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Case Study Article

The Effectiveness of Variations in Contact Time and Density of Water Hyacinth Plants in Reducing COD Level in Tofu Industrial Wastewater

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Abstract

Tofu industry X is one of 24 tofu industries in Bandungan, producing wastewater with a high organic matter content of 600 liters per day. The industry does not have a waste treatment plant and is directly discharged into water bodies, leading to environmental pollution. The phytoremediation method uses water hyacinth plants to be inexpensive and efficient. This study aims to see the effectiveness of water hyacinth plants in reducing COD levels in tofu wastewater. The method used quasi-experimental with a pretest-posttest control group design. The independent variables were contact time (2 and 4 days) and water hyacinth plant density (2 individuals/m^2, 4 individuals/m^2, and 6 individuals/m^2), for the dependent variable was a decrease in COD levels tofu wastewater. 39 samples were tested and analyzed by the Kruskal Wallis test. The results showed the effectiveness of reducing COD levels by 78.68% (2 days) and 80.15% (4 days) for a density of 2 individuals/m^2, 80.56% (2 days) and 86.58% (4 days) for density of 4 individuals/m^2, and 83.79% (2 days) and 87.33% (4 days) for a density of 6 individuals/m^2. It can be concluded that water hyacinth plants efficiently reduce COD of tofu wastewater but have not been effective in reducing COD to quality standards. There is a significant difference in reducing the COD levels of tofu wastewater using the treatment methods.

Keywords: Water hyacinth; phytoremediation; COD; tofu wastewater

1. Introduction

Management of the environment in the current era is important because many industries produce liquid waste. X tofu industry located in Jimbaran Village, Bandungan District, Semarang Regency is one of 24 tofu industries in Bandungan. Every day this industry can process about 300 to 1,000 pieces of tofu and produce around 600 liters of wastewater per day. The liquid waste is produced from making tofu which contains protein, amino acids, and chemicals that cause high organic matter and can affect the characteristics of tofu wastewater, especially COD. According to Oktorina, in tofu wastewater there is BOD (1,940 mg/l), COD (3,300 mg/l), TSS (509 mg/l), pH (3.4), and temperature (32^{o}C) (Oktorina et al., 2019). The X tofu industry does not have a sewage treatment plant, and the waste is directly discharged into water bodies. Many residents feel disturbed because of its location close to agriculture and residential area.

COD levels are used as indicators or detectors of water pollution levels (Yuningrat et al., 2012). The tofu wastewater in this study had a COD level of 973 mg/l. According to the Regional Regulation of

Central Java Province, Number 5 of 2012, this level exceeds the specified quality standard of 275 mg/l. If the wastewater discharged directly into water bodies, it will impact environmental and human health. Therefore, it is necessary to have processed not to cause pollution. One way to reduce organic matter, especially COD, is the phytoremediation method using water hyacinth plants. Phytoremediation has high efficiency to reduce organic matter in wastewater and is easy to do and low cost. Phytoremediation that is widely used is the constructed wetland system by utilizing the natural processes of microorganisms attached to the planting media (soil and coral) and aquatic plants (Gupta et al., 2016). Aquatic plants used as phytoremediators are water hyacinth plants. In Bandungan District, many aquatic plants are found because it is close to Rawa Pening. These plants include water hyacinth, kiambang, apu wood, lotus, genjer, water spinach, taro, and algae. The author tries to research by utilizing resources in the neighborhood. The choice of water hyacinth over other aquatic plants is due to the ability of plants to absorb pollutants and good adaptability. In addition, it has many long roots that can absorb impurities in water, both dissolved and suspended, with rapid proliferation (Patel, 2012). Besides, the reports that evaluate the performance of phytoremediation for treating tofu wastewater using water hyacinth plant is lacked to be found in the existing literatures.

This study is presented by seeing the knowledge gap in wastewater treatment using phyto-technology. In this study, tofu wastewater was treated using the phytoremediation method by employing constructed wetland subsurface flow system equipped with water hyacinth plants. This study aimed to see the effectiveness of water hyacinth plants in reducing COD levels in tofu wastewater. This study is hoped to contribute to the development of a low-cost wastewater treatment system using local and natural resources found nearby.

2. Research Methods

This study used quasi-experimental research conducted on a laboratory scale, while the research design was a pretest-posttest control group design. Water samples were taken from the liquid waste from the tofu production process, which contained levels of COD. From February to April 2021, the study was carried out for the acclimatization process for 10 days and treatment for 4 days in each repetition. Sampling was carried out in the tofu industry X, Bandungan, Semarang, while water hyacinth was obtained from Rawa Pening. The treatment was given at the authors' residence, while the COD test was conducted at the Environmental Engineering Laboratory, Diponegoro University.

