MIKAILALSYS
Journal of Multidisciplinary Sciences

e-ISSN : 2987-2286
p-ISSN : 2987-3924

Index: Harvard, Boston, Sydney, Copernicus, Sinta 4, Scilit, Semantic, Google, etc

https://doi.org/10.58578/mikailalsys.v4i3.11708

Wastewater Treatment of the Cracker Industry Using the Phytoremediation Method with Water Lettuce (*Pistia stratiotes*) Plants

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Article Info:

Submitted:	Revised:	Accepted:	Published:
Jun 22, 2026	Jul 20, 2026	Aug 1, 2026	Aug 6, 2026

Abstract

Cracker-industry wastewater contains substantial organic matter and suspended solids that may pollute the environment when discharged without adequate treatment. This study aimed to characterize cracker-industry wastewater, evaluate the phytoremediation effectiveness of water lettuce (*Pistia stratiotes*), and determine the effects of plant mass and contact time on total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), dissolved oxygen (DO), and pH. A batch-system experiment was conducted using plant masses of 400 and 600 g, alongside a control, with contact times of 0, 3, 6, and 9 days. The initial wastewater characteristics were 168 mg/L TSS, 492.8 mg/L COD, 8.02 mg/L DO, and a pH of 6.5. The findings demonstrate that phytoremediation using *P. stratiotes* effectively reduced TSS, COD, and BOD concentrations and improved wastewater quality. After nine days, the highest TSS removal efficiency was 84% with 600 g of plant biomass, resulting in a final concentration of 27.5 mg/L. The highest COD removal efficiency was 63% with 600 g of plant biomass, producing a final concentration of 182.05 mg/L, whereas the highest BOD removal efficiency was 75% with 400 g of plant

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biomass, resulting in a final concentration of 21.30 mg/L. Contact time significantly affected COD and BOD reductions and changes in pH, while plant mass had no significant effect. The study concludes that *P. stratiotes* has considerable potential as a simple, economical, and environmentally sustainable phytoremediation agent for cracker-industry wastewater. These findings provide practical evidence for developing low-cost biological wastewater-treatment strategies for small-scale food-processing industries.

Keywords: Cracker-Industry Wastewater; Phytoremediation; Water Lettuce; Organic Pollutant Removal; Wastewater Treatment

INTRODUCTION

The cracker industry is a food sector widely operated by Micro, Small, and Medium Enterprises (MSMEs) in Indonesia and plays an important role in the local economy. However, the production process produces liquid waste with high levels of dissolved and suspended organic matter, such as BOD, COD, and TSS, as well as oil and fat, which have the potential to exceed environmental quality standards if not treated (Novita et al., 2019; Subqi et al., 2024; Sukono et al., 2020) High concentrations of these parameters can degrade the quality of receiving water bodies through reduced dissolved oxygen, increased turbidity, and disruption to aquatic ecosystems. Therefore, effective, economical, and environmentally friendly processing methods are needed for MSMEs.

Phytoremediation using aquatic plants is a suitable approach because it can reduce organic loads and suspended solids without requiring complex infrastructure (Syuhada et al., 2025). The apu tree (Pistia stratiotes) is known for its rapid growth and dense root system, making it effective in absorbing and decomposing organic pollutants through the interaction of roots and rhizosphere microorganisms, with various previous studies showing a significant reduction in TSS and COD parameters in food industry wastewater (Kurniawan, 2017; Qohar & Rahmayanti, 2024). This study aims to determine the ability of the apu tree to reduce BOD, COD, and TSS concentrations in cracker industry wastewater using a phytoremediation system.

METHODS

This research is a quantitative descriptive study with an experimental method. The pollutant parameters analyzed in this study were Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Dissolved Oxygen (DO), and pH. The study was conducted in two stages: preliminary research and main research. The preliminary stage included an initial characterization analysis of liquid waste using the grab sampling method at the outlet channel with testing of each pollutant parameter, followed by plant acclimatization for 7 days. The phytoremediation process was carried out for 9 days. Wastewater sample testing was carried out on days 0, 3, 6, and 9 for analysis of TSS, COD, BOD, and DO parameters, while pH measurements were carried out daily throughout the research process. The experimental design of the phytoremediation process used variations of 200 grams and 600 grams of pumice wood plants. The experimental design of the research is as shown in **Table 1**. The phytoremediation process reactor uses a batch system as shown in **Figure 1**.

