewater is increasingly framed as resource recovery as well as pollution control. Techno-economic analysis of Thai cassava starch factories showed that biogas from starch wastewater can be used profitably for on-site power generation ([Wattanasilp, Songprakorp, Nopharatana, & Khompatraporn, 2021](#)), and in the Thai plants surveyed by [Chavalparit and Ongwandee \(2009\)](#), replacing open ponds with closed biogas systems substituted fuel oil, reduced odor, and returned payback periods of about two years. In Central Lampung, 22 months of full-scale monitoring at a covered-lagoon biogas plant treating cassava wastewater showed a strong linear relationship between COD removal and methane production and a site-specific methane yield of 0.23 kg CH<sub>4</sub>/kg COD, slightly below the IPCC default, which the authors attributed to seasonal dilution and operational variability ([Pratiwi, Iryani, Haryanto, Bakri, & Hasanudin, 2026](#)). Advances in digester design and co-digestion offer further routes to optimize energy recovery in existing facilities ([DelaVega-Quintero, Nuñez-Pérez, Lara-Fiallos, Barba, Burbano-García, & Espin-Valladares, 2025](#); [Suryani, Tambunan, Santosa, & Haryanto, 2024](#)). These studies, however, focus on the anaerobic stage and its energy output; they report little on the quality of the final effluent after downstream polishing, which is the focus of the present study.

## **2.4 Cyanide Management in Cassava-Derived Effluent**

Because cyanide toxicity is a distinguishing hazard of cassava processing, a substantial literature addresses its removal, and the findings can be compared by treatment route. Biological routes show the widest applicability: an anaerobic fixed-bed reactor reduced cyanide in cassava starch wastewater to below 0.5 mg/L ([Siller & Winter, 1998](#)), fixed-film sequencing batch reactors removed high levels of cyanide and COD simultaneously ([Potivichayanon et al., 2020](#)), algal–bacterial consortia in a continuous photobioreactor have been used to bioremediate cyanide-containing wastewater ([AbdelMageed & ElRakaiby, 2025](#)), and cyanide-degrading bacteria can couple detoxification with simultaneous nitrification and aerobic denitrification ([Mpongwana et al., 2020](#)). Physicochemical routes, such as adsorption onto H<sub>3</sub>PO<sub>4</sub>-activated periwinkle-shell carbon ([Eke-Emezie, Etuk, Akpan, & Chinweoke, 2022](#)), achieve rapid removal but add material and regeneration costs, while wetland systems have reported cyanide removal of up to 99.9% ([Siswoyo et al., 2020](#)). Comparing these studies suggests that long retention times and sequential anaerobic–aerobic conditions, both characteristic of lagoon trains, favor biological cyanide attenuation, although this capacity is rarely documented at full scale. This point is directly relevant to interpreting the cyanide results reported in Section 4.

## **2.5 Research Propositions**

Drawing on the literature reviewed above, this study advances two propositions rather than statistically testable hypotheses, consistent with its descriptive, single-case design. The first proposition holds that a sequential biological lagoon train combining anaerobic, facultative, and aerobic stages, supported by upstream biogas digestion, is capable of reducing the organic and cyanide loading of tapioca starch wastewater to levels consistent with the national quality standard

under routine industrial operating conditions. The second proposition holds that variation in effluent quality between successive monthly monitoring rounds reflects normal fluctuation in influent characteristics and hydraulic loading rather than a structural failure of the treatment train, provided that all measured parameters remain within the regulatory ceiling in each round. Because only two monitoring rounds were available, both propositions are examined descriptively for the observed period rather than tested statistically, and they frame the interpretation of the results presented in Section 4.

### **3. Research Methodology**

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#### ***3.1 Research Design***

This study employed a descriptive, qualitative-quantitative case-study design intended to characterize an existing industrial wastewater treatment system and to evaluate its performance against a defined regulatory benchmark. The case-study format was chosen because the research question concerns the operation of a single, bounded system, namely the wastewater treatment installation of PT XYZ, and because meaningful evaluation requires close, on-site observation of physical infrastructure that cannot be adequately captured through survey or purely archival methods ([Ribeiro & Aguiar, 2024](#)).

#### ***3.2 Site and Duration***

The research was conducted at PT XYZ, a tapioca starch processing facility located in Lampung Province, Indonesia. The facility occupies approximately forty-five hectares and has operated since 2011. Field activities were carried out over a one-month internship period, from 20 January 2025 to 20 February 2025, during which the researcher was embedded within the plant's water waste treatment and occupational health and safety unit.