The wastewater sample was taken from the tofu manufacturing activities of the X tofu industry in Jimbaran Village. The number of repetitions is calculated using the equation (1).

$$(t-1)\ (r-1) \geq 15 \quad (1)$$

$$(6-1)\ (r-1) \geq 15$$

$$r \geq 4$$

Where T is the number of treatments and R is the number of repetitions. Repetition is done by 4 times, with each receiving 6 different treatments for variations in water hyacinth plant density and contact time. The total sample consisted of 39 samples consisting of 3 controls, 12 pretest samples, and 24 post-test samples. The independent variables in this study were variations in contact time (2 and 4 days) and the density of water hyacinth plants (2 individuals/m^2, 4 individuals/m^2, and 6 individuals/m^2). In comparison, the control variable is a decrease in COD levels of tofu wastewater. The primary data sources were the results of pH, temperature, and COD levels before and after treatment. The COD level data were then analyzed using the Kruskal Wallis difference test with a 95% confidence level. At the same time, the secondary data obtained from books, journals, and the internet related to the research.
COD reduction is calculated using the following effectiveness equation (2).

$$\frac{\text{COD influen} - \text{COD effluen}}{\text{COD influen}} \times 100\% \quad (2)$$

This research includes three stages, namely preparation, implementation, and data analysis. In the implementation process (where phytoremediation are conducted), it is necessary to pay attention to the plants and wetland tubs used. This result was done to minimize research errors and reduce COD levels optimally.

2.1 Preparation Stage

The preparation stage includes obtaining a research permit in the X tofu industry, a preliminary survey, preparation of research designs and instruments, data collection from previous tests, and preparation of tools and materials. This study uses tools such as thermometers, plastic, the bottle samples, containers, faucets, pipes, sample bottles, solder, pipe glue, plastic buckets, ice boxes, and tools for testing COD levels. While the materials needed are samples of tofu wastewater, aqua dest, water hyacinth plants, gravel, sand, materials for testing COD levels, labels, pH paper, and clear plastic.

2.2 Implementation Stage

2.2.1 Making A Series of Processing Tools

The equalization tub is a 30-liter bucket with a length of 43 cm, 26 cm, and a height of 27 cm. The bottom of the bucket is perforated, pipes and faucets are installed for the effluent of the wastewater. Furthermore, the washed gravel media is put in a wetland tub, then covered with washed sand.

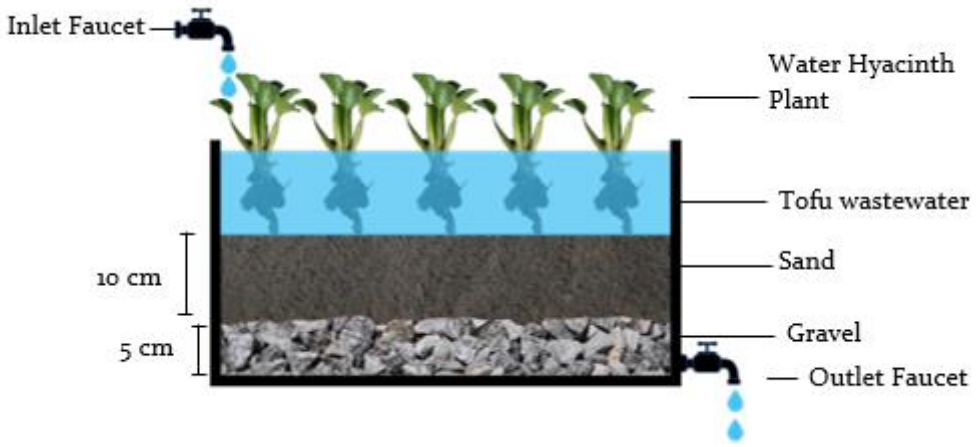

Figure 1. Series of processing tools

2.2.2 Water Hyacinth Plant Preparation and Acclimatization

Plant preparation begins with the calculation of the surface area of the tub, as shown in the equation (3):

$$2\ (43 \times 26) + (43 \times 27) + (26 \times 27) = 5{,}962\ \text{cm}^2 = 0.5962\ \text{m}^2 \quad (3)$$

