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Original Article

Performance of vertical subsurface flow constructed wetland (VSSFCW) with *T. angustifolia* and *I. aquatica* for BOD and COD removal from tofu wastewater

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Abstract

Tofu is one of the most popular foods in Indonesia. Tofu wastewater discharge contains quite a high BOD and COD which are around 5.000-10.000 mg/L and 7.000-14.000 mg/L in liquid waste effluent. Tofu wastewater effluent that exceeds the quality standard of soybean processing industry wastewater into river waters without prior treatment and reduction can certainly cause environmental damage. Meanwhile, tofu wastewater made from soybeans with high nutritional content has the potential for sustainable use. Therefore, an effective, and sustainable wastewater treatment process to minimize environmental damage and increase the circular economy is needed. This study employs in situ wastewater treatment plant using an equalization tank and a Vertical Subsurface Flow Constructed Wetland (VSSFCW) system. Two phytoremediator plants, *Typha angustifolia*, and *Ipomoea aquatica*, were used to reduce organic matter (BOD and COD) in the tofu wastewater. Results showed that the treatment plants reduced BOD levels by approximately 67.85% (*T. angustifolia*) and 55.90% (*I. aquatica*), and COD levels by 70.29% (*T. angustifolia*), and 59.04% (*I. aquatica*). *T. angustifolia* exhibited better resistance and adaptability to tofu wastewater. This study demonstrates the potential of wetland-based systems with phytoremediator plants for treating tofu wastewater. These systems offer sustainability opportunities and minimize environmental impacts while promoting resource reuse.
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Keywords: Constructed Wetland, *I. aquatica*, Phytoremediation, *T angustifolia*, Tofu wastewater treatment
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Introduction

Deteriorated water quality is certainly affecting all life on Earth, and human activity is one of the most influential causes. The increasing number of human needs that uses clean water and surface water resources such as river water, lakes, reservoirs, swamps, and other bodies of water without proper water management and treatment can pose a danger to the environment. Apart from domestic use, the industrial and agricultural sectors of human activity contribute the most to the decline of water quality (Effendi, 2022).

The high demand for plant-based protein needs of Indonesian citizens is mostly fulfilled by the tofu industry besides tempeh. Tofu is a processed food products made from soybeans with good nutrients, such as protein and vitamins. The consumption rate of tofu in Indonesia reaches 7% and has increased by 0.09% annually from 2012 to 2013 (Faisal et al., 2016). The high demand for tofu during the COVID-19 pandemic prompted the emergence of Indonesia's tofu entrepreneurs and caused an impact on river water quality, due to improper tofu wastewater treatment and discharge. As a result, decreased river water quality occurs which is characterized by an increase of organic matter present in river waters (Sandi & Hariyanto, 2019).

Organic matters in tofu wastewater contain mostly nonharmful material, but if it is left untreated it could emit volatile organic compounds (VOCs). It can cause health risks and lead to the formation of photochemical oxidants. The most prevalent method used to measure organic materials are indirect and nonspecific measurements in the form of BOD (Biological Oxygen Demand) and COD (Chemical Oxygen Demand). COD is a measure of the amount of oxygen required to chemically oxidize organic and inorganic substances in water or wastewater. Biological Oxygen Demand (BOD) is a measure of the amount of dissolved oxygen required by microorganisms to decompose the organic matter present in water or wastewater through biological processes (Qasim & Zhu, 2018a). These two parameters provide a comprehensive assessment. COD measures the total oxygen demand resulting from both biodegradable and non-biodegradable organic compounds, as well as certain inorganic substances. It provides a broad estimation of the overall organic load in wastewater. BOD, on the other hand, specifically measures the oxygen demand caused by biodegradable organic matter, providing information about the fraction of organic pollutants that microorganisms can break down within 5 days.