Table 1. Experimental Design

Reaktor (Berat Tanaman)	Waktu Kontak (Hari)			
1	0	3	6	9
400 gram	0	3	6	9
600 gram	0	3	6	9

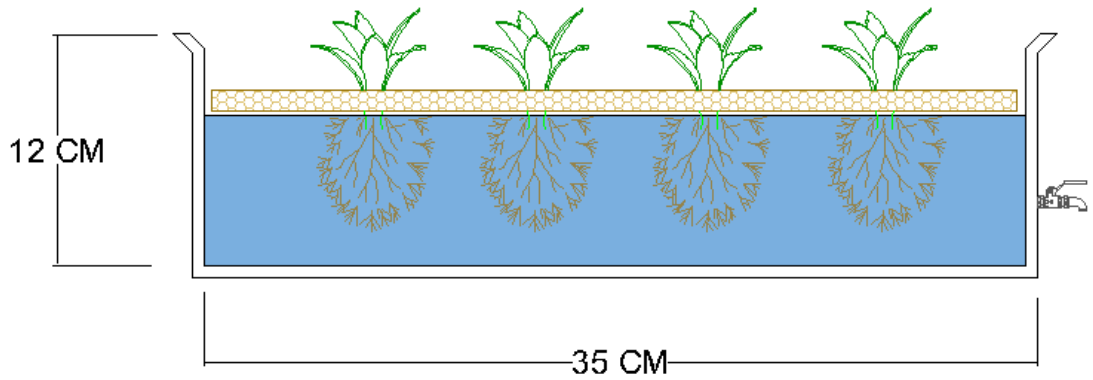


Figure 1. Phytoremediation Reactor Design

The obtained TSS, COD, BOD, and DO parameter values were then measured to determine the removal efficiency of these two parameters during the study, with the plant variations specified in the study. According to (Quraini et al., 2022), the removal efficiency

values for TSS, COD, BOD, and DO parameters were calculated using the following formula.

$$\text{Efficiency } (\%) = \frac{Co - Ci}{Co} \text{ x } 100\% \quad (1)$$

Explanation:

Co = Concentration of parameters before treatment (mg/l)

Ci = Parameter concentration after treatment (mg/l).

RESULTS

Initial Characteristics of Liquid Waste from the Cracker Industry

This initial test was conducted on day 0, or immediately after the liquid waste was collected at the site using the Grab Sampling method. The results of this test will be used as initial data for the main research. The parameters tested were TSS, COD, BOD, pH, and DO. The results of the initial characteristic test on the liquid waste from the Telagasari 3 Cracker Factory are shown below.

Table 2. Results of Initial Wastewater Characteristics Test

No	Parameter	Satuan	Hasil Uji	Baku Mutu*)
1	COD	mg/L	492,8	300
2	TSS	mg/L	168	100
3	BOD	mg/L	85,65	150
4	pH	-	6,50	6 - 9
5	DO	mg/L	8,02	Minimal 3

Sumber: *) Appendix V of the Minister of Environment Regulation No. 5 of 2014 concerning Wastewater Quality Standards for Tapioca Industrial Businesses and/or Activities

Based on the results of the initial characteristic test, it was found that the COD parameter concentration value of 492.8 mg/L and TSS 168 mg/L still exceeded the standard. The high COD concentration value in cracker industrial wastewater indicates the large amount of organic compounds originating from starch, dough residue, and additional materials wasted during the production process, such as washing and boiling. This can cause a decrease in water quality because microorganisms require a lot of oxygen to oxidize the existing organic and inorganic materials, and negatively impact aquatic life. (Kustiyaningsih & Irawanto, 2020; Napitupulu & Putra, 2024).