#### ***3.3 Data Collection Techniques***

Three complementary data collection techniques were used. Direct field observation was conducted across the seven lagoons that constitute the treatment train, recording physical characteristics such as lagoon depth, color, odor, surface activity, sediment accumulation, and aeration equipment, and photographic documentation was taken at each unit to support the descriptive analysis. Semi-structured interviews were held with the field supervisor and treatment-unit operators responsible for daily management of the lagoons and the biogas digestion system, covering retention time, sludge management practice, and historical operational issues. Secondary data consisted of laboratory test reports for effluent samples collected in January and February 2025 and analyzed by an accredited industrial testing laboratory in Indonesia., an accredited government testing laboratory, using standard national methods, including SNI 6989.11:2019 for pH, SNI 6989.72:2009 for BOD, the MU.SS-UJI.90 spectrophotometric method for COD, the MU.SS-UJI.91 spectrophotometric method for free cyanide, SNI 06-6989.23-2005 for temperature, the MU.SS-UJI.123 nephelometric method for turbidity, and SNI 6989.3:2019 for TSS. Combining observation, interviews, and documented monitoring data in this way follows case-study evaluations of full-scale wastewater treatment plants ([Ribeiro & Aguiar, 2024](#)).

#### ***3.4 Data Analysis Technique***

Data were analyzed descriptively. Observational and interview data on the design and operation of the seven lagoons were synthesized into a process-flow narrative describing how wastewater moves from the anaerobic stage through the facultative stage to the aerobic stage before discharge. Laboratory results for each of the seven parameters were tabulated by month and compared with the maximum concentrations in Regulation of the Minister of Environment Number 5 of 2014 for the tapioca industry and with the stricter limits printed on the laboratory certificates. A parameter was classified as compliant if the measured concentration in a given month did not exceed the ceiling, and the system was considered to have met the standard during the monitoring period if all regulated

parameters were compliant in both rounds. To move beyond compliance status, three quantitative indicators were calculated. The first was limit utilization, which measures the concentration as a percentage of the regulatory ceiling. The second was the month-to-month relative change between January and February. The third was indicative removal efficiency, calculated as  $E = (C_{in} - C_{out})/C_{in} \times 100$ , in which  $C_{out}$  is the measured effluent concentration and  $C_{in}$  is bounded by the raw tapioca wastewater ranges reported for Lampung ([Yosep et al., 2024](#)), because influent data were unavailable. This benchmarking approach follows the evaluative logic of full-scale treatment-performance studies ([Kurniadie et al., 2018](#); [Ribeiro & Aguiar, 2024](#)).

## 4. Results and Discussions

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### 4.1 Overview of the Wastewater Treatment Facility

PT XYZ is a national private company established in 2009 as part of the XYZ Group business expansion, with its first factory constructed in 2009 and brought into operation in 2011. The company manages approximately six thousand hectares of cassava cultivation area through a nucleus-plasma partnership with surrounding farmers, which supports a consistent supply of raw material for continuous factory operation. In October 2013, the company began installing biogas capture infrastructure over the area previously used for open waste disposal, converting what had been a wasted resource into a source of electricity that now supplements the factory's operational power supply. The company's operational permits include a building construction permit, a groundwater utilization permit, a fuel storage permit, a hazardous waste storage permit, and a wastewater discharge permit, all issued by the relevant Central Lampung regional authorities.

### 4.2 Sources of Wastewater

Two principal streams feed the treatment installation. The first originates from the washing of freshly harvested cassava roots, which generates wastewater containing suspended organic particles and biodegradable compounds. Such high-strength cassava processing wastewater requires biological treatment before discharge ([Yosep et al., 2024](#)). The second stream consists of digestate discharged from the biogas lagoon, produced through anaerobic decomposition of organic matter generated during starch extraction. Anaerobic digestion of cassava starch wastewater reduces organic loading while enabling biogas recovery for on-site energy use ([Wattanasilp et al., 2021](#)), and the reduction of COD in this upstream stage decreases the organic burden entering the subsequent biological stages ([Annachhatre & Amatya, 2000](#)).