Tofu wastewater contains high COD and BOD (Aris et al., 2021; Cahyani et al., 2021; Faisal et al., 2016; Nuriswanto, 1995), which is between 7000 – 14000 mg/L, and 5000 – 10000 mg/L (Nuriswanto, 1995). Tofu

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wastewater is produced from the process of washing, extracting, pressing, and molding tofu at high temperatures. The high levels of BOD and COD in tofu wastewater effluent exceed the quality standards for soybean-processed industrial wastewater. According to (Kementerian Lingkungan Hidup dan Kehutanan, 2014), the tofu wastewater effluent quality standards with levels of BOD and COD are 150 mg/L and 300 mg/L respectively. If these conditions occur in river waters, there will be disturbances in the ecosystem and anaerobic conditions will occur at certain depths (Fardiaz, 1992).

Tofu wastewater BOD:COD ratios are greater than 0.5 and this indicates that tofu wastewater is considered to be biodegradable. BOD:COD ratio of less than 0.3 indicate that wastewater is considered to be non-biodegradable waste and requires treatment in addition to biological treatment (Perdana et al., 2020). With that thought a constructed wetland system utilizing plants as a phytoremediator would be a sustainable approach for developing countries considering environmental, economic, and social benefits (ElZein et al., 2016). The Vertical Sub Surface Flow Constructed Wetland (VSSF-CW) system is able to remove COD and BOD levels with 94.87% and 94.17% removal efficiency after 15 days (Abdulgani & Izzati, 2014). The VSSFCW system provides better pollutant reduction results compared to the Horizontal Subsurface Flow Constructed Wetland (HSFCW) (Zurita et al., 2009).

Considering the tofu wastewater condition, resilient plants are needed to act as a phytoremediator in the VSSF-CW system. Water spinach is quite adaptive to tofu waste with certain concentrations and has a fairly good absorption of BOD in phytoremediation studies using the batch method. The ability to remove BOD by water spinach reaches 95%, while TSS reaches 94% (Ahmad et al., 2019). *T. angustifolia* is able to tolerate high nutrient loads, enhance rhizospheric activity, promote oxygenation and aeration, facilitate filtration and sedimentation, and increase hydraulic retention time in constructed wetland systems. These characteristics make it a valuable plant species for the sustainable and eco-friendly treatment of wastewater (Moshiri, 2020). This study aims to treat tofu wastewater through phytoremediation techniques in the Vertical Surface Flow Constructed Wetland system using *T. angustifolia* and *I. aquatica* plants through in-situ performance parameter tests at the tofu factory.

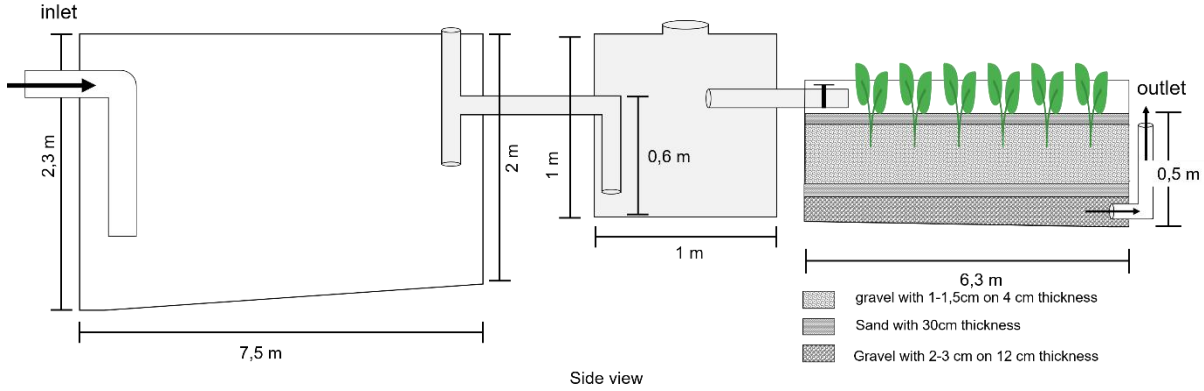

Figure 1. Tofu wastewater treatment system with constructed wetlands along with the size and arrangement of gravel and sand

Methods

Description of the constructed wetland-based treatment plants

This research was conducted from August to October 2022 at a tofu factory in Jombang, East Java (7°33'33.9"S 112°15'59.3"E) with an altitude of 38mdpl. The temperature ranges from 30°C to 33°C during the day and 23°C to 25°C during night time. The reactor was built on a rice field area with a land area of about 135 m^2 right beside the tofu factory.

