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THE EFFICIENCY OF HORIZONTAL SUB-SURFACE FLOW CONSTRUCTED WETLANDS WITH *EQUISETUM HYEMALE* IN REDUCING COD AND BOD_5 IN LAUNDRY WASTEWATER

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Abstract

Laundry businesses in Indonesia have high economic development opportunities. However, laundry wastewater in Indonesia does not yet have a good environmental culture and regulations for service users. Constructed wetland can be used as a sustainable biological processing technology, uses low energy, and does not require high costs to process laundry wastewater. The aim of this research is to analyze the ability of horizontal sub-surface flow constructed wetlands in a batch system with different numbers of aquatic bamboo plants (*Equisetum hyemale*) in degrading chemical oxygen demand (COD) and *biochemical oxygen demand* (BOD_5) in laundry wastewater. The research results showed that reactor 2 HSSF CW with a total of 200 *E. hyemale* plants produced higher removal efficiency compared to reactor 1 HSSF CW with a total of 120 *E. hyemale* plants where reactor 2 produced COD and BOD_5 removal efficiency respectively. amounted to 88.22% and 90.30% while reactor 1 produced COD and BOD_5 removal efficiencies of 86.04% and 88.10% respectively. Based on these results, reactor 1 and reactor 2 horizontal sub-surface flow constructed wetlands with *E. hyemale* plants produced effective performance in reducing COD and BOD_5 concentrations in laundry wastewater.

Keywords: Water bamboo (*Equisetum hyemale*), removal efficiency, Horizontal Sub-Surface Flow Constructed Wetlands (HSSF CWs), laundry wastewater, batch system

Introduction

The laundry business in Indonesia has high economic development opportunities. However, laundry liquid waste in Indonesia does not yet have a good corporate culture and regulations towards service users. Apart from that, Indonesian people lack insight into environmental resource management. Laundry liquid waste that is produced from the hotel and hospital business and does not go through processing at the Waste Water Treatment Plant (IPAL), is often thrown into the drainage where the waste still contains foam and pollutes local waters. This causes a negative impact on biota that live in fresh waters. Liquid laundry waste contains macro nutrients which are essential for aquatic biota. Laundry liquid waste comes from detergent constituents (Mulyo, et al., 2021). Organic and inorganic compounds in liquid waste that enter the environment without going through wastewater treatment in large quantities cause environmental pollution and eutrophication in water bodies. Laundry liquid waste originating from laundry activities is an organic and inorganic carrier in the water bodies of large Indonesian cities as a result of the increase in population and the limited availability of laundry liquid waste processing installations. Therefore, liquid laundry waste must be processed appropriately to reduce organic and inorganic compounds entering water bodies. Strategies that can be implemented for processing liquid laundry waste can be carried out using constructed wetlands (Wahyudianto, et al., 2019).

The problem is that liquid laundry waste in Indonesia collected from 25 laundry businesses has a *biochemical oxygen demand* (BOD_5) content that ranges from 1.56 mg/L to 93.3 mg/L. Chemical oxygen demand (COD) concentrations ranged from 44.2 mg/L to 366 mg/L. The BOD_5 concentration of liquid laundry waste that has entered river water bodies ranges from 0.19

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mg/L to 6.99 mg/L while the COD concentration of liquid laundry waste that has entered river water bodies ranges from 3.16 mg/L up to 11.4 mg/L (Jayanto, et al., 2021). Apart from that, there is a case of liquid laundry waste collected from Ajeng Laundry House in Depok, West Java with an average washing of clothes around 100 kg/day. However, Ajeng Laundry House renovated the premises in 2016 and opened a special delivery service so that the amount of laundry increased to 200 kg/day. The water requirement used by Ajeng Laundry House in one day is 15 liters for 1 kg of clothes. The liquid waste produced from Ajeng Laundry House in 1 day is 3000 kg/liter. Ajeng Laundry House in Depok, West Java does not have a special processing unit and liquid laundry waste is directly discharged into water bodies. The characteristics of Ajeng House Laundry liquid waste are COD of 469 mg/L, BOD_5 of 135 mg/L, temperature of 29, and pH of 11.9. The parameters of Ajeng Laundry House liquid waste show high values and do not meet waste water quality standards, except for temperature (Meiliasari, 2016).

Constructed Wetlands (CW) is a wastewater treatment technology designed to simulate the biological, chemical and physical processes that occur in natural wetlands. Constructed Wetlands include man-made wetlands that are built to replicate natural wetlands using vegetation, microorganisms, media such as soil, sand, gravel, and ecological systems that act as new or restored habitats for migrating living creatures in the ecosystem. Constructed wetland technology acts as an environmentally friendly and sustainable wastewater treatment, utilizes microorganisms, natural vegetation, balances the ecosystem, does not require high costs, uses low energy, maintenance and operations can be applied for socio-economic impacts (Waly et al., 2022). Factors that influence the effectiveness of constructed wetlands are media thickness, media type, hydraulic retention time (HRT), water depth and feeding stage (Wahyudianto, et al., 2019). The economic value resulting from the use of CW technology, namely adding clean water for irrigation and water recreation and increasing the quality of clean water. Liquid laundry waste that has been processed using CW into clean water can be used for industrial, pharmaceutical, agricultural activities, adding aesthetics, landscapes and biodiversity (Waly, et al., 2022).

Water bamboo (*Equisetum hyemale*) is a type of plant that comes from the Spenophyta phylum and the Equisetaceae family. Water bamboo is often found in temperate and tropical areas. Aquatic bamboo plants can be used in phytoremediation systems using constructed wetlands which can remove, stabilize, transfer and destroy pollutants in the form of organic and inorganic compounds originating from contaminated soil or waters. The stems of water bamboo have a high silica content to bind absorbed particles. Apart from that, water bamboo has roots that contain chelating compounds so they can absorb contaminants (Fitri, et al., 2021).

The government regulates the discharge of waste water into water bodies in the Minister of Environment and Forestry Regulation Number 5 of 2014 concerning "Waste Water Quality Standards for Businesses and/or Activities that Do Not Have Established Waste Water Quality Standards". Processing laundry liquid waste using constructed wetlands and biofilters with observations for 4 weeks ranging from 27-28. The pH value obtained was 7.3-7.8 and there was a decrease in COD and BOD_5 concentrations by 50%. A hybrid biofilter system with constructed wetlands and aquatic bamboo plants (*Equisetum hyemale*) can reduce BOD_5 concentrations (Violenta, et al., 2022).

Based on the research results of Wardono et al (2017), liquid laundry waste from five locations in Purwokerto, Central Java has been processed using water bamboo plants (*Equisetum hyemale*) and constructed wetland type vessel subsurface flow (SSF) with HRT of 1, 3, and 7 days because the average reason for washing laundry services is 1-3 days and 7 days a week. Research analysis shows that aquatic bamboo plants (*Equisetum hyemale*) with a residence time of 1,3, and 7 days and a continuous system produce a reduction in COD concentrations (90-99.5%) (Wardono, et al., 2017).

The aim of the research is to evaluate laundry liquid waste processing in Depok, West Java and provide technology proposals for liquid waste processing*laundry*with a constructed wetland which can be applied to laundry business entrepreneurs and the Depok City government, West Java so that liquid laundry waste can be disposed of into water bodies safely and meets clean water needs. The detailed research objectives are to Analyzing the efficiency of COD and BOD_5 removal in horizontal sub-surface constructed wetlands (HSSF CWs) with water bamboo plants (*Equisetum hyemale*) in processing liquid laundry waste.