Calculation of plant density

$$\frac{1\ \text{individual}}{0.5962} = 1.68 = 2\ \text{individuals/m}^2$$

$$\frac{2\ \text{individuals}}{0.5962} = 3.35 = 4\ \text{individuals/m}^2$$

$$\frac{3\ \text{individuals}}{0.5962} = 5.03 = 6\ \text{individuals/m}^2$$

Water hyacinth plants were selected that met the criteria, namely ± 10 cm root length with 5 – 7 stalks for each individual, ± 30 cm plant height from root, ± 20 – 30 g wet weight per stem, and fresh leaves with physical characteristics not yellowing. Plants were then acclimatized for 10 days in growing media. Acclimatization begins with giving ordinary water that is neutral for 2 days to

adapt to the new environment. Then proceed with optimizing the tofu wastewater concentration of 25% (4 days) and followed by 50% (4 days).

2.2.3 Tofu Waste Water Sampling

A sampling of tofu wastewater was carried out by the time composite sample method, where sampling was carried out at a particular time. Samples were taken when the tofu industry carried out the production process at around 09.00 GMT+7. The collection used a plastic jerry can as a pretest, while tofu wastewater was put into a plastic bottle for the post-test. After being filled without any air bubbles entering, the bottle samples, and plastic are tightly closed and labeled.

2.2.4 Treatment with Water Hyacinth Plants

Phytoremediation equipment for constructed wetland subsurface flow systems uses water hyacinth plants arranged with variations in density of 2 individuals/m^2, 4 individuals/m^2, and 6 individuals. A pretest sample of tofu wastewater for 12 liters was put in a container. Then measured pH, temperature, and levels of COD. Sample from the reservoir flowed into the container. The flow rate was 0.002 liters/minute and waited for 2 and 4 days, and the study was repeated 4 times. The effluent from the container was taken. The results are used as a post-test, and the pH, temperature, and COD levels are measured. The results obtained were then analyzed and described.

2.3 Data Analysys Stages

The next stage is the stage of data analysis which is descriptive quantitative. COD levels were analyzed using the Kruskal Wallis difference test to determine whether there was a difference in the average decrease in COD levels between groups of variables. Meanwhile, the Mann Whitney follow-up test determined the difference in the reduction in COD levels that occurred between treatment variations.

3. Result and Discussion

3.1 Characteristics of Tofu Waste Water

Liquid waste in this study is tofu wastewater from soybean sorting, washing, soaking, milling, cooking, filtering, clumping, printing, and cutting processes. The primary raw material is soybeans with coagulant additives, namely acid from the remaining liquid resulting from the transfer of tofu lumps that have been left overnight. Before processing, an initial characteristic analysis was carried out to determine the quality of tofu wastewater by measuring several parameters, namely COD, temperature, and pH. COD levels show a fluctuating number because it is influenced by the sampling method, which only describes the characteristics of the sample at the time of collection. The sample of this research was taken between 09.00 to 10.00 WIB on different days. The initial attributes of the tofu industry liquid waste X are presented in the following table :

Table 1. Initial characteristics of tofu wastewater

No.	Parameter	Unit	Results	*Quality standards	Information
1	Temperature	^oC	27.3	38	Below the range of quality standards
2	pH	-	6	6.0 – 9.0	Below the range of quality standards
3	COD	mg/l	973	275	Exceeding the quality standards

* Source: Central Java Provincial Regulation Number 5 of 2012 concerning Amendments to Central Java Provincial Regulation Number 10 of 2004 concerning Wastewater Quality Standards

The results of the initial characteristic test of tofu wastewater for COD, temperature, and pH levels are 973 mg/l, 27.3^{0}C, and 6. The processed tofu wastewater has the characteristics of dark yellow and white, acidic pH values, the temperature tends to be warm, and smells good. High COD levels are due to microorganisms' adaptation process in the growing media. In addition, there are also environmental factors such as protein and vinegar that cause organic matter to be high.

3.2 Acclimatization and Plant Observation After Treatment

Acclimatization is done to adjust the plants to a new place, both for plants and bacteria that live for 10 days. Adequate acclimatization can cause water hyacinth plants to grow and spread well during the treatment of tofu wastewater. Observations of the condition of water hyacinth plants were carried out every day during the treatment. Before acclimatization and treatment, water hyacinth plants reached ± 30 cm in height. After the acclimatization process, some plants were not as upright as before. There is a change in the plant's color from fresh green to dark green, and brownish spots appear. In addition, the condition of the water hyacinth plant also grows new shoots, and the roots are getting longer.