The high concentration of TSS in cracker industry wastewater is caused by suspended solid particles in the form of starch or flour residue, fiber, and other organic materials derived from the washing process of production equipment and raw materials, as well as boiling. High TSS concentrations can increase water turbidity, reducing sunlight penetration into the water, which can inhibit photosynthesis (Fajriaty et al., 2025; Hafidhin et al., 2023).

COD (Chemical Oxygen Demand) Removal Efficiency

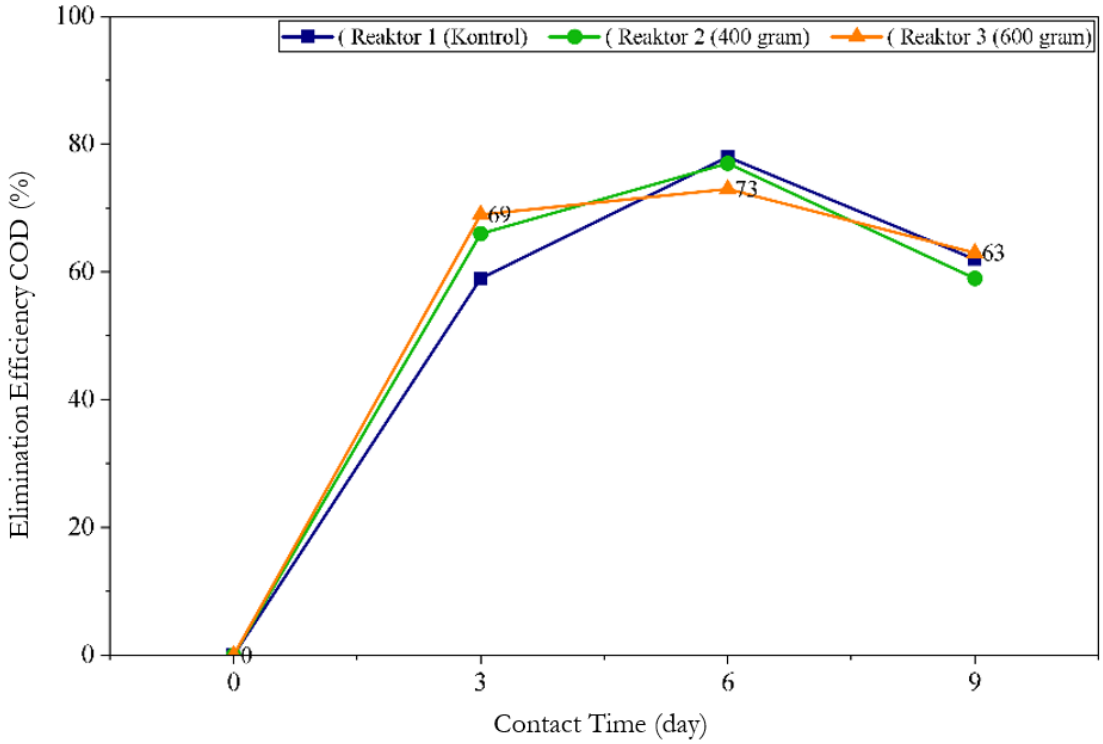


Figure 2. COD Removal Efficiency

COD concentration decreased during the phytoremediation process. The highest COD removal efficiency of 63% with a final concentration of 182.05 mg/L was obtained in reactor 3 (600 g) after 9 days of contact time. The decrease in COD indicates a reduction in the content of oxidizable organic compounds in the wastewater. The presence of Kayu Apu plants supports the activity of microorganisms in the rhizosphere, thus optimizing the biodegradation of organic matter. Furthermore, the decrease in concentration in the control treatment could be due to natural mechanisms such as sedimentation of suspended particles and the activity of microorganisms that decompose organic matter (Kurnianingtyas et al., 2026). On the 9th day, removal efficiency decreased in all reactors. This decrease in removal is thought to be due to the plants experiencing stress from prolonged exposure to waste,

which causes the leaves to turn yellow and wilt, thus reducing removal efficiency (Hasanah, 2023; Ruhmawati et al., 2017).

