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Evaluation of Palm Oil Mill Liquid Waste Utilization with the Land Application Method at PT. X

Muhammad Izhar[1]*, Muh. Bambang Prayitno[2], T. Zia Ulqodry[3]

[1]*Environmental Management Study Program, Postgraduate Program, Universitas Sriwijaya. Jl. Padang Selasa No.524, Palembang 30139, South Sumatra, Indonesia*
[2]*Soil Science Study Program, Faculty of Agriculture, Universitas Sriwijaya Jl. Raya Palembang Prabumulih Km.32 Indralaya, Ogan Ilir, South Sumatra, Indonesia*
[3]*Department of Marine Science, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya. Jl. Raya Palembang-Prabumulih KM. 32, Ogan Ilir 30862, South Sumatra, Indonesia*
**Corresponding Author: muhbang_prayitno@yahoo.com*

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Abstract: Palm oil mill effluent (POME), one of the largest wastes produced in the crude palm oil (CPO) production process, is one of the significant environmental challenges in the palm oil industry. POME contains low pH and also contains organic and highly nutritious materials, so it has the potential to be utilized. The land application method has been proposed to utilize POME sustainably. This study evaluated the utilization of POME through the land application method at PT. X, focusing on the palm oil mill liquid waste management system and its effect on surface water quality. The data obtained showed that the PT.X palm oil mill liquid waste management system already succeeded in reducing BOD levels by 64.83%. The results of surface water quality tests in the upstream and downstream water bodies around the activity location also showed that most parameters were still below the quality standards required by government regulations. However, supervision of the implementation of land application must always be carried out because it also has a risk of water pollution if not managed properly.
Keywords: Land Application, POME, Quality of water surface.

1. Introduction

The palm oil industry in Indonesia has become one of the fastest-growing economic sectors in recent decades. With the increasing global demand for palm oil, Indonesia has become the world's largest producer [1]. However, the growth of the palm oil industry has also brought significant environmental challenges. One of the main challenges faced is waste management. Palm oil mills produce liquid waste containing hazardous chemicals and organic residues [2].

Palm oil production is also important in tropical regions, producing the most significant by-product waste [3]. Palm oil mill waste consists of solid, liquid, and gas waste [4]. Typically, palm oil residue and palm oil mill effluent (POME) from Fresh Fruit Bunch (FFB) are produced during processing [5]. The POME is the largest palm oil mill effluent produced from palm oil [6]. This wastewater is a liquid with high viscosity, brown in colour, and at a temperature of 80–90 °C. It has a very low pH value, has high chemical and biochemical oxygen demand, and is highly toxic [7]. The POME is considered one of the significant problems arising in large quantities from the palm oil industry [8]. The Palm Oil Mill Effluent is a thick brownish liquid that contains high solids, oil and grease, COD and BOD values [9]. The POME contains high organic matter and nutrients, which, if not appropriately managed, can pollute the environment [10]. The Palm oil mill liquid waste is usually acidic with a pH of 3.3 – 4.6 [11] [12]. The POME is also reported to have high biological oxygen demand (BOD), high chemical oxygen demand (COD) and acidic pH due to the presence of organic acids in complex form [13].

The POME treatment before discharge into the environment is essential to protect human health and the environment.Biological treatment is preferred due to its environmentally friendly nature and technical and economic feasibility [14]. A more environmentally friendly process is expected to form a better environment and a strategic choice in the modern economy[15]. The land application method is expected to be a solution to manage the POME while increasing soil fertility and oil palm productivity [16]. The POME will be managed in a liquid waste treatment plant before being discharged into the environmental media. It can also be reused because it has high organic content such as nitrogen, phosphorus, and potassium [17]. However, if not appropriately managed, the POME will be a source of environmental pollution, especially for surface water and groundwater [18]. It can cause reduced biodiversity and the ability of aquatic ecosystems [19].Land application as a method of liquid waste management has the potential to reduce the negative impacts of POME by utilizing its nutritional content to support plant growth [20][21]. POME application on land can also improve some chemical properties of acidic mineral soil (Ultisol) around flatbed [22].