3.3 Decrease in COD

Tofu wastewater treatment to reduce COD levels can use the phytoremediation method of the constructed wetland subsurface flow system with water hyacinth based on plant density and contact time. The results of decreasing COD levels after treatment are :

Table 2. COD levels before, control, and after treatment

Group	Test	Pre	Treatment (mg/l)	
			PT1	PT2
Control		3,000	2,433.33	633.33
G1 (2 individuals/m^2)	1	3,000	866.67	700
	2	2,433.33	500	466.67
	3	5,350	956.67	943.33
	4	4,616.67	960	946.67
Average		3,850	820.84	764.17
G2 (4 individuals/m^2)	1	3,200	500	133.33
	2	2,266.67	733.33	400
	3	5,416.67	953.33	876.67
	4	5,283.33	953.33	760
Average		4,041.67	785	542.5
G3 (6 individuals/m^2)	1	2,900	203.33	153.33
	2	2,533.33	500	133.33
	3	5,150	963.33	940
	4	4,883.33	840.00	733.33
Average		3,866.67	626.67	490

Information :
PT1 : 2nd day check
PT2 : 4th day check
Pre : Initial experiments were carried out to determine the initial level of waste

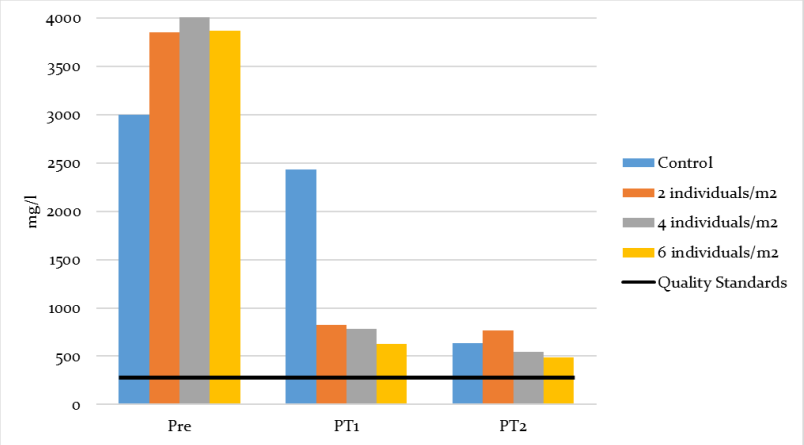

Figure 2. COD levels before, control, and after treatment

Table 2 and Figure 2 show that the average COD level of tofu wastewater decreased after passing through the control and treatment. The COD level decreased, which tended to be constant. However, the COD level still exceeds the specified quality standard. In addition, the decrease in COD levels in each treatment has a difference that is not much different. The reduction that occurred after the treatment was more significant than the control although there was a decrease in the control group.

COD levels and the volume of tofu wastewater decreased after being left for 4 days, and there was sediment. There is a sedimentation process when left for 4 days that reduce the pollutants in the liquid waste. The condition of the water that lacks oxygen due to contamination with organic substances and other contaminants can facilitate the sedimentation process. The sediment is formed from the media of sand, gravel, and plants in the reactor tank, and the tofu wastewater changes color to clear when it comes out as the effluent. The decrease in COD levels after treatment was not much different. That is due to the unintentional aerobic decomposition process when transferring the sample to a smaller medium.

Water hyacinth has been proven to reduce COD levels in tofu wastewater. It demonstrates physical, biological, and chemical processes due to plants, growing media, and microorganisms. The method of photosynthesis provides oxygen to the roots for microorganisms that plants act as a medium for growing microorganisms. Water hyacinth plants can absorb pollutants in water, both dissolved and suspended, with rapid proliferation, especially in the roots. The roots of the water hyacinth plant are fibrous. The number of fibers causes the soil's porosity to decrease, and the filtration process is getting better. It is expected that the industry owners know to treat liquid waste with this method before being discharged into water bodies.

The primary process in this tofu wastewater treatment is the rhizofiltration process, accumulating contaminants in the waste using plant roots (Golubev, 2011). In this method, there is also cooperation between plants and microorganisms around the bases (rhizosphere microorganisms), reducing COD levels. Microorganisms use oxygen from photosynthesis to decompose organic substances whose results in the form of nutrients will be absorbed by plants (Khiattudin, 2003). The decrease in all reactor tanks was excellent because it almost completely removed the COD levels from the quality standard limits. However, this value still exceeds the quality standard because the adsorption process has not run optimally. Several influencing factors include water hyacinth plants, acclimatization, growing media, sunlight intensity, pH, temperature, and other contaminants. As a result of contamination of the organic content of tofu wastewater which can cause plant metabolic disorders, so plants experience nutritional deficiencies and cell death, growth inhibition, leaves become curly and black and lose their chlorophyll. The factors must be controlled to not interfere with the effectiveness of the absorption of pollutants by water hyacinth plants. In addition, further research is also needed with other variations such as the weight of water hyacinth plants and