Biological Oxygen Demand (BOD) Removal Efficiency

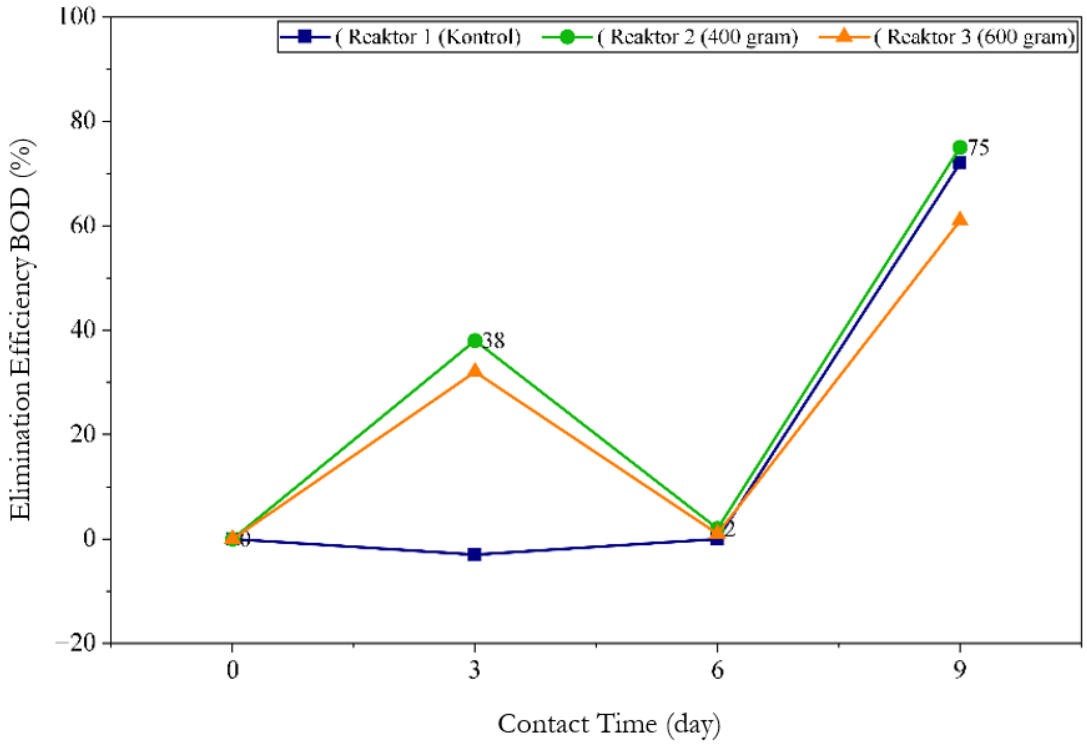


Figure 3. BOD Removal Efficiency

BOD values also decreased during the phytoremediation process. The highest removal efficiency reached 75% in reactor 2 (400 g) with a contact time of 9 days. BOD removal efficiency increased with increasing contact time in all reactors, although with different patterns. On day 3, the control reactor had not shown a decrease in BOD, while the reactors with 400 g and 600 g of pumice plants had achieved removal efficiencies of 38% and 32%, respectively. This indicates that the presence of plants accelerates organic matter removal through rhizofiltration mechanisms and increased microbial activity in the root zone (Indrawati et al., 2025).

On the 6th day of the phytoremediation process, the removal efficiency in the plant reactor decreased slightly, which is thought to be due to plant stress, resulting in reduced absorption and photosynthesis capabilities (Kencana & Radityaningrum, 2022). However, on the 9th day, all reactors again experienced increased efficiency, with the 400 g reactor showing the highest BOD removal. This increase was influenced by the longer contact time, which optimized the phytodegradation process and microbial activity, and was supported by

environmental conditions such as pH and temperature that supported the biodegradation of organic matter (Wiratama, 2024).