Using POME as an organic fertilizer can also increase plantation yields by up to 30% [23]. Research [24] also shows the feasibility of utilizing POME as a growth medium for microalgae. However, it is important to understand that using POME can also affect surface and groundwater quality, so proper management is essential [25]. This study discussed how POME is applied by PT. X in PT. Y plantation land that could affect the local ecosystem. The study focused on the effect of land application applied to the quality of liquid waste used as a substitute for synthetic fertilizers and the quality of surface water around the activity location.

2. Material and Methods

2.1. Materials

The study was conducted at PT. X and PT. Y located in Gasing Village, Talang Kelapa Subdistrict, Banyuasin District of South Sumatra Province. The distance from PT. X to the center of Banyuasin District government is ± 50.83 km via Tanjung Api-api Road (± 12.3 km) and the Palembang-Pangkalan Balai Trans-Sumatra Road (± 38.532 km). This research was carried out from November 2024 to January 2025. It was conducted through observation, calculation, measurement, and direct interviews in the field using the purposive sampling method for the parameter sampling environment at 2 locations, namely contacted fond and upstream and downstream locations of water bodies around the activity site. The tools used in this study were a camera for documentation, sampling bottle (sterile bottle), thermometer, measuring instrument (scale), stopwatch, checklist/form, pH meter, litmus paper, and Global Positioning System (GPS). The POME characteristics are presented in Table 1 as follows.

Table 1. POME Characteristics [18]

No	Parameter	Unit	Concentration range
1	pH	-	4.14 – 4.45
2	COD	mg/l	45,500 – 65,000
3	BOD	mg/l	21,500 – 28,500
4	oil and grease	mg/l	1,077 – 7,582
5	TSS	mg/l	15,500 – 29,000

2.2. Methods

2.2.1. Sample collection and preparation

This study used primary and secondary data. Field observations were conducted to directly observe PT.X's liquid waste management system process at PT.X until it was utilized using the land application method to PT.Y's land. The liquid waste samples were taken at the inlet and outlet of the contacted pond or pool that would be channelled to the land application. The surface water samples were taken from the upstream and downstream of the Gasing River near PT. Y. The samples were taken in November 2024 and then taken to the KAN-accredited PT. ITEC Solution Indonesia laboratory to be analyzed for several parameters such as pH, COD, BOD, DO and TSS to then be compared with the required quality standards in accordance with the government regulation number 22 of 2021 concerning the implementation of environmental protection and management.

2.3. Experimental variable and analytical procedures

The variables studied included the quality of liquid waste used as a substitute for synthetic fertilizers and surface water quality. The parameters tested were pH and biological oxygen demand (BOD). For the surface water quality, the parameters tested covered pH, biological oxygen demand (BOD), chemical oxygen demand (COD), Total suspended solids (TSS), Dissolve Oxygen (DO), oil and fat and e-Coli in the upstream and downstream of the Gasing River around the PT.Y. location.

2.4 Data Analysis

The data used in this study were primary and secondary data. The field observations were conducted to directly observe the process of managing liquid waste produced at WWTP PT.X. Evaluation of the quality of liquid waste to be used as land application, namely waste from the contacted pond was taken and then tested in the laboratory for pH and biological oxygen demand (BOD) parameters and then compared with the Decree of the Minister of Environment No. 28 of 2003 concerning Technical Guidelines for the Assessment of Liquid Waste Utilization from the Palm Oil Industry to Palm Oil Plantation Land as amended in the Regulation of the Minister of Environment and Forestry Number 05 of 2021 concerning Procedures for Issuing Technical Approvals and Operational Eligibility Letters in the Field of Environmental Pollution Control, while the evaluation of surface water quality will be sampled from the upstream and downstream of the water body around the PT. X location. The results of the sample analysis for each parameter were compared with the Attachment V of Government Regulation Number 22 of 2021 concerning the implementation of environmental protection and management for class 2 quality standards.

3. Results and Discussion

3.1 Liquid waste management of PT. X

The amount of liquid waste from a factory depends on its capacity. PT. X's palm oil processing factory has a capacity of 30 tons of FFB/hour. On average, the amount of wastewater produced is around 60% of the factory's capacity. So if the capacity of the CPO factory = 30 tons of FFB/hour, then the amount of wastewater is around 18 m^3/hour. The installed production process runs in two shifts, 20 hours/day. So, the amount of wastewater is 20 x 18 = 360 m3/day. Due to the high organic content in waste, a series of treatments are required, such as anaerobic, aerobic and facultative ponds and tank systems, before it can be discharged into the river [26].