### 4.3 Process Flow of Wastewater Treatment

The treatment train at PT XYZ comprises seven lagoons occupying a combined area of approximately 8.8 hectares, engineered to handle a daily production wastewater volume of roughly 2,500 cubic meters, in addition to a smaller domestic wastewater stream of about 40 cubic meters per day that is discharged separately. Wastewater first passes through Lagoons 1 through 4, which operate under anaerobic conditions, then proceeds to Lagoon 5, which functions as a facultative unit, and finally to Lagoons 6 and 7, which operate aerobically before the treated water is released to the receiving river.

The anaerobic lagoons are excavated to an average depth of approximately six meters, a depth sufficient to prevent sunlight penetration and to sustain the oxygen-free environment required by anaerobic microorganisms ([Harris & McCabe, 2020](#)). Hydraulic retention time in this stage is at least ten days, during which complex organic compounds carried in from the cassava washing, grating, and extraction stages are broken down into simpler substances through the successive microbial pathways of hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Visible gas bubbling at the lagoon surface, observed during field visits, was interpreted by plant operators as an indicator of active fermentation and methane generation. The first lagoon in the anaerobic series functions primarily as an initial receiving and settling basin, accumulating residual *onggok*, or starch pulp fiber, carried over from the grating process, while subsequent anaerobic lagoons continue to reduce the remaining

organic load before the partially treated water advances to the facultative stage, a pond-in-series arrangement also common in Thai tapioca plants ([Chavalparit & Ongwandee, 2009](#)).

Lagoon 5, the facultative unit, is shallower than the anaerobic ponds, with a depth of roughly one to two meters that permits sunlight to penetrate the upper water column. This configuration sustains aerobic bacterial activity near the surface while anaerobic conditions persist in the lower layer, allowing the two microbial communities to act in complementary fashion on the residual organic load. Field observation indicated that water entering this stage had already lost much of the turbidity and pungent odor characteristic of fresh tapioca wastewater, evidence that the bulk of readily degradable organic matter had already been broken down in the preceding anaerobic stage.

The final stage comprises two aerobic lagoons, Lagoon 6 and Lagoon 7, each approximately one meter deep to allow full sunlight penetration to the pond floor and equipped with aeration pumps that supply supplemental dissolved oxygen. This mechanical aeration supports vigorous aerobic bacterial metabolism, which continues to oxidize the remaining organic matter into carbon dioxide, further lowering chemical oxygen demand, biochemical oxygen demand, and total suspended solids while producing an effluent that plant operators described as visibly clearer and largely free of odor. Only after passing through this seventh and final lagoon is the treated water released to the adjacent public river, consistent with the discharge point sampled for the laboratory analyses reported below.

#### 4.4 Laboratory Monitoring Results

Effluent samples were collected at the outlet of Lagoon 7 and analyzed by an accredited laboratory using standardized methods. During the internship period, two sampling rounds were completed, in January and February 2025, covering seven parameters, including pH, BOD, COD, free cyanide, temperature, turbidity, and TSS.

Table 1. Laboratory test results of liquid waste from PT XYZ, January 2025

| No. | Parameter                       | Unit | Test Method                         | Quality Standard | Test Result |
|-----|---------------------------------|------|-------------------------------------|------------------|-------------|
| 1   | pH                              | -    | SNI 6989.11:2019                    | 6–9              | 7.78        |
| 2   | Biochemical Oxygen Demand (BOD) | mg/L | SNI 6989.72:2009                    | 100              | 38          |
| 3   | Chemical Oxygen Demand (COD)    | mg/L | MU.SS-UJI.90<br>(Spectrophotometry) | 250              | 81          |
| 4   | CN / Free Cyanide               | mg/L | MU.SS-UJI.91<br>(Spectrophotometry) | 0.2              | 0.012       |
| 5   | Temperature                     | °C   | SNI 06-6989.23-2005                 | -                | 29.7        |
| 6   | Turbidity (*)                   | NTU  | MU.SS-UJI.123<br>(Nephelometry)     | -                | 37.3        |
| 7   | Total Suspended Solids (TSS)    | mg/L | SNI 6989.3:2019                     | 100              | 71.83       |

Note: The quality standard values in Tables 1 and 2 are those printed on the laboratory certificates. The corresponding national limits under Regulation of the Minister of Environment Number 5 of 2014 are pH 6–9, BOD 150 mg/L, COD 300 mg/L, cyanide 0.3 mg/L, and TSS 100 mg/L.

Based on Table 1, in January 2025, the measured pH was 7.78, biochemical oxygen demand was 38 milligrams per liter, chemical oxygen demand was 81 milligrams per liter, free cyanide was 0.012 milligrams per liter, temperature was 29.7 degrees Celsius, turbidity was 37.3 NTU, and total suspended solids was 71.83 milligrams per liter.