TSS (Total Suspended Solids) Removal Efficiency

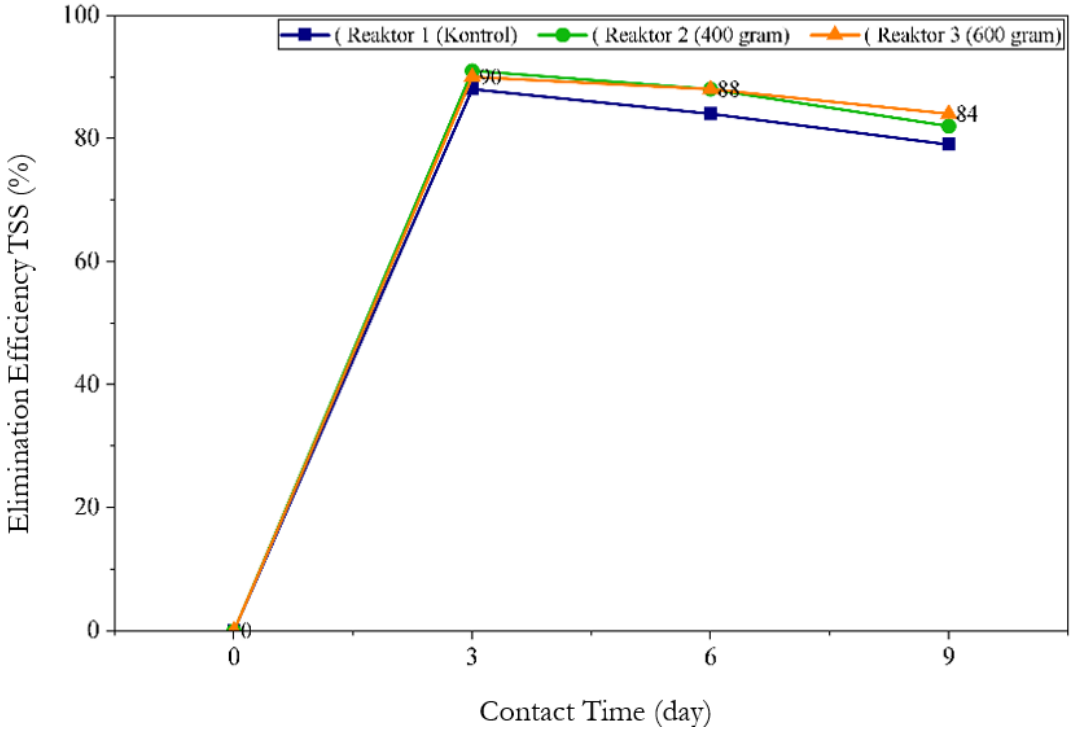


Figure 4. TSS Removal Efficiency

The results of the study showed that the Kayu Apu plant was able to reduce TSS concentration during the phytoremediation process. The highest TSS removal efficiency reached 84% with a final concentration of 27.5 mg/L in a reactor with a plant mass of 600 grams and a contact time of 9 days. The reduction in TSS occurred because the Kayu Apu root system was able to trap suspended particles and accelerate the particle sedimentation process in the reactor. In addition, the plant roots also function as a growth medium for microorganisms that help the process of decomposing organic materials and suspended solids in waste. (Wahyuni & Aulia, 2025)

According to (Rahadian et al., 2017), SS removal is not only influenced by the presence of plants, but also by physical processes such as sedimentation or settling of suspended particles at the bottom of the reactor. From day 6 to day 9, there was a decrease in removal efficiency throughout the reactor. This condition is thought to occur due to parts of the plants that began to die during the phytoremediation process. Damaged plant tissues

such as roots and leaves can decompose and release organic matter into the wastewater, thereby increasing the amount of suspended solids (Wahyuni & Aulia, 2025).