Research Methods

This type of research is experimental research for the processing of liquid laundry waste which is included in domestic wastewater (*gray water*) from a laundry business, namely Dobis Laundry, Sukamaju, Depok, West Java using Horizontal Sub-surface Flow Constructed Wetlands (HSSF CWs). Experimental research is research that includes experiments where the independent, control and dependent variables are determined by the researcher himself. The research was carried out using a pilot scale field experiment. This research was carried out using a quantitative approach to analyze the level of removal efficiency using constructed wetlands in removing BOD_5 and COD pollutants from laundry liquid waste. Independent, control and dependent variables are determined using a quantitative approach. A quantitative approach is a method of collecting data, analyzing data, and interpreting the results of data analysis to obtain information for decision making and making conclusions resulting from sampling in the form of numbers that can be quantified.

The sample used in this research was liquid laundry waste originating from Dobis Laundry, Sukamaju, Depok, West Java. Sampling of liquid laundry waste aims to obtain initial data on the concentration of BOD_5 and COD in liquid laundry waste. This was done to determine the characteristics of liquid laundry waste originating from Dobis Laundry. The results of samples of liquid laundry waste originating from Dobis Laundry are as follows:

Table 1. Laundry Liquid Waste Sample Data from Dobis Laundry

Parameter	Unit	Mark
Temperature		29
pH	-	8.86
Biochemical Oxygen Demand (BOD_5)	mg/L	235
Chemical Oxygen Demand (COD)	mg/L	489

[Source: Author's Analysis, 2024]

Data analysis

Pollutant Removal Efficiency

Pollutant removal is obtained by processing data on the quality of water parameters tested on laundry liquid waste influent before going through processing in reactor 1 and reactor 2*Horizontal Sub-Surface Flow Constructed Wetlands* (HSSF CWs) and quality parameters tested on the effluent resulting from processing in reactor 1 and reactor 2 HSSF CWs. The formula that can be used to determine the removal of pollutants in liquid laundry waste is as follows:

$$\text{Removal Efficiency (\%)} = \frac{C_0 - C_t}{C_0}$$

Information:
C_0 = initial concentration (mg/L)
C_t = final concentration (mg/L)

Based on this allowance, the efficiency of removing pollutants originating from liquid laundry waste is obtained. The results of pollutant removal in liquid laundry waste can be determined using the pollutant removal efficiency formula as follows (Olguin, et al., 2017)

Results and Discussion

Acclimatization

Acclimatization is the adjustment or adaptation stage for aquatic bamboo plants (*Equisetum hyemale*) and microorganisms in reactor 1 and reactor 2 of horizontal sub-surface flow constructed wetlands (HSSF CWs) to the surrounding environment. Additionally, acclimatization is used to prevent shock loading caused by high concentrations of wastewater contaminants. The conditions of acclimatization can be used by microorganisms to attach to the rhizosphere and porous media. Based on tables 4.2 and 4.3, acclimatization in this study had a percentage increase in laundry liquid waste influent concentration of 25% to 100% with a hydraulic retention time (HRT) of 2 days each. The hydraulic retention time was chosen for 2 days so that reactor 1 and reactor 2 HSSF CWs were more stable and there was no shock loading during the feeding stage. During acclimatization, COD parameters were tested to determine the quality of the influent and effluent in reactor 1 and reactor 2. An adaptable system was indicated by data on the COD concentration removal efficiency in the effluent reaching 50%. The COD concentration was chosen as a representative of the effluent quality parameter because the COD concentration in the influent was quite high in the initial test. During acclimatization in reactor 1 and reactor 2, observations of the quality of liquid laundry waste on plants were carried out by observing the steady state of the water bamboo plants in reactor 1 and reactor 2. The steady state of the plants in reactor 1 and reactor 2 could be seen visually through the emergence of shoots. and increase in plant height in reactor 1 and reactor 2.

Table 2. Concentration and COD Removal Efficiency of Reactor 1 at the Acclimatization Stage

Days to-	Date	Time	Clean Water: Waste Water	COD (mg/L)		Elimination Efficiency (%)
				Influent	Effluent	
1	March 10 -March 12, 2024	16.00	75% : 25%	432	245	43%
2	March 12 -March 14, 2024	17.00	50% : 50%	549	213	61%
3	March 14 - March 16, 2024	18.00	25% : 75%	417	181	56%
4	March 16 - March 18, 2024	19.00	0% : 100%	634	208	67%
Minimum				**417**	**181**	**43%**
Maximum				**634**	**245**	**67%**
Average				**508**	**212**	**56.75%**

[Source: Author's Analysis, 2024]

Table 3. Concentration and COD Removal Efficiency of Reactor 2 at the Acclimatization Stage

Days to-	Date	Time	Clean Water: Waste Water	COD (mg/L)		Elimination Efficiency (%)
				Influent	Effluent	
1	March 10 -March 12, 2024	16.00	75% : 25%	432	210	51%
2	March 12 - March 14, 2024	17.00	50% : 50%	549	195	62%
3	March 14 – March 16, 2024	18.00	25% : 75%	417	121	70%
4	March 16 – March 18, 2024	19.00	0% : 100%	634	170	73%
Minimum				**417**	**121**	**58%**
Maximum				**634**	**188**	**73%**
Average				**508**	**165**	**66.50%**

[Source: Author's Analysis, 2024]

Based on table 2 and figure 1, the results from the acclimatization stage of HSSF CW reactor 1 were on day 1, the COD concentration in the influent was 432 mg/L and the effluent was 245 mg/L with a removal efficiency of 43%. On day 2 of the acclimatization stage, the COD concentration in the influent was 549 mg/L and the effluent was 213 mg/L with a removal efficiency of 61%. On day 3 of the acclimatization stage, the COD concentration in the influent was 417 mg/L and the effluent was 181 mg/L with a removal efficiency of 56%. On the 4th day of acclimatization, the COD concentration in the influent was 634 mg/L and the effluent was 208 mg/L with a removal efficiency of 67%. Acclimatization in reactor 1 had laundry liquid waste influent ranging from 417 mg/L to 634 mg/L and effluent ranging from 175 mg/L to 221 mg/L with a removal efficiency ranging from 45% to 72%.

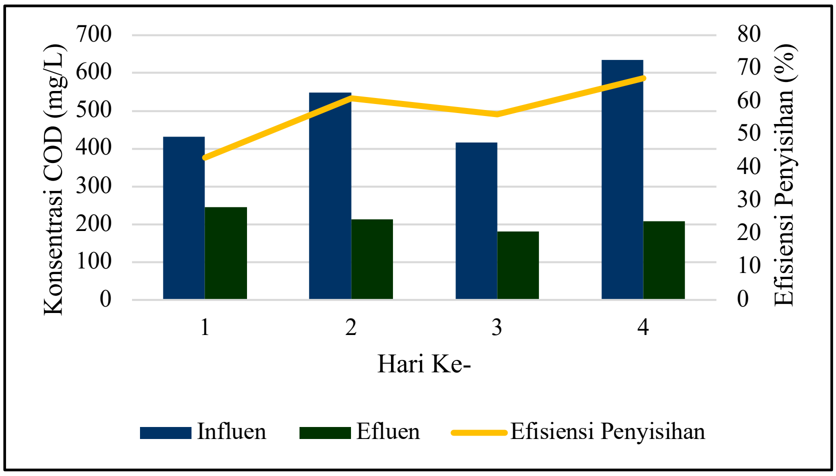

Figure 1. Graph of COD Concentration and Removal Efficiency in Reactor 1 HSSF CW
[Source: Author's Analysis, 2024]

Based on table 3 and figure 2, the results of the acclimatization stage for HSSF CW reactor 2 were on day 1, the COD concentration in the influent was 432 mg/L and the effluent was 221 mg/L with a removal efficiency of 45%. On the 2nd day of acclimatization, the COD concentration in the influent was 549 mg/L and the effluent was 197 mg/L with a removal efficiency of 64%. On the 3rd day of acclimatization, the COD concentration in the influent was 417 mg/L and the effluent was 126 mg/L with a removal efficiency of 69%. On the 4th day of acclimatization, the COD concentration in the influent was 634 mg/L and the effluent was 175 mg/L with a removal efficiency of 72%. The acclimatization stage in reactor 1 has laundry liquid waste influent ranging from 417 mg/L to 634 mg/L and effluent ranging from 175 mg/L to 221 mg/L with a removal efficiency ranging from 45% to 72%.