Table 2. Laboratory test results of liquid waste from PT XYZ, February 2025

| No. | Parameter | Unit | Test Method      | Quality Standard | Test Result |
|-----|-----------|------|------------------|------------------|-------------|
| 1   | pH        | -    | SNI 6989.11:2019 | 6–9              | 8.18        |

| No. | Parameter                       | Unit | Test Method                      | Quality Standard | Test Result |
|-----|---------------------------------|------|----------------------------------|------------------|-------------|
| 2   | Biochemical Oxygen Demand (BOD) | mg/L | SNI 6989.72:2009                 | 100              | 48          |
| 3   | Chemical Oxygen Demand (COD)    | mg/L | MU.SS-UJI.90 (Spectrophotometry) | 250              | 99          |
| 4   | CN / Free Cyanide               | mg/L | MU.SS-UJI.91 (Spectrophotometry) | 0.2              | 0.010       |
| 5   | Temperature                     | °C   | SNI 06-6989.23-2005              | -                | 29.8        |
| 6   | Turbidity (*)                   | NTU  | MU.SS-UJI.123 (Nephelometry)     | -                | 51.40       |
| 7   | Total Suspended Solids (TSS)    | mg/L | SNI 6989.3:2019                  | 100              | 44.25       |

Based on Table 2, in February 2025, the measured pH was 8.18, biochemical oxygen demand was 48 milligrams per liter, chemical oxygen demand was 99 milligrams per liter, free cyanide was 0.010 milligrams per liter, temperature was 29.8 degrees Celsius, turbidity was 51.40 NTU, and total suspended solids was 44.25 milligrams per liter.

#### 4.5 Treatment Performance Evaluation

Table 3. Compliance margin, month-to-month change, and indicative removal efficiency of the treated effluent, January–February 2025

| Parameter    | Unit | Jan 2025 | Feb 2025 | Change (%)  | National limit | Limit utilization (%) Jan / Feb | Indicative removal (%) |
|--------------|------|----------|----------|-------------|----------------|---------------------------------|------------------------|
| pH           | –    | 7.78     | 8.18     | +0.40 units | 6–9            | –                               | –                      |
| BOD          | mg/L | 38       | 48       | +26.3       | 150            | 25.3 / 32.0                     | 98.4–99.4              |
| COD          | mg/L | 81       | 99       | +22.2       | 300            | 27.0 / 33.0                     | 97.5–99.7              |
| Free cyanide | mg/L | 0.012    | 0.010    | –16.7       | 0.3            | 4.0 / 3.3                       | n.e.                   |
| TSS          | mg/L | 71.83    | 44.25    | –38.4       | 100            | 71.8 / 44.3                     | 95.2–99.1              |
| Temperature  | °C   | 29.7     | 29.8     | +0.1 °C     | –              | –                               | –                      |
| Turbidity    | NTU  | 37.3     | 51.40    | +37.8       | –              | –                               | –                      |

Note: Limit utilization = measured concentration ÷ national limit × 100. Indicative removal =  $(C_{in} - C_{out}) / C_{in} \times 100$ , with  $C_{in}$  taken as the raw tapioca wastewater ranges reported by [Yosep, Mulkhan, Hasanudin, and Iryani \(2024\)](#): BOD 3.000–6.000 mg/L, COD 4.000–30.000 mg/L, and TSS 1.500–5.000 mg/L; values are literature-bounded estimates, not measured efficiencies. n.e. = not estimated; – = no numerical limit or not applicable.

Table 3 summarizes the compliance margin, month-to-month variation, and indicative removal performance of the system. Against the national ceilings of Regulation of the Minister of Environment Number 5 of 2014, all regulated parameters were compliant in both months: BOD used 25.3–32.0% of its ceiling, COD 27.0–33.0%, cyanide 3.3–4.0%, and TSS 44.3–71.8%, while pH (7.78–8.18) remained within the 6–9 range. The stricter limits printed on the laboratory certificates were also met, with utilization of 38–48% for BOD, 32.4–39.6% for COD, 5.0–6.0% for cyanide, and 44.3–71.8% for TSS. TSS was therefore the parameter closest to its limit, reaching 71.8% of the ceiling in January. Between January and February, BOD increased by 26.3%, COD by 22.2%, and turbidity by 37.8%, whereas TSS decreased by 38.4% and cyanide by 16.7%. Temperature (29.7–29.8 °C) and turbidity (37.3–51.4 NTU) have no numerical ceiling in the tapioca standard and are reported for information only.