Analysis of Changes in DO (Dissolved Oxygen) Values

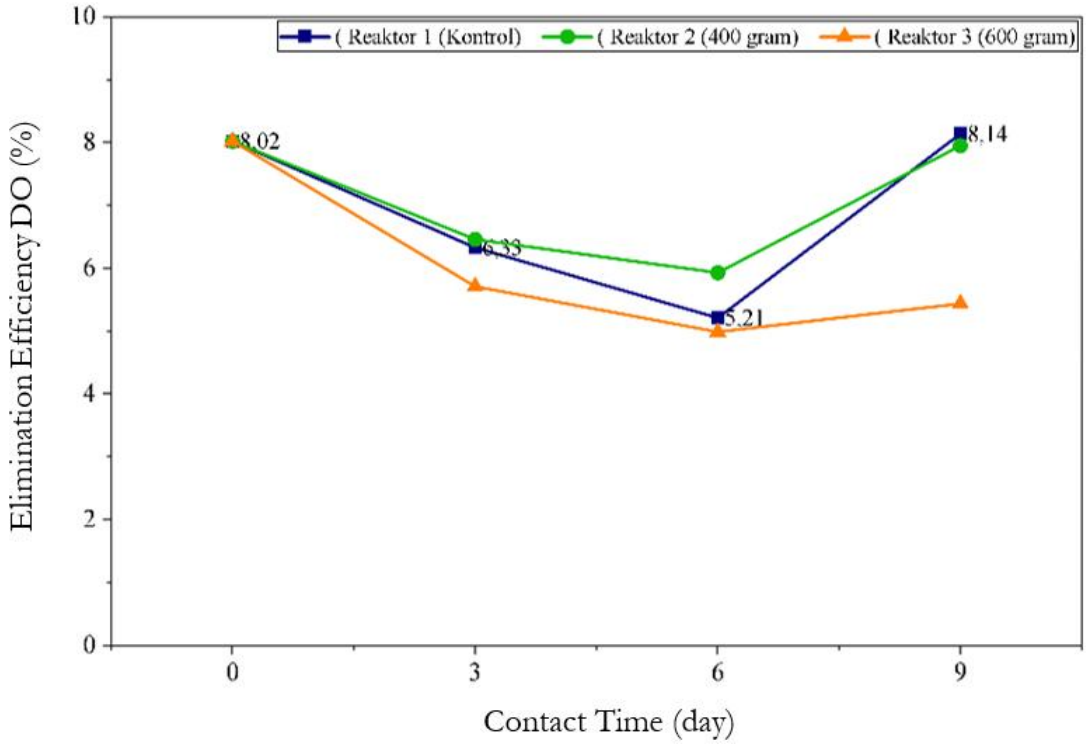


Figure 5. Change in DO Value

The DO concentration in all reactors decreased from day 0 to day 6 due to the high oxygen demand by microorganisms in decomposing organic materials, while the oxygen produced by plant photosynthesis was not yet able to compensate for this oxygen consumption (Indrawati et al., 2025). (Indrawati et al., 2025). The planted reactor showed DO levels that were more influenced by plant respiration activity and oxygen release through roots in the rhizosphere, while the control reactor only relied on oxygen diffusion from the air (Santosa et al., 2025).

On the 9th day, DO levels increased again in all reactors, especially in the control reactor and the 400 g reactor, which indicated that most of the organic material had been degraded so that the oxygen requirements of microorganisms decreased, while oxygen from photosynthesis began to accumulate in the water. (Napitupulu & Putra, 2024). All reactors continued to meet the DO quality standards for Class III river water as per Government Regulation No. 22 of 2021 (≥3 mg/L). The increase in DO at the end of the observation period also corresponded to an increase in BOD removal efficiency, although this did not

fully translate into an increase in COD efficiency due to the presence of more difficult-to-degrade organic compounds.