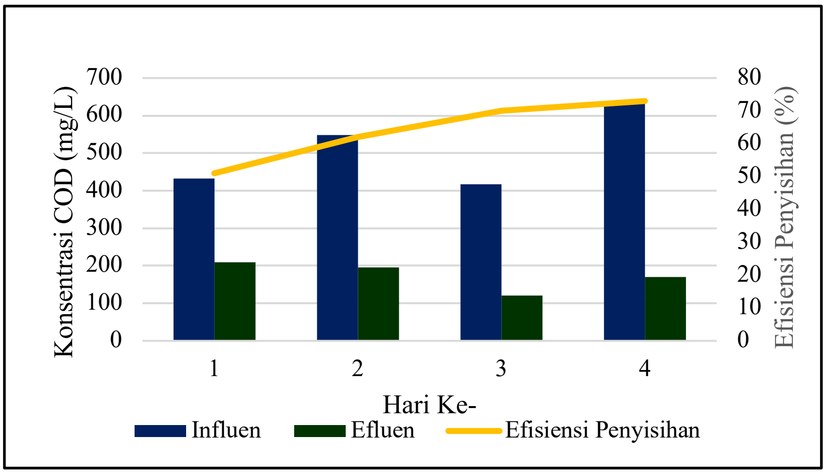

Figure 2. Graph of COD Concentration and Removal Efficiency in Reactor 2 HSSF CW
[Source: Author's Analysis, 2024]

Based on Figure 1 and 2, the concentration of wastewater influent increases along with the increase in concentration of wastewater (Qomariyah, et al., 2017). However, the results of testing the influent concentration of laundry liquid waste in this study did not increase along with the addition of the concentration of laundry liquid waste in reactor 1 and reactor 2. This occurs because the liquid laundry waste taken from Dobis Laundry fluctuates every day where the use of water, detergent, and the bleach agents used by Dobis Laundry are influenced by the number of dirty clothes washed by customers who enter each day.

Based on Figure 1 and 2, the COD concentration removal efficiency in reactor 1 and reactor 2 reached more than 50% on days 2, 3, and 4. However, the COD concentration removal efficiency in reactor 1 decreased on day 3 and experienced improvement returned on day 4. This happens because reactor 1 is not yet stable. The COD concentration removal efficiency value shows that reactor 2 is more effective in removing organic pollutants in the form of COD. Even though the COD concentration in the effluent has decreased and the removal efficiency in reactor 1 and reactor 2 is more than 50%, the COD value in the effluent from reactor 1 and reactor 2 has not met the waste water quality standards regulated by the Republic of Indonesia Minister of Environment Regulation Number 5 of 2014. This is due to because reactor 1 and reactor 2 HSSF CWs with water bamboo plants (*Equisetum hyemale*) are still adapting to liquid laundry waste during the acclimatization stage. Providing a higher COD concentration in the HSSF CWs reactor causes an increase in COD removal efficiency in reactor 1 and reactor 2. This occurs because there is an increase in the growth of microorganisms in reactor 1 and reactor 2 as an energy source so that the microorganisms are more active in degrading the COD contained in them. laundry liquid waste.

Based on visual observations in figures 3 and 4, the steady state that occurred in water bamboo plants (*Equisetum hyemale*) in reactor 1 and reactor 2 of HSSF CW during the acclimatization stage on day 1 was not found to have yellowed or wilted water bamboo plants. In the acclimatization stage on the last day, several aquatic bamboo plants in reactor 1 and reactor 2 were found to be yellow or wilted. However, as several water bamboo plants died, the water bamboo plants in reactor 1 became increasingly green, experienced upright growth, and put out new shoots. The water bamboo plants in reactor 1 formed several new shoots with a height of 5-15 cm. The water bamboo plants in reactor 2 also formed several new shoots with a height of 3-10 cm. This shows that reactor 1 and reactor 2 HSSF CWs are stable.

Figure 3. New Shoots from Water Bamboo Plants (*Equisetum hyemale*) in Reactor 1 HSSF CW

[Source: Personal Documentation]

Figure 4. New Shoots from Water Bamboo Plants (*Equisetum hyemale*) in Reactor 2 HSSF CW
[Source: Personal Documentation]

Effectiveness of Horizontal Sub-Surface Flow Constructed Wetlands in Removing Chemical Oxygen Demand (COD) in Liquid Laundry Waste

Reduction and Efficiency of Removal of Chemical Oxygen Demand (COD)

Based on the data obtained in figure 5, the COD concentration value in the liquid laundry waste influent is fluctuating or an unstable value. This is because the amount of laundry, dirty clothes and detergent used by each laundry business is not always the same during the washing process (Pontiani, et al., 2023). The average concentration value of laundry liquid waste influent that enters the reactor by running 15 times is 573.012 mg/L. The average effluent concentration value produced by reactor 1 HSSF CW with water bamboo plants (*Equisetum hyemale*) was 79.37 mg/L with a total of 12 *E. hyemale* plants or a total of 120 *E. hyemale* plants. Reactor 1 HSSF CW with *E. hyemale* plants and HRT for 2 days produced an average COD removal efficiency of 86.04%.

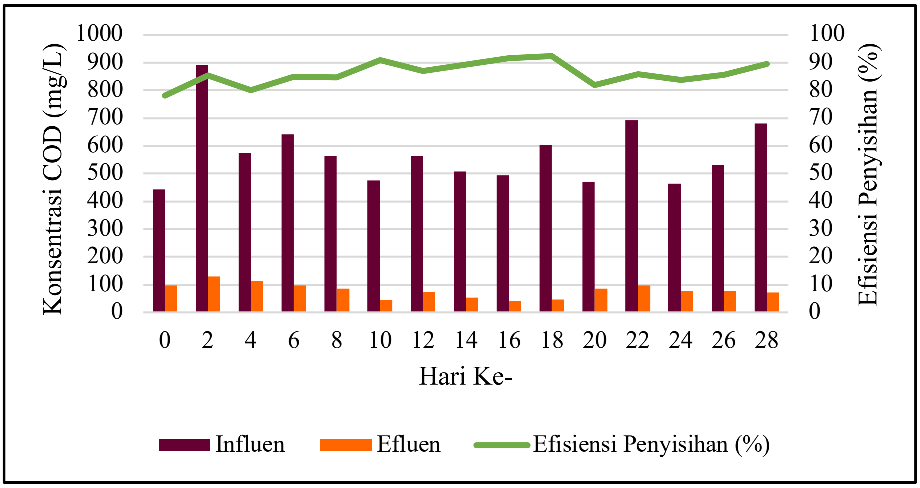

Figure 5. COD Concentration Removal Efficiency in Reactor 1 Horizontal Sub-Surface Flow Constructed Wetland (HSSF CW) with Water Bamboo Plants (*Equisetum hyemale*)
[Source: Author's Analysis, 2024]

Based on figure 5, the largest pollutant removal in the form of COD in reactor 1 HSSF CW with *E. hyemale* plants occurred on the 18th day of effluent with a COD concentration in the effluent of 45.87 mg/L and a removal efficiency of 92.37% from liquid waste influent. laundry amounting to 601.6 mg/L. The smallest pollutant removal in the form of COD in reactor 1 HSSF CW occurred on day 0 with a COD concentration in the effluent of 97.06 mg/L and a removal efficiency of 78.12% from the liquid laundry waste influent of 443.73 mg/L. The following are the COD concentrations in the influent and effluent as well as the efficiency of COD removal after processing in the 1 HSSF CW reactor using *E. hyemale* plants.