The treatment plants consist of an equalization tank with a capacity of 40.31 m^3, a distribution tank with a capacity of 1 m^3, and the VSSFCW. The VSSFCW system was composed of gravel and layered sand shown in Figure 1. *T angustifolia* and *I. aquatica* plants were planted with a total population of 25 each in each column, plus 1 column without plants as a control. The column size is about 6.3 meters in length and 0.25 meters in width. Acclimatization was done by letting the tofu wastewater settles inside the treatment plant for approximately 1 week to grow microbes in the system (Meng et al., 2014).

Tofu wastewater characteristic

The parameters of wastewater measured include BOD and COD with the characteristics shown in Table 1. The quality standard for pollutant content refers to the Regulation of the Minister of Environment of the Republic of Indonesia No. 5 of 2014 (Kementerian Lingkungan Hidup dan Kehutanan, 2014). BOD levels ranged from 290 mg/L to 6710 mg/L with an average of 4193.33 mg/L. While COD levels ranged from 1226 mg/L to 8656 mg/L with an average of 5304.67 mg/L. The tofu factory wastewater levels exceed the soybean processing industrial wastewater quality standards of 150 mg/L BOD and 300 mg/L COD. Sampling for characterization is carried out 3 times a week at different hours during morning, afternoon, and evening at the end of production.

Wastewater treatment sampling and analysis

The wastewater treatment sampling was carried out at the Equalization inlet, constructed wetland inlet, and constructed wetland outlet. BOD analysis was carried out using the respirometric method referring to APHA (1999). COD analysis was carried out using the colorimetric method (APHA, 1999). Sampling was carried out 6 times every week, from September to October.

Data collection

The treatment efficiency for each parameter is calculated using equation (1) below:

$$Removal\ efficiency(\%) = \left(\frac{C_{in} - C_{out}}{C_{in}}\right) x100 \quad (1)$$

Where C_{in} (mg/L) is the concentration at the inlet and C_{out} (mg/L) is the concentration at the outlet point.

Results

Weather conditions and atmospheric temperature

The research was conducted in a location with a tropical climate. Due to climate change, unpredictable heavy downpours occur in 7 days during 6 weeks of observation. In the 3rd week of observation, the rainfall intensity increased and was at its highest during the 6 weeks of observation at 12.10 mm. While in the 4th and 5th weeks, the rainfall intensity decreased to 11.95 and 4.96 mm. While in the last week, the rainfall reached 3. 27 mm as shown in Figure 2.

Table 1 Characterization data of tofu wastewater

Parameter	Average (mg/L)	Max(mg/L)	Min(mg/L)	Quality standards (mg/L)
BOD	4193.33	6710	290	150
COD	5304.67	8656	1226	250