Analysis of pH Value Changes

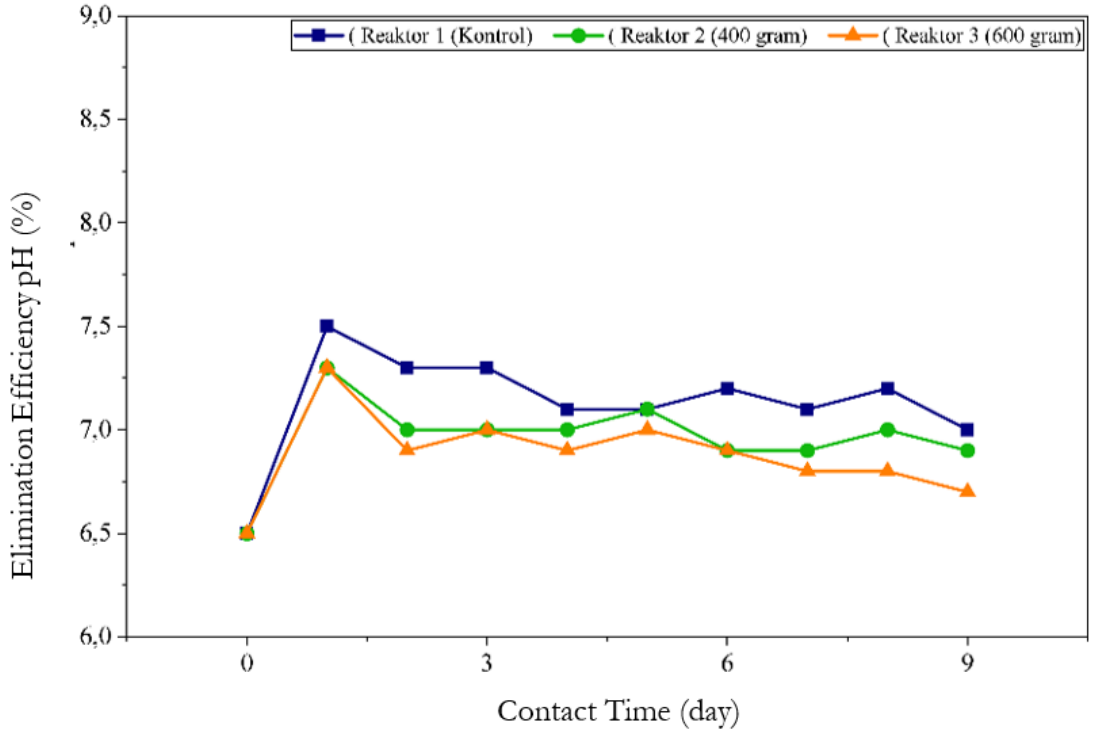


Figure 6. Changes in pH Value

The pH value in all reactors was in the range of 6.5–7.5 during the phytoremediation process, thus still meeting the quality standards for tapioca industrial wastewater based on Ministerial Regulation of the Environment No. 5 of 2014 (pH range 6–9). On the first day, the pH of all reactors increased, which is thought to be influenced by the low CO_2 formation in the control reactor and the start of photosynthesis in the pumice wood plants that utilize dissolved CO_2, resulting in an increase in pH (Ni'mah L et al., 2019).

The pH tends to decrease gradually until the 9th day due to the respiration activity of microorganisms and the decomposition of organic matter, which produces CO_2, as well as the phytoremediation process in the rhizosphere area (Wahyuni & Aulia, 2025). The decrease in pH is also thought to be influenced by the onset of wilting and decay of some plant tissues, which produce acidic compounds (Aziz et al., 2020). The reactor with a plant mass of 600 g showed the lowest pH value at the end of the observation period due to higher plant and microorganism metabolic activity in the root zone compared to the other treatments. However, pH fluctuations were relatively small and remained neutral, supporting

microorganism activity in the biodegradation process, enabling optimal BOD and COD removal (Wahyuni & Aulia, 2025).

DISCUSSION

This study shows that the phytoremediation method using pumice (Pistia stratiotes) plants can improve the quality of cracker industry wastewater by reducing the concentrations of TSS, COD, and BOD, as well as changes in DO and pH values over 9 days of treatment. In general, the increase in removal efficiency occurs with increasing contact time, although the magnitude of the reduction varies for each parameter and with variations in plant mass. The reactor with a plant mass of 600 g provided the highest removal efficiency for TSS and COD parameters, while the reactor with a mass of 400 g showed the best performance in BOD removal. These differences indicate that the removal mechanism of each parameter is influenced by the characteristics of the pollutant and the phytoremediation process taking place in the reactor, so that variations in plant mass have different effects on the removal effectiveness of each parameter.