Based on the data obtained in figure 6, reactor 2 HSSF CW with *E. hyemale* plants, the average COD concentration value in the liquid laundry waste influent that entered the reactor with running 15 times was 573.012 mg/L. The average effluent concentration value produced by reactor 2 HSSF CW with *E. hyemale* plants was 68.55 mg/L with a total of 20 *E. hyemale* plants or a total of 200 *E. hyemale* plants. The average COD removal efficiency produced by the 2 HSSF CW reactors with HRT for 2 days was 88.22%.

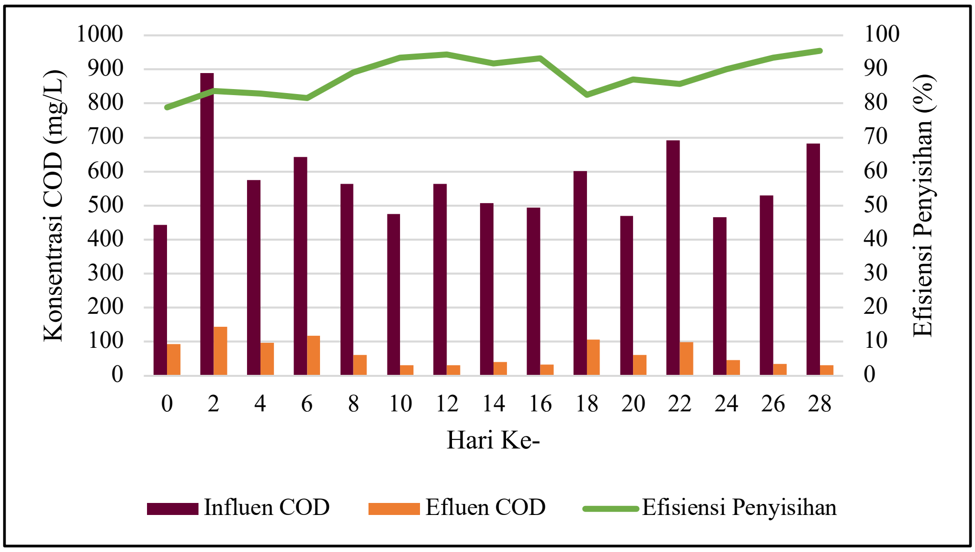

Figure 6. COD Concentration Removal Efficiency in Reactor 2 Horizontal Sub-Surface Flow Constructed Wetland (HSSF CW) with Water Bamboo Plants (*Equisetum hyemale*)

[Source: Author's Analysis, 2024]

Based on the data obtained in Figure 6, the largest pollutant removal in the form of COD in the 2 HSSF CW reactor with *E. hyemale* plants occurred on the 28th day of effluent with a COD concentration in the effluent of 30.93 mg/L and a removal efficiency of 95.46% of laundry liquid waste influent was 681.60 mg/L. The smallest pollutant removal in the form of COD in reactor 2 HSSF CW occurred on day 0 with a COD concentration in the effluent of 93.78 mg/L and a removal efficiency of 78.85% from laundry liquid waste influent of 443.73 mg/L. The following are the COD concentrations in the influent and effluent as well as the efficiency of COD removal after processing in the 2 HSSF CW reactor using *E. hyemale* plants.

Based on COD testing in liquid laundry waste in graphs 5 and 6, the chemical oxygen demand (COD) parameter is one of the water indicators that shows the amount of total oxygen needed to chemically oxidize organic materials. The COD value is higher than the BOD_5 value due to the amount of organic substances that do not undergo biological processes in a short period of time (Akköz, 2017). The efficiency of removing COD concentration in laundry liquid waste is influenced by the initial concentration of the influent and hydraulic retention time (HRT). Microorganisms need sufficient HRT to convert organic compounds contained in liquid laundry waste into simpler compounds. These simple compounds are reused by plants as nutrients and materials used by the plant root system to produce oxygen so that it can be reused as an energy source in a series of metabolic processes for the life of microorganisms in constructed wetlands reactors. Based on the research results in graphs 5 and 6, the decrease in COD concentration in laundry liquid waste in reactor 1 and reactor 2 shows that the adaptation time for microorganisms to the media has been optimal. The media in reactor 1 and reactor 2 HSSF CWs act as a place for growth and reproduction for plants and microorganisms which can accelerate the decomposition of COD concentrations in processing liquid laundry waste. Apart from that, the type of flow in reactor 1 and reactor 2 in this study is sub-surface flow (SSF). Sub-surface flow constructed wetlands can remove dissolved organic matter through anaerobic metabolism and aerobic metabolism by microorganisms through the surface of gravel media and plant roots. The horizontal flow pattern in reactor 1 and reactor 2 functions to accelerate the absorption process of organic materials in the media and plants which are then degraded by microorganisms into simpler compounds (Kasman, et al., 2022). The increase in COD concentration removal efficiency in reactor 1 and reactor 2 of HSSF CWs with *E. hyemale* plants in this study almost occurred simultaneously with plant growth after initial loading from the influent. *E. hyemale* plants in horizontal sub-surface flow constructed wetlands (HSSF CWs) act as carbon suppliers for the metabolism of microorganisms, provide attachment sites for microorganisms in the root system, and transfer oxygen needs to increase the efficiency of pollutant removal through plant roots (Stefanakis, et al., 2012).

Based on graphs 5 and 6, the increase in COD concentration removal efficiency in reactor 1 and reactor 2 of HSSF CWs with *E. hyemale* plants in laundry liquid waste processing was 86.04% and 88.22% respectively. The efficiency of removing COD concentration from laundry liquid waste in reactor 1 and reactor 2 in this study is due to the activity of the interaction of microorganisms and plants through the oxidation process by aerobic bacteria that grow and reproduce around the rhizosphere of plants as well as heterotrophic bacteria found in waste water (Tangahu & Warmadewanthi, 2001). Based on research by Wahyudianto et al. (2019), the efficiency of removing COD concentrations in liquid laundry waste is around 74-95%. The highest COD removal was produced at 60% dilution of laundry liquid waste which resulted in a removal efficiency of 95%. Apart from that, the increase in the efficiency of removing COD concentrations in liquid laundry waste is due to the type of media in the form of soil, sand and gravel which facilitates the filtration mechanism to remove organic material. Detention time affects removal efficiency in laundry liquid waste processing using constructed wetlands with *E. hyemale* plants. Applying a detention time of 4 days resulted in a COD concentration removal efficiency in laundry liquid waste of 85.12% (Wahyudianto et al., 2019). Research conducted by Sultana et al. (2015), a detention time of 1 day in a constructed wetlands unit resulted in a COD removal efficiency of 91%.