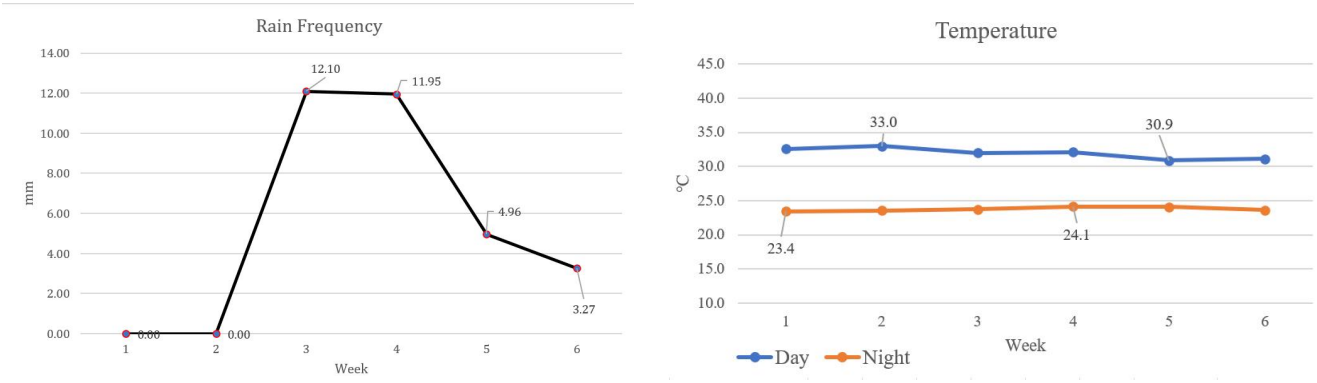

Figure 2 Rain frequency and average air temperature during the observation

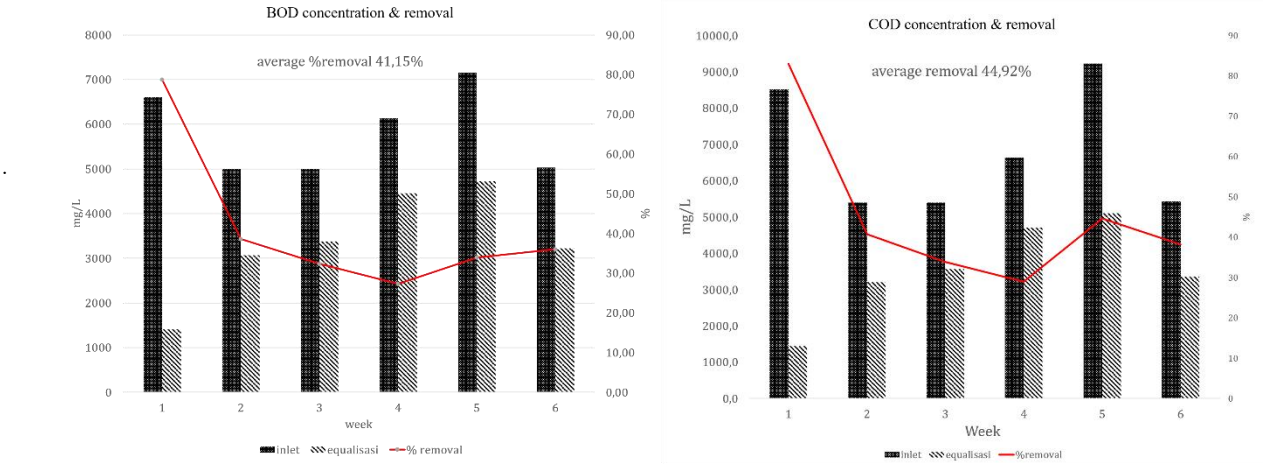

Figure 3 Variation of BOD and COD concentrations and their removal percentage during 6 weeks of observation

Equalization tank performance

The equalization tank act to stabilize the concentration of BOD and COD with a detention time of 5 h. The COD concentration at the Equalization tank outlet fluctuated between 1443 mg/L - 5110 mg/L which was lower than the inlet concentration of about 5400

mg/L - 9230 mg/L. The highest removal percentage occurred in the first week, which was 83.08%, while the minimum removal percentage occurred in the 4th week, which was 28.963%. Similar to COD, a decrease in BOD also occurs from the inlet to the equalization tank outlet. The concentration of BOD in the equalization tank outlet fluctuated, between 1405.06 mg/L - 4459.17 mg/L. Removal percentage that occurs ranges from 27.3% - 78.74% (Table 3). The maximum removal percentage occurs in the first week when the system is in optimal condition. The minimum percentage of removal occurs in the fourth week, during which the frequency of rain is quite high.