The decrease in TSS concentration indicates that the root system of the pumice tree acts as a natural filtering medium capable of capturing suspended particles, while simultaneously creating conditions that support the sedimentation of solids to the bottom of the reactor. In addition to these physical processes, the presence of roots also provides a surface for the growth of microorganisms in the rhizosphere, which helps stabilize and decompose organic matter attached to suspended particles. These results are in line with research (Santosa et al., 2025) which states that the rhizosphere is a habitat for microorganisms that play an important role in the biodegradation process during phytoremediation.

The reduction in COD and BOD indicates that pumice wood is able to enhance the biodegradation process of organic compounds through interactions between plants and microorganisms. The root system provides oxygen and root exudates that stimulate microbial activity; thus, the decomposition process of organic matter is more effective. However, the COD removal efficiency at the end of the observation did not increase as much as BOD. This condition indicates that most of the easily degraded organic compounds have been successfully decomposed, while there are still more complex organic compound fractions that require a longer residence time to decompose. This finding is consistent with the

characteristics of COD, which represents the total organic matter, both easily and difficult to degrade.

Changes in DO and pH values during the study also illustrate the dynamics of biological processes within the phytoremediation reactor. The decrease in DO at the beginning of the study indicates that microorganisms utilize more dissolved oxygen to decompose organic matter than the oxygen produced by plants through photosynthesis. After most of the organic matter has degraded, DO levels rise again due to the reduced oxygen demand of microorganisms and the increased contribution of plant photosynthesis. Meanwhile, the pH value remains in the neutral range throughout the study, creating conditions that support both microbial activity and plant growth. The stability of the pH value indicates that the phytoremediation system is able to maintain the balance of biological processes despite the decomposition of organic matter.

The results of this study indicate that phytoremediation using Pistia stratiotes has the potential to be a simple, economical, and environmentally friendly alternative for processing liquid waste from the cracker industry. The use of optimum plant masses of 400 g and 600 g with a contact time of 9 days can increase the efficiency of pollutant parameter removal without requiring additional chemicals or an aeration system. Therefore, this method has the potential to be applied as a small- to medium-scale biological treatment, especially in the household cracker industry.

However, this study has several limitations. Observations were conducted over only nine days with limited variation in plant mass, so it does not yet describe the effectiveness of phytoremediation over a longer period or at a wider variety of plant densities. Furthermore, this study did not analyze the microbial population in the rhizosphere or the nutrient content absorbed by the plants, so the pollutant removal mechanism cannot be explained in more depth. Future research is recommended to evaluate longer residence times, more diverse plant biomass variations, and examine microbial activity and pollutant accumulation in plant tissues to achieve a more comprehensive understanding of the phytoremediation mechanism.

CONCLUSION

Based on the results of the phytoremediation research on liquid waste from the cracker industry using the Apu Wood Plant (Pistia Stratiotes) to reduce the concentration of TSS, COD, and BOD, the following conclusions can be drawn.:

1. The initial characteristics of cracker industry wastewater before the phytoremediation process showed that COD parameter values of 492.8 mg/L and TSS of 168 mg/L were still above the wastewater quality standards, and BOD of 85.65 mg/L, pH 6.50, and DO of 8.02 mg/L were in accordance with the wastewater quality standards.

2. 2. The Apu Wood plant (Pistia Stratiotes) has been proven effective in reducing TSS, COD, and BOD concentrations. The highest TSS removal efficiency of 84% (27.5 mg/L) was obtained in Reactor 3 with a plant mass variation of 600 grams on the 9th day of contact time, which had a pH value of 6.75 and DO of 5.44 mg/L. The highest COD removal efficiency of 63% (182.05 mg/L) was obtained in Reactor 3 with a plant mass variation of 600 grams at the 9th day of contact time, which had a pH value of 6.75 and DO of 5.44 mg/L. The highest BOD removal efficiency of 75% was obtained in Reactor 2 with a mass of 400 grams at a 9-day contact time, which had a pH value of 6.85 and DO of 7.95 mg/L.

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