Based on the results of research conducted by Wahyudianto et al. (2019), it shows that processing laundry liquid waste using constructed wetlands with *E. hyemale* plants produces a slightly higher COD concentration removal efficiency compared to previous research. Based on research by Stefanakis et al. (2012), plant types play an important role in horizontal sub-surface flow (SSF) and free water surface (FWS). However, the type and number of plants have less influence on the efficiency of pollutant removal in vertical flow constructed wetlands. Therefore, the difference in the number of *E. hyemale* plants in reactor 1 and reactor 2 of the HSSF CWs resulted in different COD removal efficiencies from each reactor where reactor 2 produced a higher COD removal efficiency compared to the COD removal efficiency resulting from reactor 1 (Stefanakis, et al., 2012).

The roots and rhizomes of *E. hyemale* plants in reactors 1 and 2 HSSF CWs in this study can penetrate below the soil surface to absorb pollutants in the form of COD and *E. hyemale* plant litter can decompose quickly so that nutrients are easily released to the soil surface. This can support the growth and reproduction of *E. hyemale* plants (Marsh et al., 2000). As laundry liquid waste was processed using reactor 1 and reactor 2 horizontal sub-surface flow constructed wetlands with HRT for 2 days in this study, *E. hyemale* plants produced new shoots. This is because Equisetum plants have root and shoot primordia that have been previously formed during acclimatization on each rhizome that grows underground and aerial stem nodes. This accelerates Equisetum stems in producing new shoots and roots on aerial stems when the stem is fully or partially in the soil. Even though some of the stems or roots are destroyed by sediment or soil, the upper part of the Equisetum stem can still survive and create new plants. This is an advantage of the Equisetum plant to survive in wetland and riverside habitats (Husby, 2013). The primordia of Equisetum roots and shoots function to facilitate vegetative propagation. Equisetum stems have the ability to have adventitious roots or a fibrous root system. This helps Equisetum in producing and multiplying new plants. Water bamboo plants have the ability to reproduce vegetatively through adventitious roots. Equisetum plants that are bred in sand media or a sand mixture such as the type of media used in this research produce fungal structures in the roots. Equisetum plants have a long root structure. This causes Equisetum to have high adaptability in water. Equisetum plants have root hairs which function to increase the absorption of pollutants, where this ability is similar to the ability of mycorrhiza. Environmental conditions with low oxygen availability in constructed wetland reactors suppress the growth of *E. hyemale* root hairs in the soil (Husby, 2013).

Based on the data results in graphs 5 and 6 the COD removal efficiency in reactor 1 and reactor 2 of HSSF CWs with *E. hyemale* plants is different due to the influence of the number of *E. hyemale* plants used in reactor 1 and reactor 2 where reactor 2 has a total of E plants. hyemale as many as 200 plants and reactor 1 has a total of 120 *E. hyemale* plants. Based on research conducted by Tampubolon et al (2020), the efficiency of COD removal from constructed wetlands with 12 apu wood plants (*Pistia stratiotes L.*) for domestic wastewater treatment was 87.90%. The COD removal efficiency value using 12 apu wood plants (Pistia stratiotes L.) is greater than the COD removal efficiency resulting from using 4 plants and 8 plants with HRT for 9 days where the respective COD removal efficiency values were 74.80%. and 78.83%. The results of research conducted by Tampubolon et al (2020) support the results of COD removal efficiency from laundry liquid waste influent in this study, namely that the number of plants influences the reduction in COD concentration in wastewater. The greater the number of plants, the efficiency of pollutant removal in wastewater increases. Sand as a type of media used in reactor 1 and reactor 2 of HSSF CWs with *E. hyemale* plants acts as a filtration agent to filter organic matter and remove pollutants in waste water. Gravel as a type of media used in reactor 1 and reactor 2 HSSF CWs with *E. hyemale* plants helps to increase oxygen in the constructed wetland and provides better adhesion or attachment sites for microorganisms (Priya, et al., 2013). Therefore, the use of a variety of soil, sand and gravel media provides high pollutant removal efficiency in wastewater (Stottmeister, et al., 2003).

Suitability of COD Concentrations to Environmental Quality Standards

Based on Republic of Indonesia Government Regulation Number 5 of 2014 concerningWastewater Quality Standards for Businesses and/or Activities that do not yet have Wastewater Quality Standards, the maximum concentration of COD for liquid laundry waste which is included in liquid waste from activities that do not yet have class I wastewater quality standards is 100 mg/L. Based on figure 7 and 8, the average COD concentration in the effluent resulting from processing reactor 1 HSSF CW using aquatic bamboo plants (*Equisetum hyemale*) is 79.37 mg/L. Average COD concentration in effluent from processing reactor 2 HSSF CW using plants *E. hyemale* amounting to 68.55 mg/L. This shows that the liquid laundry waste originating from Dobis Laundry with horizontal surface flow constructed wetlands processing with *E. hyemale* plants meets class I quality standards. However, the effluent from reactor 1 HSSF CW with plants *E. hyemale* on days 2 and 4 with COD concentrations of 130.13 mg/L and 114, 13 mg/L did not meet class I quality standards. Effluent originating from reactor 2 HSSF CW on days 2, 6 and 18 with COD concentration of 145.07 mg/L; 118.40 mg/L; and 105.60 mg/L does not meet the quality standards for group I. The effluent on day 2 in reactors 1 and 2 does not meet the quality standards because the COD concentration in the laundry liquid waste influent is very high compared to the COD concentration in other influents of 889. 60 mg/L. This causes disruption in the adaptation of microorganisms to new environments due to the entry of very high levels of organic matter and reduces the oxygen content required by microorganisms. Apart from that, the effluent in reactor 1 on the 4th day and the effluent in reactor 2 on the 4th and 18th days experienced anomalies and did not meet quality standards because there was waste water influent from testing on the previous day and the influent was still left in the tank. reactor 1 and reactor 2. Based on the obtained COD concentration of effluent in reactor 1 and reactor 2 HSSF CWs with *E. hyemale* plants, the COD value meets the Waste Water Quality Standards for Businesses and/or Activities that do not yet have Group I Waste Water Quality Standards inRepublic of Indonesia Government Regulation Number 5 of 2014 indicates that the results of processing laundry liquid waste using HSSF CWs with *E. hyemale* plants are safe for disposal into waters or the environment.

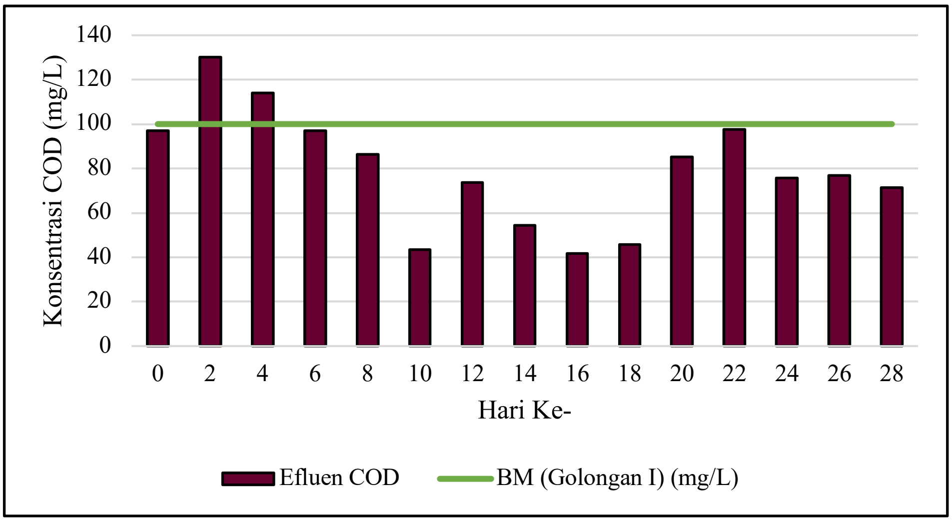

Figure 7. Changes in Effluent COD Concentration in Reactor 1 Horizontal Sub-Surface Flow Constructed Wetland (HSSF CW) with Water Bamboo Plants (*Equisetum hyemale*)
[Source: Author's Analysis, 2024]