Chemical oxygen demand removal

T. angustifolia is known as a good phytoremediator for several types of organic and inorganic pollutants. In this study, *T. angustifolia* performed better than *I. aquatica* as a phytoremediator. COD levels decreased in the control column and *T. angustifolia* column by an average of 39.20% and 42.04% (Table 4). Whereas in column *I. aquatica*, there was an increase in COD levels in the first week. This is due to the addition of substrate by the process of decayed organs of deceased *I. aquatica* plants that are unable to survive in tofu wastewater characteristic conditions as shown in Figure 4, It proves that *I. aquatica* is less resistant than *T. angustifolia* (Perdana et al., 2020). According to Figure 5, it is shown that the maximum percentage of COD removal is achieved in the 3rd week where in that week the rain intensity is higher than the other weeks. In the same week, both the control column and treatment column achieved the highest COD removal due to high rainfall and nutrient dilution by these conditions.

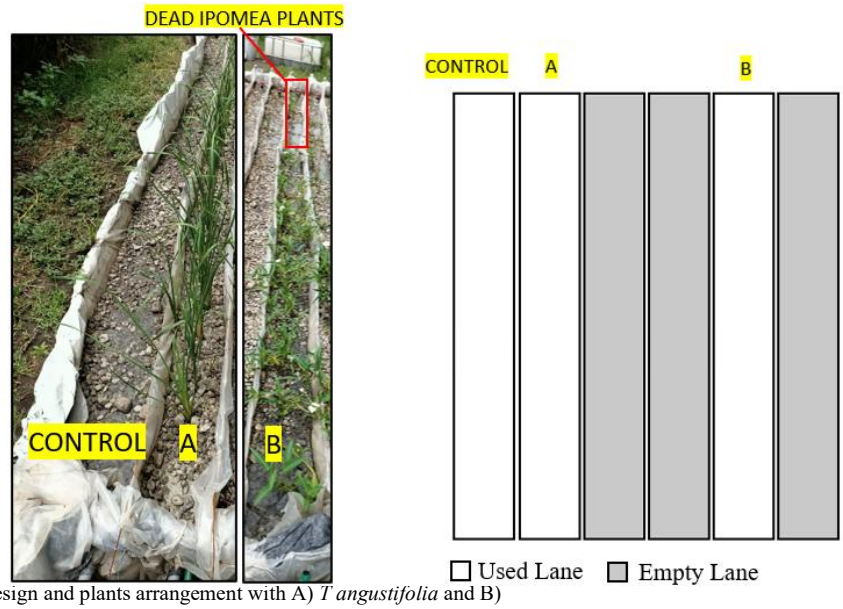

Figure 4 VSSCW Lane Design and plants arrangement with A) *T angustifolia* and B)