other aquatic plants. Leaves become curly and black and lose their chlorophyll. These factors must be controlled to not interfere with the effectiveness of the absorption of pollutants by water hyacinth plants. In addition, further research is also needed with other variations such as the weight of water hyacinth plants and other aquatic plants. Leaves become curly and black and lose their chlorophyll (Suswati & Wibisono, 2013). These factors must be controlled so as not to interfere with the effectiveness of the absorption of pollutants by water hyacinth plants. In addition, further research is also needed with other variations such as the weight of water hyacinth plants and other aquatic plants.

This decrease in COD levels indicates a process of absorption and accumulation of COD levels by water hyacinth plants, which consists of three stages: absorption of COD levels by plant roots and translocation of COD levels from roots to other parts, and localization of COD levels. The presence of COD levels in certain aspects that plant metabolism does not occur disturbances. The absorption of COD levels in water hyacinth plants is carried out at the roots by forming phytosidorophores (chelate molecules) which then bind pollutant parameters and are carried to root cells through an active transport process (Permanandiah et al., 2017). Absorption by plant roots involves cation energy characterized by the ability to enter the electrochemical gradient in the cell passively. Meanwhile, anion energy is actively transported into root cells.

Furthermore, COD levels are translocated from roots to other parts such as stalks and leaves through the xylem and phloem transport networks. Stems and leaves play a role in increasing oxygen transfer into the bases. Then localization of COD levels in specific tissues so that plant metabolism is not disturbed, and plant cells are protected from poisoning. The illustrates the ability of water hyacinth plants to tolerate contaminants that enter the water hyacinth plant (Caroline & Moa, 2015).

Table 3. The effectiveness of reducing COD levels with the length of contact and density of water hyacinth plants

Sample	Effectiveness			
	2 days		4 days	
	Difference	Percentage	Difference	Percentage
Control	566.67	18.89%	2,366.67	78.89%
Density 2 individuals/m^2	3,029.16	78.68%	3,085.83	80.15%
Density 4 individuals/m^2	3,256.67	80.56%	3,499.17	86.58%
Density 6 individuals/m^2	3,240	83.79%	3,376.67	87.33%

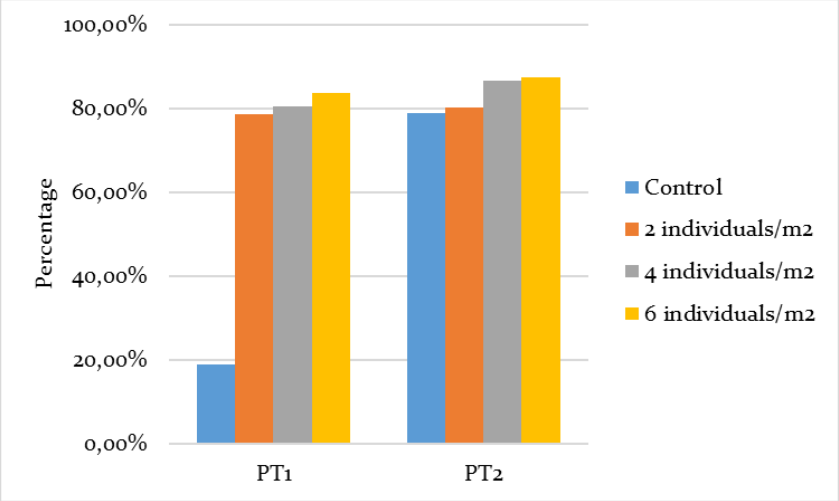

Figure 3. The effectiveness of reducing COD levels with variations in contact time and density of water hyacinth plants

Table 3 and Figure 3 show that the average effectiveness of the most significant reduction was at 4 days of contact with a plant density of 6 individuals/m², which was 87.33%. That shows that the higher the density and the longer the time, the lower the COD level. After doing different tests with Kruskal Wallis, the p-values of each were 0.002 (≤ 0.05). There was a significant difference in decreasing COD levels between contact time and plant density variations. Water hyacinth plants can reduce COD levels in tofu wastewater, but these levels still exceed the specified quality standards. Those water hyacinth plants still have not reduced COD to quality standards.