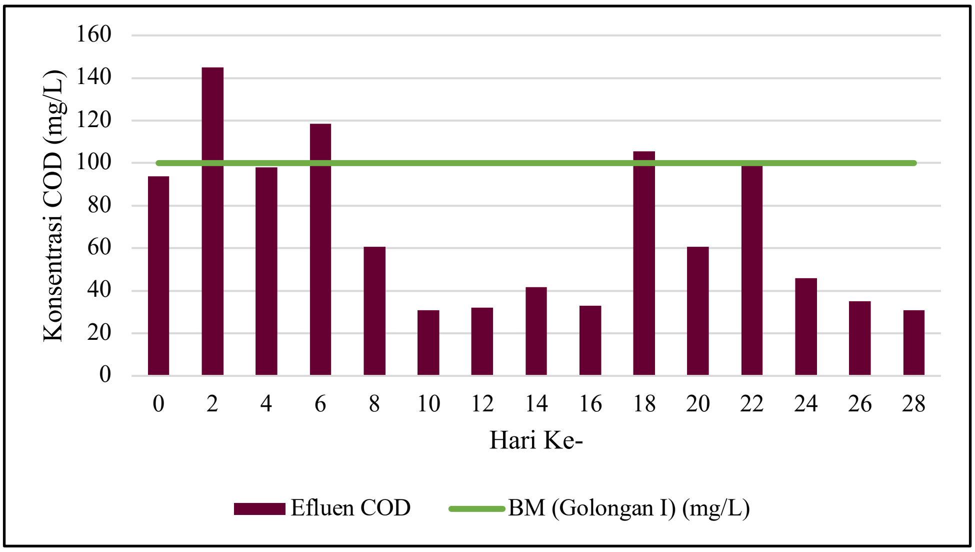

Figure 8. Changes in Effluent COD Concentration in Reactor 2 Horizontal Sub-Surface Flow Constructed Wetland (HSSF CW) with Water Bamboo Plants (*Equisetum hyemale*)
[Source: Author's Analysis, 2024]

Effectiveness of Horizontal Sub-Surface Flow Constructed Wetland on Removing *Biochemical Oxygen Demand* (BOD_5) in Liquid Laundry Waste

Reduction and Efficiency of Biochemical Oxygen Demand (BOD_5) Removal

Based on the data obtained in figure 9, the average BOD_5 concentration value of laundry liquid waste influent that enters the reactor with running 15 times is 150.47 mg/L. The average effluent BOD_5 concentration value produced by reactor 1 HSSF CW is 18.36 mg/L. Reactor 1 HSSF CW with 12 clumps of aquatic bamboo (*Equisetum hyemale*) plants and a total of 120 *E. hyemale* plants produced an average BOD_5 removal efficiency of 88.10%. The following are the BOD_5 concentrations in the influent and effluent as well as the BOD_5 removal efficiency after going through processing in the 1 HSSF CW reactor. The greatest removal of pollutants in the form of BOD_5 in reactor 1 HSSF CW occurred on the 10th day of effluent with a BOD^5 concentration of 5.29 mg/L and a removal efficiency of 95.13% from laundry liquid waste influent of 108.61 mg/L. The smallest pollutant removal in the form of BOD_5 in reactor 1 HSSF CW occurred on day 0 with a BOD_5 concentration in the effluent of 22.25 mg/L and a removal efficiency of 78.47% from the liquid laundry waste influent of 103.32 mg/L.

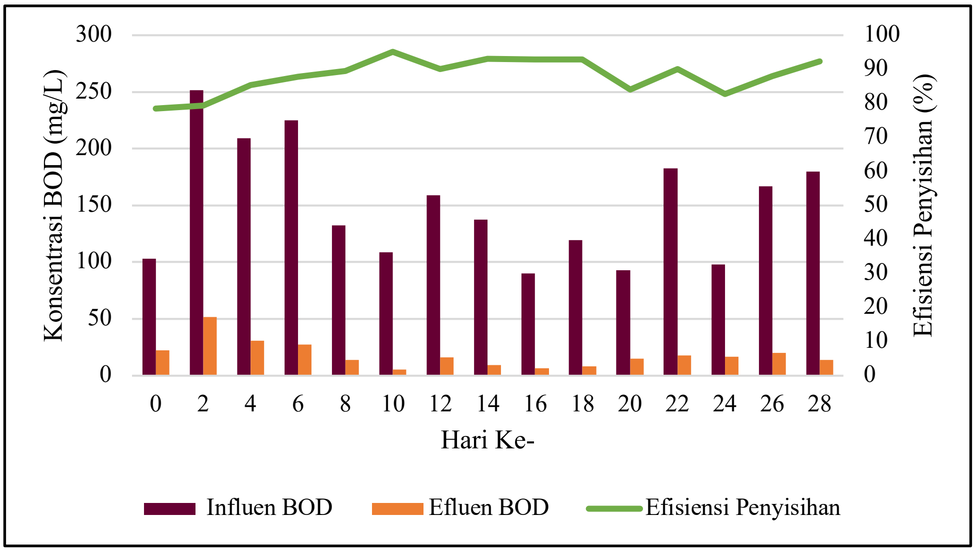

Figure 9. Efficiency of BOD_5 Concentration Removal in Reactor 1 Horizontal Sub-Surface Flow Constructed Wetland (HSSF CW) with Water Bamboo Plants (*Equisetum hyemale*)

[Source: Author's Analysis, 2024]

Based on the data obtained in figure 10, the average BOD5 concentration value of laundry liquid waste influent that enters the reactor with running 15 times is 150.47 mg/L. The average BOD5 concentration value in the effluent produced by reactor 2 HSSF CW is 16.14 mg/L. The average BOD5 removal efficiency produced by the 2 HSSF CW reactors is 90.30%. The greatest removal of pollutants in the form of BOD5 in reactor 2 HSSF CW occurred on the 12th day of effluent with a BOD5 concentration in the effluent of 2.65 mg/L and a removal efficiency of 98.33% from laundry liquid waste influent of 158.95 mg/L. The smallest pollutant removal in the form of BOD5 in reactor 2 HSSF CW occurred on day 2 with a BOD5 concentration in the effluent of 62.52 mg/L and a removal efficiency of 75.15% from laundry liquid waste influent of 251.67 mg/L. The following are the BOD5 concentrations in the influent and effluent as well as the BOD5 removal efficiency after going through processing in the 2 HSSF CW reactor.