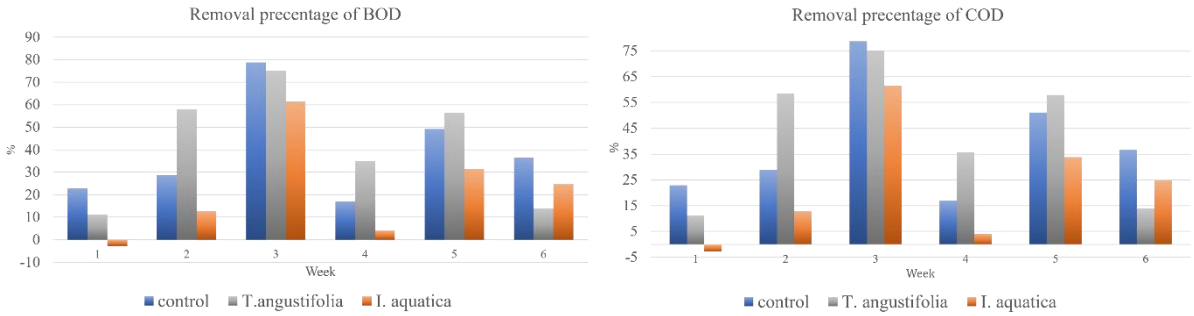

Figure 5 removal percentage chart of BOD and COD in constructed wetland

Biological Oxygen Demand removal

The BOD removal is shown in Figure 5 and Figure 6. BOD removal in the control column is around 719.53 mg/L – 3701.78 mg/L with an average of 2021.42 mg/L. BOD concentration fluctuations in the control column ranged from 719.53 mg/L – 3701.78 mg/L. *T angustifolia* showed the best performance with an average removal percentage of 41.54%. *I. aquatica* had the lowest performance compared to the control and *T angustifolia* because of its poor adaptability. The control column was able to reduce the average BOD by 38.88%. This result is slightly better than *I. aquatica* (Table 5). In week 3, the performance for every column decreased significantly, due to the effects of weather and dilution

then increased again after evapotranspiration occurred the following week. *I. aquatica* experienced a significant increase in BOD concentration in the 4th week. The frequency of heavy rains that occurred decreased during the 4th week of observation which affected the increase in BOD concentrations.

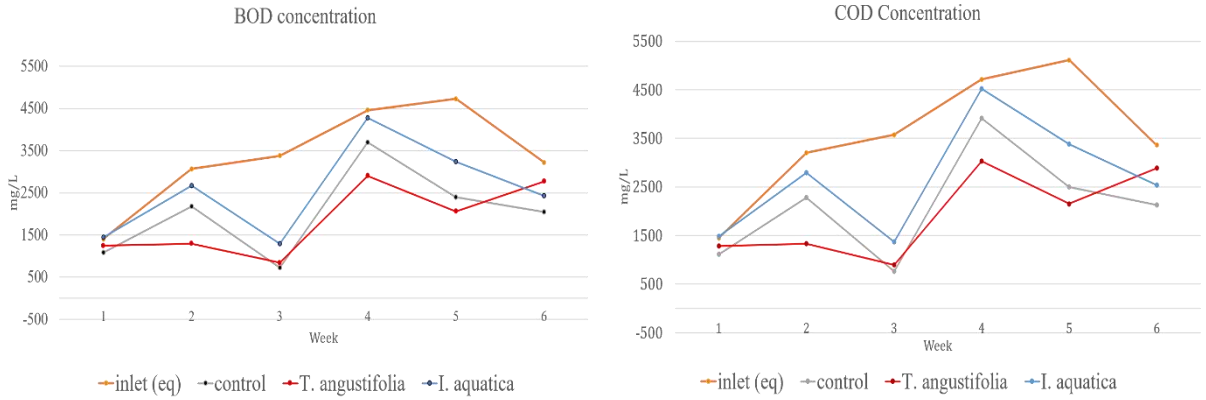

Figure 6 Fluctuation of BOD and COD concentration on three columns

Table 2 Comparison of COD and BOD between control, T. angustifolia and I. aquatica as a whole in the treatment plan

Parameters	Inlet	Control		T. angustifolia		I. Aquatica	
		Effluent (outlet)	Removal	Effluent (outlet)	Removal	Effluent (outlet)	Removal
BOD	5820.08	2021.42	65.17%	1853.73	67.85%	2559.83	55.90%
COD	6771.0	2114.7	67.59%	1928.7	70.29%	2678.8	59.04%

Table 3 COD and BOD concentrations at the equalization tanks inlet and constructed wetland inlet

Parameter	Inflow (mg/L)	Effluent (mg/L)	Removal
BOD	5820.08	3376.46	41.15%
COD	6771.0	3565.5	44.92%

Table 4 Comparative analysis of COD in artificial wetland inlet, control column, T. angustifolia column and I. Aquatica column