The liquid waste in the contacted pond will be pumped to the land at the location of the land application at PT. Y with pipes or continue to the aerobic pond, depending on the needs. The size of this pond is 80 x 15 x 4 m. Utilizing or disposing of the waste depends on the standard quality value that has been set.The management of liquid waste of PT. X's palm oil factory consists of 7 ponds, including:

3.1.1 Sand Cascade

It captures oil from the released waste before the liquid waste is channelled into the holding pond. The size of the sand cascade pond is 40 x 40 x 4 m with a tiered depth of 0.65 - 1.0 m.

3.1.2 Fat Pit

The hot and fresh liquid waste in the fatpit can still be separated again for oil and water content based on specific gravity. The top layer of flowing waste is returned to the clarifier. Furthermore, the liquid waste with low oil content is flowed into the holding pond.

3.1.3 Cooling Pond

The cooling pond aims to cool the liquid waste that is still 800^0 C to below 400^0 C to support the life of anaerobic bacteria in the next pond. The size of this pond is 40 m x 40 m for the bottom of the pond 39 m and 40 m x 40 m for the top of the pond with a depth of 2 m and the installation of a 4 m high embankment.

3.1.4 Mixing Pond

The liquid waste is channelled from the cooling pond into two mixing ponds, each measuring 80 x 15 m with a depth of 4 m. The liquid waste has a pH between 4 - 5 which is suitable for the life of acidifying bacteria. The bacteria playing a role in biochemical oxidation are known as acid-producing bacteria due to their reaction in changing compound organic components into volatile acids (volatile fatty acids). The reaction time for the acidification pond is 20 days. From this process the pH of the waste increases to between 6 – 7.

3.1.5 Anaerobic Pool

There are two anaerobic ponds measuring 80 x 15 x 4 m. In these ponds, the process of breaking down organic matter from liquid waste by microbes originating from the breeding pond into simpler organic acid compounds occurs, which then become methane, carbon dioxide and hydrogen gas (organic matter → CH_4 + CO_2 + H_2O + energy). The decomposition of organic compounds is carried out by acid-producing bacteria (acetogenic bacteria), namely Lactobacillus bulgaricus, and Clostridium tetani. This first group of bacteria is tasked with breaking down various types of compound organic compounds into volatile acid compounds, especially acetic acid. The first group of bacteria is called acid producing bacteria. The efficiency of reducing or decreasing the BOD effluent levels in anaerobic ponds is between 70 - 75%. The process requires a retention time of 20 days, the decomposition efficiency is 90 - 98%. From this process, the BOD drops to 1,000 - 1,500 mg/L.

3.1.6 Contact Pond

This pond serves as a place to drain waste to the Land Application (LA) on PT.Y's land or continue to the aerobic pond depending on the needs. The size of this pond is 80 m x 15 m x 4 m. To utilize or dispose of waste depends on the standard quality value that has been set.

3.1.7 Aerobic Pond

This pond consists of 1 pond, each measuring 32 m x 34 m with a depth of 2 m. In order for the BOD value to decrease, surface aerator equipment is needed. With the help of this tool, BOD with a level of 1,000 - 1,500 mg/L is sprayed into the air so that the activity of aerobic microorganisms increases rapidly and the BOD level drops to 250 mg/L. The time for this process is 25 days. The aerobic bacteria are those that require O_2 for their growth. The enzyme system requires O_2 as an electron acceptor in the oxidative phosphorylation process. Several types of bacteria used to break down organic matter in aerobic ponds are *Bacillus* sp., *Escherichia coli*, and *Streptococcus*.

The following is a flow diagram of liquid waste management at PT. X's palm oil mill.