Because influent samples were not analyzed during the monitoring period, removal efficiency could not be calculated from paired influent–effluent data. As an indicative evaluation, the measured effluent concentrations were compared with the characteristic ranges of raw tapioca wastewater reported for Lampung ([Yosep et al., 2024](#)). On this basis, the treatment train corresponds to overall removal of approximately 98.4–99.4% for BOD, 97.5–99.7% for COD, and 95.2–99.1% for TSS (Table 3). These ranges are of the same order as the 99.07% BOD<sub>5</sub> and 98.99% COD removal

measured over nine months at a full-scale tapioca wastewater wetland in West Java ([Kurniadie, Wijaya, Widayat, Umiyati, & Iskandar, 2018](#)). They are, however, estimates bounded by literature values rather than measured efficiencies and should be confirmed through paired influent and effluent sampling. Cyanide removal was not estimated because raw cyanide concentrations vary too widely with cassava variety and process stream to provide a meaningful bound.

#### 4.6 Discussion

The results are consistent with the first proposition: during the two monitoring rounds, the sequential anaerobic, facultative, and aerobic lagoon train, combined with upstream biogas digestion, produced effluent well within the national standard. This agrees with evidence that anaerobic treatment of tapioca and cassava wastewater can achieve COD conversion of about 90% or more under appropriate loading and retention conditions ([Annachhatre & Amatya, 2000](#); [Siller & Winter, 1998](#)), and it suggests that, at PT XYZ, anaerobic pretreatment followed by facultative and aerobic polishing achieved an effluent quality comparable to that of other full-scale tapioca treatment systems ([Chavalparit & Ongwandee, 2009](#); [Kurniadie et al., 2018](#)). However, because the evidence consists of only two monthly effluent samples without paired influent data, the results demonstrate compliance during the observed period rather than consistent long-term performance.

The observed cyanide concentrations of 0.012 and 0.010 mg/L were more than an order of magnitude below the 0.3 mg/L national ceiling, even though raw cassava starch wastewater can contain up to about 200 mg/L of cyanide ([Siller & Winter, 1998](#)). This is consistent with reports that anaerobic biomass and cyanide-degrading bacteria can substantially degrade cyanide ([Potivichayanon et al., 2020](#); [Mpongwana et al., 2020](#)) and suggests that the retention time of at least ten days across four anaerobic lagoons may contribute to biological cyanide attenuation without a dedicated cyanide-treatment unit. Because cyanide was not measured in the influent, however, the relative contributions of biodegradation, volatilization of hydrogen cyanide from open ponds, and dilution cannot be distinguished from the present data.

The month-to-month variation also merits attention. BOD rose from 38 to 48 mg/L, COD from 81 to 99 mg/L, and turbidity from 37.3 to 51.40 NTU between January and February, while TSS fell from 71.83 to 44.25 mg/L. None of these shifts approached the regulatory ceiling. With only two observations, the shifts cannot be separated statistically from sampling and analytical variability; they are nonetheless consistent with the second proposition that normal fluctuation in influent characteristics, such as variation in the volume or freshness of cassava processed or rainfall affecting hydraulic loading, can account for such variation without indicating a structural weakness in the treatment train. Full-scale monitoring in Central Lampung has likewise shown that seasonal dilution and operational variability measurably affect anaerobic lagoon performance ([Pratiwi et al., 2026](#)).

Comparison with other full-scale studies places these findings in context. The constructed wetland studied by [Kurniadie et al. \(2018\)](#) produced lower mean effluent BOD<sub>5</sub> (17 mg/L) and COD (22 mg/L) than PT XYZ, and did so over a nine-month record with paired influent data, which provides a much stronger basis for judging consistency than the two rounds available here. The 22-month record of [Pratiwi et al. \(2026\)](#) indicates that the January–February window, which falls within the rainy season in Lampung, may not represent dry-season conditions. In Thailand, pond-in-series systems similar to that of PT XYZ met national effluent standards, and conversion to closed biogas systems further reduced odor and fuel costs ([Chavalparit & Ongwandee, 2009](#); [Wattanasilp et al., 2021](#)). Relative to these studies, the likely contributors to compliance at PT XYZ are the land available for seven sequential ponds, the long retention time this allows, and the upstream biogas stage that removes part of the organic load. Other Indonesian studies have similarly assessed treatment effectiveness by monitoring physicochemical water quality parameters before and after treatment ([Satya, Legiso, & Juniar, 2025](#)) and by comparing BOD and COD with applicable quality standards ([Agustina & Muliadisa, 2023](#)).