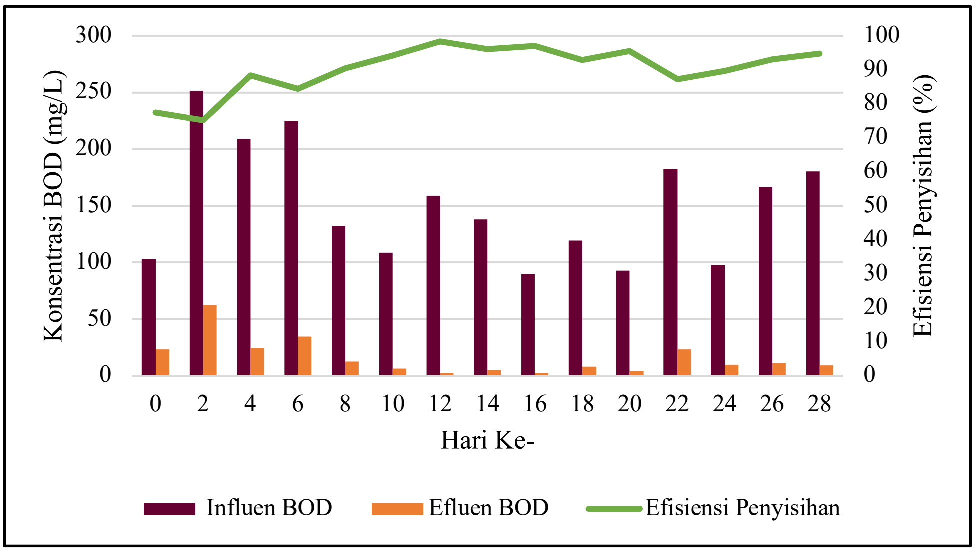

Figure 11. Efficiency of BOD5 Concentration Removal in Reactor 2 Horizontal Sub-Surface Flow Constructed Wetland (HSSF CW) with Water Bamboo Plants (*Equisetum hyemale*)

[Source: Author's Analysis, 2024]

Based on BOD_5 testing in liquid laundry waste at figure 10 and 11, BOD_5 is the amount of oxygen needed by microorganisms to decompose almost all organic compounds dissolved in water (Tangahu & Putri, 2017). Anaerobic processes dominate in constructed wetlands with sub-surface flow (SSF) flow types. *E. hyemale* plants help eliminate BOD_5 concentrations in wastewater treatment in reactor 1 and reactor 2 horizontal sub-surface flow constructed wetlands (HSSF CWs) with optimal HRT for wastewater treatment. The decrease in BOD_5 concentration in laundry liquid waste using horizontal sub-surface flow constructed wetlands (HSSF CWs) was caused by the interaction between the soil and the roots of the E. hyemale plant. The type of media in reactor 1 and reactor 2 HSSF CWs with E. hyemale plants to remove BOD_5 concentrations in this study used soil, sand and gravel. Soil is the main supporting material for the growth of plants and microorganisms. In addition, media variations using soil, sand, and gravel result in high pollutant removal. Hydraulic conditions of the soil such as porosity influence the flow of wastewater in constructed wetlands in removing pollutants. Degradation of microorganisms and the growth of dead plant roots causes the formation of new soil pores in constructed wetlands (Stottmeister et al., 2003).

Based on figure 10 and 11, reactor 1 and reactor 2 are horizontal sub-surface flow constructed wetland (HSSF CW) with plants *E. hyemale* resulting in BOD_5 removal efficiency of 88.10% and 90.93% respectively. The BOD_5 removal efficiency in reactor 1 and reactor 2 has a fairly high percentage due to the presence of oxygen concentrations produced by swamp plants or macrophytes. Plants with the ability to adapt to waterlogged areas, such as *E. hyemale*, have characteristics that are able to facilitate these plants in surviving for long periods of time. The adaptability and survival capabilities of constructed wetland plant types vary greatly. The *E. hyemale* plant is a plant that can adapt to anoxic rhizosphere conditions. This happens because *E. hyemale* can collect oxygen from the atmosphere into the root system. Gas transport occurs from the parts of the plant above the ground to the rhizomes into the fine roots. The transport of this gas is influenced by the aerenchyma or area of tissue formed inside the plant (Stottmeister et al., 2003). Aerenchyma functions to increase aeration in submerged root tissue .Aerenchyma generally forms in the root cortex, rhizomes and stems of plants (Seago et al., 2005).

E. hyemale plants in reactor 1 and reactor 2 HSSF CWs are assisted by aerenchyma in obtaining oxygen from the atmosphere. The aerenchyma in the rhizome is protected by segmentations such as diaphragms and nodes that can be penetrated by gas. However, the gas space or aerenchyma still has a barrier to prevent fluid from entering. The distribution of oxygen carried out by constructed wetland plant types such as the *E. hyemale* plant is assisted by a diffusion process which causes low and high pressure on the plant. The formation of low pressure occurs in parts of the plant that need oxygen, such as the roots, and the formation of high pressure occurs in the leaves. The formation of high pressure on the plant leaves causes air to flow to all parts of the plant. The main process that causes the formation of high pressure in plants is thermoosmosis (Stottmeister et al., 2003).

The *E. hyemale* plant was used in this research because *E. hyemale* has an anatomy that is perennial or able to survive for more than one year. The leaf morphology of the *E. hyemale* plant reduces to small scales on the stem segments. The small leaves of *E. hyemale* are grayish with thin black lines on the top and bottom of the leaves. *E. hyemale* plants can distribute oxygen to the roots to support the growth of microorganisms in reactor 1 and reactor 2 HSSF CWs in building interactions between microorganisms and plants to remove pollutants in liquid laundry waste. The oxygen distribution process begins with the leaves of the *E. hyemale* plant which generally experience thermoosmosis where the temperature between the outside and inside of the leaf is different. Thermoosmosis causes air molecules to enter the young leaves. This results in the pores in young leaves being smaller than the pores in old leaves. The warmer temperature of the inside of the leaf causes the gas to expand and limits the return of the gas through the leaf pores. The excess pressure built up on the inside of the leaf is compensated in the aerenchyma. This event causes the gas molecules transported through the plant to be distributed to all parts of the plant roots. Pressure compensation from the plant system results in gas being released through the roots and leaves of older plants with larger pores. Sufficient amounts of oxygen available to the rhizome and root zones of the plant are used for respiration and plant survival. Oxygen contained in the root system is released into the rhizosphere through the root tips. The release of oxygen from the plant root system into the rhizosphere forms an oxidative protective layer directly on the surface of the plant roots. This layer functions to protect sensitive root areas due to damage resulting from toxic components in wastewater and anoxic rhizosphere (Stottmeister et al., 2003).

Based on figure 10 and 11, the BOD^5 removal efficiency is higher in reactor 2 compared to reactor 1 due to the influence of the number of *E. hyemale* plants used in reactor 1 and reactor 2 where reactor 2 has a total of 200 *E. hyemale* plants and reactor 1 has a total of 120 *E. hyemale* plants. Based on the research results in graphs 4.7 and 4.8, the efficiency of BOD_5 removal is higher when the number of *E. hyemale* plants used in HSSF CWs increases. This happens because the more plants there are, the higher the oxygen production produced by plants through the process of photosynthesis. The amount of oxygen used by microorganisms to decompose organic pollutants contained in wastewater. All wastewater substances in the soil can be absorbed by plant roots (Tangahu & Putri, 2017). Based on research conducted by Kholif et al (2020), the *E. hyemale* plant has the ability to reduce pollutants in domestic wastewater with a BOD_5 removal efficiency reaching 90.34%. Therefore, the type and number of plants play an important role in wastewater treatment using SSF CWs.