COD levels of tofu wastewater decreased with increasing contact time and density of water hyacinth plants. So that the COD reduction efficiency depends on the plant density and the contact time of water hyacinth in the constructed wetland, that is because the length of contact between plants and the tofu wastewater is sufficient to provide an opportunity for microorganisms to absorb pollutants in the reactor tank. The role of microorganisms in this reactor is to decompose organic particles in water as nutrients for plant growth. The reactor tank is not used repeatedly. The decrease in pollutant levels is more optimal.

The higher the plant density, the efficiency of reducing COD levels will increase, meaning that the plant density is directly proportional to the COD efficiency. Water hyacinth plant density affects the average number of plant root hairs and will affect the phytoremediation ability. High COD levels cause the rfizofiltration process to be higher. The higher the levels of COD absorbed by the water hyacinth plant, the higher the plant's toxicity. After the treatment, the water hyacinth plant will grow new shoots, and the roots will be longer. To live, plants need nutrients taken in molecules through the sources. The longer the plant roots, the more available nutrients for plants. The length of the plant roots allows the plant to reach more profound and more comprehensive. The ability of water hyacinth plants to reduce pollutant levels due to variations in contact time and plant density is in line with Aldo's research. In this study, water hyacinth plants were used according to the density of 8 individuals/m², 15 individuals/m², 22 individuals/m², and contact times of 3 and 6 days. The effective treatment was found at a density of 22 individuals/m² within 6 days, 99.9%.

3.4 pH and Temperature

Tofu wastewater is acidic because the ingredients for making tofu are soybeans and vinegar. That creates a foul odor due to the release of volatile substances. In this study, before being given treatment, the average pH value was 6, which means that it is already in the pH range of standard conditions for plants to grow and by the requirements of constructed wetlands. It does not need to be conditioned to meet the pH requirements and directly treated. In the control group is 6-7, while after being given treatment in treatment I (2 individuals/m²) is 6-7.5, treatment II (4 individuals/m²) is 6.5-8.25, and treatment III (6 individual/m²) is 7.25 – 8.25. The pH is by Central Java Provincial Regulation No. 5 of 2012, which is 6 – 9.

Acid and alkaline pH levels interfere with the phytoremediation process, which causes the process not to occur optimally, resulting in disruption of plant metabolism (Ratnani et al., 2011). The pH value can increase the rate of contaminant absorption by the plants used and is related to the solubility of contaminants in the soil. The pH range for processing with the phytoremediation method of the constructed wetland system for the growth of microorganisms is 6-9, while the optimum pH range for the use of water hyacinth is 6-8 (Disyamto et al., 2014). The pH must be related to the pH range determined that plant metabolism is not disturbed and the tofu wastewater is optimal.

Temperature measurements were carried out every day during the treatment. In this study, the temperature before being treated was 27.3°C, so the tofu wastewater did not need to be conditioned and could be directly treated. The temperature in the control group dropped to 25.5°C (2 days) and 25.9°C (4 days). After treatment I (2 individuals/m²), the average temperature became 27.7°C on day 2 and 27.8°C on day 4. After treatment II (4 individuals/m²), the average temperature became 27.5°C on day 4. 2 and

27.9°C on day 4. Meanwhile, after treatment III (6 individuals/m^2), the average temperature was 27°C on day 2 and 27.9°C on day 4. Overall, the temperature of tofu wastewater was still within the optimal temperature limit. For plant metabolic processes, that water hyacinth plants can survive.

Temperature affects the activity of microorganisms and plant metabolism for photosynthesis and transpiration. That affects the performance of wastewater treatment in the reactor basin (Astuti et al., 2017). The optimum temperature for plant growth is 27°C - 30°C, while to maintain the performance of bacteria, the temperature must be in the range of 10°C - 40°C. Temperature also affects the rate of transpiration in the form of the release of water from the plant surface through diffusion and evaporation of plant water, then the process of water absorption from the planting medium. An increase in temperature will cause an increase in vapor pressure in the leaves, which is associated with an increase in transpiration rate.

4. Conclusion

Water hyacinth has been proven to reduce COD levels in tofu wastewater. However, water hyacinth plants did not lower COD levels to the specified quality standard. The results of the Kruskal Wallis test analysis showed a significant difference in reducing COD levels of tofu wastewater using the phytoremediation method of the constructed wetland subsurface flow system using water hyacinth plants. Further research is needed on the use of water hyacinth plants or other aquatic plants in the field (especially the tofu industry) to reduce COD levels.

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