Field observation also identified operational vulnerabilities that, while not reflected in a compliance failure during the monitoring period, warrant proactive attention. Solid sediment accumulation was

visibly greater in the first two anaerobic lagoons than in later units, consistent with their function as primary settling basins for residual starch pulp fiber, or *onggok*, entrained from the grating and washing stages. Left unmanaged, progressive sediment accumulation can reduce effective lagoon volume and thereby shorten actual hydraulic retention time below the design value, which over the longer term could erode the safety margin observed between measured concentrations and regulatory ceilings. Similarly, since dissolved oxygen supply in the aerobic lagoons depends on mechanical aeration equipment, any reduction in pump reliability or aeration capacity could directly constrain the oxidative capacity of the final treatment stage. Variations in wastewater quality parameters across monitoring periods are commonly evaluated to determine whether treatment systems maintain stable performance despite changes in influent characteristics ([Kasanudin, Yuliawati, & Fernianti, 2025](#)), and longer records would be needed to establish this for PT XYZ.

Overall, the discussion suggests that compliance at PT XYZ during the monitoring period reflects a combination of adequate hydraulic retention time, sufficient lagoon depth differentiation to establish distinct anaerobic, facultative, and aerobic zones, and upstream biogas pretreatment that reduces the organic burden entering the main lagoon train. These design features illustrate how a conventional, relatively low-technology lagoon system can meet regulatory standards for a challenging waste stream when adequately sized and maintained. Whether this performance is sustained across seasons, production levels, and sediment-accumulation cycles remains to be confirmed through longer monitoring, so the system is best regarded as a practical reference point rather than a proven benchmark for other tapioca and cassava processors.

## 5. Conclusions

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This study examined the wastewater treatment system operated by PT XYZ in Central Lampung, and evaluated whether its treated effluent met the quality standard for tapioca industry wastewater. The system consists of seven interconnected lagoons arranged in a sequential biological train: four anaerobic lagoons that reduce the bulk of the organic load, a facultative lagoon that further stabilizes residual organic matter, and two mechanically aerated lagoons that polish the effluent before its release to the receiving river. An upstream biogas digestion unit reduces the organic strength of the digestate stream and generates renewable electricity for the factory. In the January and February 2025 monitoring rounds, all regulated parameters (pH, BOD, COD, free cyanide, and TSS) were below both the national limits for the tapioca industry and the stricter limits listed on the laboratory certificates, with TSS closest to its limit at 71.8% of the ceiling in January. Within this observed period, the treatment system therefore met the applicable effluent standards. These findings describe the system's performance during the two monitoring rounds and should not be interpreted as evidence of consistent long-term effectiveness.

The study has several limitations. It relies on two monthly effluent samples from a single facility collected during the rainy season, with no paired influent data, so removal efficiencies could only be estimated from literature ranges and seasonal effects could not be assessed. Future research should collect paired influent and effluent samples at each lagoon stage over at least one full wet and dry season, survey sediment depth to track the loss of effective lagoon volume, and relate effluent quality to biogas output and production volume.

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## Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article. The research was conducted independently, and no financial, institutional, or personal relationships influenced the study design, data collection, analysis, interpretation of findings, or manuscript preparation.