The greater number of effective plants used in SSF CWs reactors to reduce pollutants in wastewater can be proven from research conducted by Kholisah et al. (2022), processing tofu industrial waste using a sub-surface flow constructed wetlands (SSF CWs) system with an X1Y1 reactor using 35 stems of *E. hyemale* plants with media in the form of soil and gravel; the X2Y1 reactor uses 70 stems of *E. hyemale* plants with media such as soil and gravel; the X1Y2 reactor uses 35 stems of *E. hyemale* plants with media such as soil and sand; and the X2Y2 reactor using 70 stems of *E. hyemale* plants with media in the form of soil and sand produced BOD_5 concentration removal efficiencies of 40.93%, 79.10%, 26.53% and 53.61%, respectively. The highest BOD_5 concentration removal efficiency was obtained from the X2Y1 reactor using 70 *E. hyemale* plant stems and media types in the form of soil and gravel. The number of *E. hyemale* plants of 35 plants resulted in a decrease in BOD_5 concentration of 184.67 mg/L and 75 plants resulted in a decrease in BOD_5 concentration of 79.1 mg/L from the BOD_5 concentration in the tofu industry wastewater influent of 558 mg/L. Therefore, the reactor with 70 *E. hyemale* plants produced a better ability to reduce BOD_5 concentrations compared to the reactor containing 35 *E. hyemale* plants. So, the greater the number of *E. hyemale* plants, the higher the decrease in the BOD_5 concentration of tofu industry wastewater.

Based on the efficiency of BOD_5 removal in liquid laundry waste in graphs 4.7 and 4.8, it is influenced by variations in the type of media in reactors 1 and 2 HSSF CWs with *E. hyemale* plants consisting of soil, sand and gravel, where this type of media helps reduce the BOD_5 concentration in the water. waste. The media in the reactor with the SSF constructed wetland system acts as a place for the growth of microorganisms. Based on the research results of Kholisah et al. (2022), media variations in the form of gravel and soil were able to reduce the BOD_5 concentration to 65.33 mg/L while media variations in the form of sand and soil were able to reduce the BOD_5 level to 145 mg/L from the influent concentration value of 312 .6 mg/L. Therefore, sand and soil media are more effective in reducing BOD_5 concentrations in wastewater (Kholisah et al., 2022). SSub-surface flow constructed wetlands (SSF CWs) systems are more effective in reducing BOD_5 concentrations in wastewater (Kadlec, 2009).

Suitability of BOD_5 Concentration to Environmental Quality Standards

Based on Republic of Indonesia Government Regulation Number 5 of 2014 concerningWastewater Quality Standards for Businesses and/or Activities that do not yet have Wastewater Quality Standards, the maximum BOD_5 concentration for liquid laundry waste which is included in liquid waste from activities that do not yet have class I wastewater quality standards is 50 mg/L. Based on figure 11 and 12, the average BOD_5 concentration in the effluent resulting from processing reactor 1 HSSF CW using water bamboo plants (*Equisetum hyemale*) is 18.36 mg/L. The average BOD_5 concentration in the effluent resulting from processing reactor 2 HSSF CW using aquatic bamboo plants (*Equisetum hyemale*) was 16.14 mg/L. This shows that the liquid laundry waste originating from Dobis Laundry which has gone through horizontal surface flow constructed wetlands processing with water bamboo plants has met class I quality standards. However, the effluent from reactor 1 HSSF CW with water bamboo plants on the 1st day 2 with a BOD_5 concentration of 51.92 mg/L so it does not meet class I quality standards. The effluent originating from reactor 2 HSSF CW on day 2 with a BOD_5 concentration of 62.52 does not meet class I quality standards. This happens because the entry of a high BOD_5 concentration on day 2 amounted to 251.67 mg/L which disrupted the adaptation of microorganisms to the new environment due to the very high entry of organic matter and reduced the oxygen content required by microorganisms to eliminate the BOD_5 concentration in laundry liquid waste.

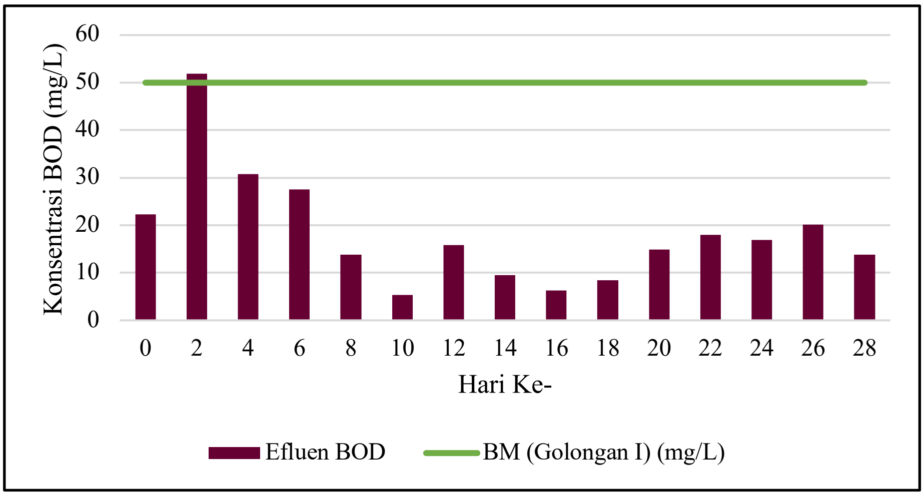

Figure 11. Changes in Effluent BOD Concentration in Reactor 1 Horizontal Sub-Surface Flow Constructed Wetland (HSSF CW) with Water Bamboo Plants (Equisetum hyemale)

[Source: Author's Analysis, 2024]

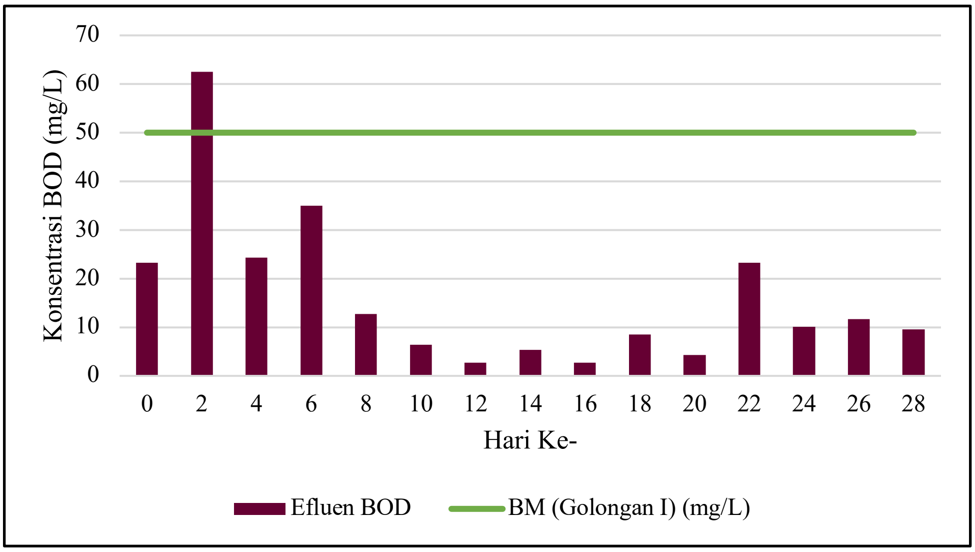

Figure 12. Changes in Effluent BOD Concentration in Reactor 2 Horizontal Sub-Surface Flow Constructed Wetland (HSSF CW) with Water Bamboo Plants (*Equisetum hyemale*)
[Source: Author's Analysis, 2024]

Conclusion

Horizontal sub-surface flow constructed wetlands (HSSF CWs) with water bamboo plants (*Equisetum hyemale*) produce quite high chemical oxygen demand (COD) and *biochemical oxygen demand* (BOD_5) removal efficiency in processing liquid laundry waste. Reactor 1 HSSF CWs with a total of 120 *E. hyemale* plants produced a COD removal efficiency of 86.04% and BOD_5 of 88.10%, while reactor 2 HSSF CWs with a total of 200 *E. hyemale* plants produced a COD removal efficiency of 88. 22% and BOD_5 of 90.30%.

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