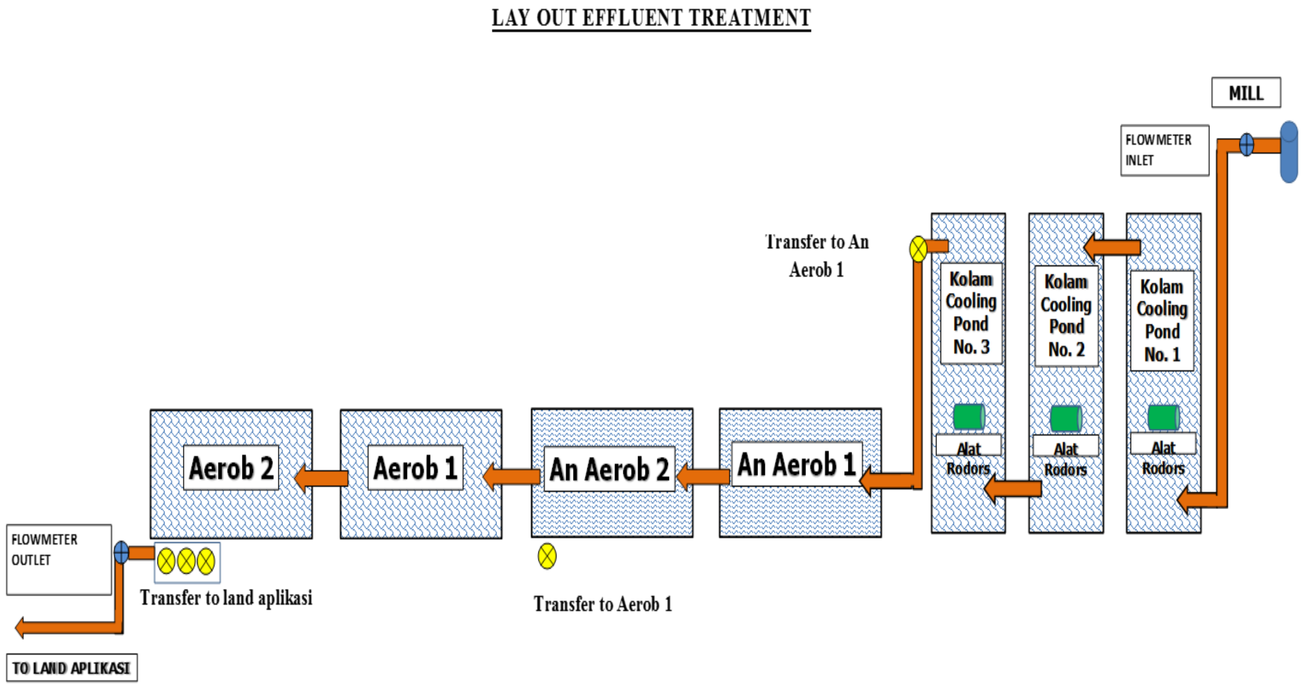

Figure 1. Processing System Flowchart in Liquid Water Treatment Plant at PT. X

From the Waste Management Installation owned by PT. X, will be applied to the land of PT. Y, which is taken from pond 6 (contact pond) with a benchmark referring to the Decree of the Minister of Environment No. 28 of 2003 concerning Technical Guidelines for the Assessment of Wastewater Utilization from the Palm Oil Industry to Palm Oil Plantation Land as amended in the Regulation of the Minister of Environment and Forestry Number 05 of 2021 concerning Procedures for Issuing Technical Approvals and Operational Eligibility Letters in the Field of Environmental Pollution Control.

Rotation of palm oil mill liquid waste application to PT. Y plantation land is carried out every three months or 4 times a year. Each long bed is filled with PKS liquid waste as high as 40 cm, a ditch with a depth of 60 cm, a width of 150 cm and a length of 230 m. In each 25 Ha plant block, there are 60 long beds, so the dose given is described as follows.

Waste volume/long bed/application = waste length x waste width x waste height
= 230 m x 1,5 m x 0,4 m
= 138 m^3

Waste volume/Year/Plant block = Waste volume/Long bed/Application x Frequency of application per year x number of long beds = 138 m^3 x 4 x 60 = 33,120 m^3

Volume of liquid waste application/Ha/Year = Volume of waste/Year/Plant Block / area of plant block = 13,800/25 Ha = 1,324.8 m^3

Based on the permit granted, the maximum amount of wastewater that can be utilized on land in PT. Y is 1,324.8 m^3 per hectare per year, with Application Blocks E09, E10, E11, E12, E16, with 3 (three) monitoring wells consisting of SP Block E09, SP Block E10 and SP Control Land Block E15.