## References

- AbdelMageed, M. F., & ElRakaiby, M. T. (2025). Algal–bacterial bioremediation of cyanide-containing wastewater in a continuous stirred photobioreactor. *World Journal of Microbiology and Biotechnology*, 41(2), 26. <https://doi.org/10.1007/s11274-024-04230-5>
- Agustina, A., & Muliadisa, I. K. (2023). Dampak Pariwisata terhadap Kualitas Air Danau Beratan Berdasarkan Parameter BOD dan COD. *Jurnal Studi Perhotelan Dan Pariwisata*, 1(1), 21-30. <http://doi.org/10.35912/jspp>
- Annachhatre, A. P., & Amatya, P. L. (2000). UASB treatment of tapioca starch wastewater. *Journal of Environmental Engineering*, 126(12), 1149-1152. [https://doi.org/10.1061/\(ASCE\)0733-9372\(2000\)126:12\(1149](https://doi.org/10.1061/(ASCE)0733-9372(2000)126:12(1149)
- Chavalparit, O., & Ongwandee, M. (2009). Clean technology for the tapioca starch industry in Thailand. *Journal of Cleaner Production*, 17(2), 105-110. <https://doi.org/10.1016/j.jclepro.2008.03.001>
- Chisenga, S. M., Workneh, T. S., Bultosa, G., & Alimi, B. A. (2019). Progress in research and applications of cassava flour and starch: A review. *Journal of food science and technology*, 56(6), 2799-2813. <https://doi.org/10.1007/s13197-019-03814-6>
- DelaVega-Quintero, J. C., Nuñez-Pérez, J., Lara-Fiallos, M., Barba, P., Burbano-García, J. L., & Espín-Valladares, R. (2025). Advances and challenges in anaerobic digestion for biogas production: Policy, technological, and microbial perspectives. *Processes*, 13(11), 3648. <https://doi.org/10.3390/pr13113648>
- Eke-Emezie, N., Etuk, B. R., Akpan, O. P., & Chinweoke, O. C. (2022). Cyanide removal from cassava wastewater onto H<sub>3</sub>PO<sub>4</sub> activated periwinkle shell carbon. *Applied Water Science*, 12(7), 157. <https://doi.org/10.1007/s13201-022-01679-3>
- Harris, P. W., & McCabe, B. K. (2020). Process optimisation of anaerobic digestion treating high-strength wastewater in the Australian red meat processing industry. *Applied Sciences*, 10(21), 7947. <https://doi.org/10.3390/app10217947>
- Hoffmann, N. K., Duarte, I. C. S., & Amí, M. B. (2020). Diversity of anoxygenic phototrophic bacteria in anaerobic lagoons and facultative stabilization pond used in treatment of sewage. *International Journal of Aquatic Biology*, 8(1), 9-17. <https://doi.org/10.22034/ijab.v8i1.688>
- Kasanudin, A., Yuliawati, E., & Fernianti, D. (2025). Aplikasi Fenton – Fotokatalisis TiO<sub>2</sub> pada Pengolahan Air Gambut. *Jurnal Teknologi Riset Terapan*, 2(2), 103-113. <https://doi.org/10.35912/j>
- Kurniadie, D., Wijaya, D., Widayat, D., Umiyati, U., & Iskandar. (2018). Constructed wetland to treat tapioca starch wastewater in Indonesia. *Asian Journal of Water, Environment and Pollution*, 15(3), 107-113. <https://doi.org/10.3233/AJW-180049>
- Mamat, H., Ronie, M. E., Aziz, A. H. A., Ridhwan, N. M., Kobun, R., Pindi, W., ... & Putra, N. R. (2025). Innovative uses of tapioca (*Manihot esculenta* Crantz) flour and starch in food products—a review. *International Journal of Food*, 2(1), 34-64. <https://doi.org/10.51200/ijf.v2i1.5421>