Unit		Average	Min	Max	Average Removal Procentage (%)
Equalization Tanks (inlets)	(mg/L)	3565.5	1443.00	5110.00	-
Control	(mg/L)	2114.7	760.00	3910.00	39.20 %
T angustifolia	(mg/L)	1928.7	890.00	3030.00	42.04 %
I. aquatica	(mg/L)	2678.8	1370.00	4520.00	22.38 %

Table 5 BOD analysis in three columns of constructed wetland

Unit		Average	Min	Max	Average Removal Procentage (%)
Equalization tank (Inlet)	(mg/L)	3376.46	1405.06	4727.09	-
Control	(mg/L)	2021.42	719.53	3701.78	38.88%
T angustifolia	(mg/L)	1853.73	842.6	2904.15	41.54%
I. aquatica	(mg/L)	2559.83	1297.04	4279.29	21.98%

Discussion

The rainfall intensity certainly affects the concentration of BOD and COD levels in the system. Increased water precipitation can reduce BOD and COD concentrations due to dilution, both in equalization tanks and constructed wetlands. The dilution that occurs disrupts the treatment plan and hinders its efficiency in reducing BOD and COD levels. Constructed wetland works better when the BOD and COD levels are high and the ratios are greater than 0,5 (Eddy et al., 2014).

The COD concentration in all columns has not reached the water quality standard yet. The continuous flow in this study has a shorter retention time than the batch method. As a result, *T* angustifolia is unable to absorb nutrients optimally hence low COD removal in the outlet. Compared to previous studies, *T* requires a

stay of up to 7 days in the batch system in the phytoremediation process with a COD removal of 98.5% (T. Muhammad et al., 2021). The control column (without plants) was able to reduce 39.2% of COD. The function of filtration by the growing media works in reducing and degrading COD with the help of microbes that grow in it. Figure 5 shows the COD concentration at the control column outlet fluctuating between 760-3910 mg/L with an average of 1853.73 mg/L. *I.* aquatica showed good performance in COD removal in a batch system with a retention time of 6 days (Nguyen et al., 2018). Compared to this study, *I. aquatica* in a continuous system were not completely able to survive and show results less than in the batch system. Efforts to increase efficiency can be carried out by increasing the detention time by extending the trajectory of constructed wetlands so that the process of phytoremediation and COD degradation can occur longer and optimally.

The average BOD concentration after going through a phytoremediation process for 6 weeks still needs to meet the quality standards for soybean-processed wastewater. When compared to previous studies, a removal efficiency of 95.5% can be achieved in the batch method for 7 days (Ahmad et al., 2019). This proves that *I. aquatica* requires a longer time to process and degrade BOD in tofu wastewater. BOD concentrations experienced the highest removal in week 3 and rainfall was an influential factor in decreasing BOD concentrations.

The short detention time of the system is caused by the short-sized trial VSSFCW system with only 6.3 meters in length and 0.25 in width. Because of that, the tofu wastewater could not be completely treated in the systems causing it to degrade the organic matter inefficiently. It is shown in the result that the removal efficiency of BOD and COD from the VSSFCW system is only 41.54% and 42.04% at best. In this case, the VSSFCW system with the design in the trial are need to be scaled up 2x larger in order to increase its efficiency (Eddy, et al., 2014).

Constructed wetland-based wastewater treatment systems can be developed to achieve better performance. *T angustifolia* and *I. aquatica* planted in constructed wetlands can help reduce the pollutants contained in tofu wastewater. The general performance of the system that combines pilot-scale phytoremediation processes has good performance. *T angustifolia* works very well in the VSSF-CW type with COD and BOD removal percentages of 42.04% and 41.54%. Meanwhile, *I. aquatica* was able to reduce COD and BOD below *T angustifolia* about 22.38% and 21.98%. This result does not meet the quality standard so it requires a longer detention time to get a more optimal absorption.

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