3.2 Evaluation of the WWTP Efficiency of PT. X

The purpose of this evaluation is to find out the ability of PT. X's liquid waste management system to reduce the concentration of certain liquid waste parameters in conditions before and after the process. This evaluation can be used as a benchmark for the success of carrying out the operation and maintenance of the liquid waste treatment plant.

$$Efficiency = \frac{BOD\ Inlet - BOD\ Outlet}{BOD\ Inlet} x\ 100\% \quad (1)$$

$$Efficiency = \frac{10.750 - 3.780}{10.750} x\ 100\%$$

$$Efficiency = 64{,}83\%$$

The results of this efficiency measurement shows that the operational and maintenance programs carried out by PT. X have been implemented well and the waste to be applied has met the required quality standards.

3.3 Evaluation of the quality of PT.X liquid waste as a

substitute for synthetic fertilizer

The quality of liquid waste of PT.X is a key factor in determining the success of the land application method. According to the standards set by the Ministry of Environment and Forestry (KLHK), POME must meet certain criteria before being used for land application. Parameters that need to be considered include pH and BOD. A study by [12] showed that POME that has undergone an anaerobic treatment process has a lower BOD content than raw POME, making it safer for use in land applications..

Table 2. Liquid Waste Analysis Results of PT. X Factory

No	Parameter	Unit	Analysis Results		Quality standards
			Inlet	Outlet	
1	pH	-	5,25	8,02	6 – 9
2	BOD	mg/l	10.750	3.780	< 5.000

The analysis results show that the pH level ranges from 8.02 after processing. In contrast, the BOD POME level drops from 10,750 mg/L to 3,780 mg/L, below the maximum limit of the Ministry of Environment and Forestry. The data show that the liquid waste produced has met the requirements for use in land applications. However, although treated POME shows better quality, it should be noted that excessive use can cause the accumulation of pollutants in soil and surface water. Excessive application of POME can increase nitrate levels in soil, which has the potential to pollute surface water sources [28]. Therefore, careful management and regular monitoring are essential to ensure that the POME application does not harm the environment.Furthermore, the quality of liquid waste used in land applications is also influenced by environmental factors, such as rainfall and soil type. High rainfall can cause leaching of nutrients from the soil, thereby reducing the effectiveness of POME applications [29]. Consequently, selecting the right time and application method is very important in maximizing the benefits of POME.

3.4 Evaluation of the effect of the use of PT.X liquid waste on surface water quality

Laboratory analysis shows that liquid waste from PT.X has varying characteristics depending on the sampling location. At the upstream point of the river, the pH of surface water was recorded at 4.27, while at the downstream, it increased to 4.45. Although the BOD and COD parameters showed relatively low values, namely 2.31 mg/l and 13.84 mg/l upstream and 2.64 mg/l and 16.42 mg/l downstream, the low pH value remains a significant concern. This condition is because this water body is greatly influenced by the natural conditions, namely acid sulfate swamp land around the sampling location and the increased community activities around it.

Other parameters that need to be considered are the TSS and oil and fat content. The analysis results show that the TSS at the upstream point is 11 mg/l and at the downstream point 13 mg/l, while the oil and fat content is 0.42 mg/l and 0.52 mg/l, respectively. Although this value is still below the established threshold, a long-term accumulation can cause more serious pollution if not managed properly. TSS accumulation can affect water quality and the health of aquatic ecosystems [30]. Overall, the evaluation of surface water quality is still below the established quality standards except for the pH parameter.

Table 3. Results of the surface water quality analysis around PT. X location

Parameter	Unit	Locations		Quality standards	Test Method
		Upstream	Downstream		
pH	-	4.27	4.45	6 - 9	SNI 6989.11-2;2019
BOD_5	mg/l	2.31	2.64	3	SNI 6989.72:2009
COD	mg/l	13.84	16.42	25	SNI 6989.2:2019
DO	mg/l	5.10	5.84	Minimum 4	SNI 06-6989.214-2004
TSS	mg/l	11	13	50	SNI 6989.3:2019
Oil and Fat	mg/l	0.42	0.52	5	ITEC.IK-7.2-1.17

4. Conclusion

Based on the results of this study, almost all of the parameters required by government regulation number 22 of 2021 concerning the implementation of environmental protection and management have met the permitted quality standards. The pH parameter that has not reached the expected quality standard is because the water body of the sampling point site has the characteristics of acid sulfate swamp land, and there is an increase in community activities in the surrounding area.

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