- Mpongwana, N., Ntwampe, S. K. O., Omodanisi, E. I., Chidi, B. S., Razanamahandry, L. C., Dlangamandla, C., & Mukandi, M. R. (2020). Bio-kinetics of simultaneous nitrification and aerobic denitrification (SNaD) by a cyanide-degrading bacterium under cyanide-laden conditions. *Applied Sciences*, 10(14), 4823. <https://doi.org/10.3390/app10144823>
- Nizzy, A. M., & Kannan, S. (2022). A review on the conversion of cassava wastes into value-added products towards a sustainable environment. *Environmental science and pollution research*, 29(46), 69223-69240. <https://doi.org/10.1007/s11356-022-22500-3>
- Potivichayanon, S., Toensakes, R., Supromin, N., & Seaung, K. (2020). Removal of high levels of cyanide and COD from cassava industrial wastewater by a fixed-film sequencing batch reactor. *Water, Air, & Soil Pollution*, 231(6), 301. <https://doi.org/10.1007/s11270-020-04642-7>
- Pratiwi, E. M., Iryani, D. A., Safe'i, R., Haryanto, A., Bakri, S., & Hasanudin, U. (2026). Evaluation of site-specific methane emission factors from biogas production in tapioca industrial wastewater treatment systems. *Jurnal Teknik Pertanian Lampung*, 15(2), 811-820. <https://doi.org/10.23960/jtepl.v15i2.811-820>
- Profile pengelolaan lingkungan industri di Kabupaten Lampung Tengah. (2015). Badan Lingkungan Hidup Kabupaten Lampung Tengah.
- Putra, J. M., Mahadewi, E. P., Sundary, Z. E., Hari, R. T. ., & Muhajir, M. (2025). Exploring Sustainable Hospitality: The Green Hotel Concept in Tourism. *Journal of Economics, Management, Entrepreneurship, and Business*, 5(1), 9-17. <https://doi.org/10.52909/jemeb.v5i1.217>
- Remmas, N. (2022). Biotreatment potential and microbial communities in aerobic bioreactor systems treating agro-industrial wastewaters. *Processes*, 10(10), 1913. <https://doi.org/10.3390/pr10101913>
- Ribeiro, T.S., Aguiar, A. (2024). Performance evaluation of a wastewater treatment plant from a dairy in the state of Minas Gerais, Brazil: A case study.
- Ruscitasari, Z., Marzuqoh, M. ., & Mutia, G. R. (2025). Kesiapan Pelaporan Keberlanjutan Pemerintah Daerah: Kepatuhan Standar Gri di Bantul dan Sleman. *Jurnal Studi Pemerintahan Dan Akuntabilitas*, 4(1), 55-67. <https://doi.org/10.35912/jastaka.v4i1.4241>
- Saini, S., Tewari, S., Dwivedi, J., & Sharma, V. (2023). Biofilm-mediated wastewater treatment: A comprehensive review. *Materials Advances*, 4(6), 1415-1443. <https://doi.org/10.1039/d2ma00945e>
- Satya, I. P., Legiso, L., & Juniar, H. (2025). Efektivitas Arang Aktif Sekam Padi dan Kulit Pisang Kepok sebagai Adsorben pada Pengolahan Air Sungai Sekanak 26 Ilir Palembang. *Jurnal Teknologi Riset Terapan*, 2(2), 75-85. <https://doi.org/10.35912/jatra.v2i2.5002>
- Siller, H., & Winter, J. (1998). Treatment of cyanide-containing wastewater from the food industry in a laboratory-scale fixed-bed methanogenic reactor. *Applied Microbiology and Biotechnology*, 49, 215–220. <https://doi.org/10.1007/s002530051161>
- Siswoyo, E., Faisal, F., Kumalasari, N., & Kasam, K. (2020). Constructed wetlands dengan tumbuhan eceng gondok (*Eichhornia crassipes*) sebagai alternatif pengolahan air limbah industri tapioka. *Jurnal Sains dan Teknologi Lingkungan*, 12(1), 59-67. <https://doi.org/10.20885/jstl.vol12.iss1.art5>
- Suryani, A. S., Tambunan, T. T., Santosa, B., & Haryanto, J. T. (2024). A Circular Economy Approach to Managing Used Cooking Oil for Biofuel Production. *Journal of Economics, Management, Entrepreneurship, and Business*, 4(2), 65-76. <https://doi.org/10.52909/jemeb.v4i2.142>
- Thepubon, T., Choeisai, P., Choeisai, K., & Syutsubo, K. (2023). Treating tapioca starch industrial wastewater using two-phase multi-staged up-flow anaerobic sludge blanket (MS-UASB). *Environment and Natural Resources Journal*, 21(1), 78-89. <https://doi.org/10.32526/ennrj/21/202200210>

- Wattanasilp, C., Songprakorp, R., Nopharatana, A., & Khompatraporn, C. (2021). Techno-cost-benefit analysis of biogas production from industrial cassava starch wastewater in Thailand for optimal utilization with energy storage. *Energies*, 14(2), 416. <https://doi.org/10.3390/en14020416>
- Yosep, Y., Mulkhan, U., Hasanudin, U., & Iryani, D. A. (2024). Unleashing the sustainable transition of circular economy: A case study of SMEs tapioca industry in Lampung, Indonesia. *Circular Economy and Sustainability*, 4(4), 3119-3138. <https://doi.org/10.1007/s43615-024-00358-6>
- Yudhistira, A. ., Suprpto, H. ., & Sulmartiwi, L. (2023). Influence of addition surimi wastewater to macronutrient content (nitrogen, phosphor, and potassium) of gracilaria sp. *Liquid organic fertilizer. Jurnal Ilmiah Pertanian Dan Peternakan*, 1(1), 19-25. <https://doi.org/10.35912/jipper.v1i1.2601>