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Potential of Phytoremediation Using *Kiambang* (Salvinia molesta) for Treating Textile Industry Wastewater in Indonesia

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Abstract
This study aims to evaluate the effectiveness of phytoremediation using plants in reducing chromium (Cr) levels and modifying pH in batik wastewater. The research was conducted using three experimental tanks: Control Tank (without plants), Tank 1 (with 8 plants) and Tank 2 (with 16 plants). The results showed that in the control tank the pH fluctuated and reached 8.1 on the 9th day, while in tank 1 and tank 2 the pH was more controlled with peak values of 7.9 and 8.2 respectively. The most significant reduction in chromium levels occurred in tank 2, with treatment efficacy reaching 70% on day 9, compared to 45% in tank 1 and 10.5% in the control tank. These results indicate that phytoremediation with more plants can significantly improve the treatment efficiency of batik wastewater, making it a potential and environmentally friendly method for industrial wastewater treatment. The phytoremediation method was carried out by observing variations in the number of plants using 3 reactor tanks. The first tank was a control tank, the second tank (BR2) contained 8 plants and the third tank (BR3) contained 16 plants. Samples were taken on days 3, 6 and 9. The results showed that the highest effectiveness in reducing total chromium (Cr) levels occurred in the third tank (BR3) on day 9, with a reduction of 70%.
Keywords: *phytoremediation plants, chromium (cr), kiambang, textile wastewater*

Abstrak
Penelitian ini bertujuan untuk mengevaluasi efektivitas fitoremediasi menggunakan tanaman dalam mengurangi kadar Krom (Cr) dan memodifikasi pH pada limbah cair batik. Penelitian dilakukan menggunakan tiga bak percobaan: Bak Kontrol (tanpa tanaman), Bak 1 (dengan 8 tanaman), dan Bak 2 (dengan 16 tanaman). Hasil penelitian menunjukkan bahwa pada Bak Kontrol, pH mengalami fluktuasi dan mencapai 8,1 pada hari ke-9, sementara pada Bak 1 dan Bak 2, pH lebih terkendali dengan nilai tertinggi masing-masing 7,9 dan 8,2. Penurunan kadar Krom paling signifikan terjadi pada Bak 2, dengan efektivitas pengolahan mencapai 70% pada hari ke-9, dibandingkan dengan 45% pada Bak 1 dan 10,5% pada Bak Kontrol. Hasil ini menunjukkan bahwa fitoremediasi dengan menggunakan lebih banyak tanaman dapat meningkatkan efektivitas pengolahan limbah cair batik secara signifikan, menjadikannya metode yang potensial dan ramah lingkungan untuk pengolahan limbah industri batik. Metode fitoremediasi dilakukan dengan mengamati variasi jumlah tumbuhan, dengan menggunakan 3 bak reaktor. Bak pertama yaitu bak kontrol, bak kedua (BR2) berisi 8 Tumbuhan dan bak ketiga (BR3) berisi 16 Tumbuhan. Pengambilan dilakukan pada hari ke-3, hari ke-6 dan hari ke-9. Hasil penelitian menunjukkan tingkat efektivitas penurunan kadar Krom Total paling tinggi terjadi pada bak ketiga (BR3) dengan waktu pengambilan hari ke-9 dan penurunan kadar Krom Total mencapai 70%.
Kata kunci: *fitoremediasi, tanaman, krom (cr), kiambang, limbah cair batik*

1. Introduction

The development of the batik industry in Indonesia significantly contributes to the economy, particularly through job creation and textile production. However, this industry also contributes to environmental pollution, primarily due to the liquid waste generated during the dyeing process. Batik industry wastewater is characterized by its intense color, strong odor, high turbidity, and contains hazardous substances such as heavy metals (Zn, Cd, Cu, Cr, Pb), phenols, sulfides, and organic compounds. Wastewater treatment in this sector, especially for small and medium enterprises (SMEs), is still considered expensive and ineffective, leading many industries to discharge their waste directly into water bodies without treatment [1]–[3].

Wastewater is the liquid residue from various human activities. Batik industry wastewater contains hazardous substances such as heavy metals, phenols, sulfides, high levels of BOD, COD, and TSS [4]–[6]. According to PERMENLHKRI No. 16 of 2019, batik industry wastewater must meet specific quality standards before being discharged into the environment. Phytoremediation is a technology that uses plants to remove contaminants from the environment. This method is considered cost-effective and environmentally friendly. Phytoremediators such as Kiambang (Salvinia molesta) are effective in absorbing heavy metals and reducing pollutant concentrations in wastewater [7]–[10]. Kiambang is an aquatic plant with the ability to act as a heavy metal hyperaccumulator. This plant can grow in shallow waters with slow flow and has the capacity to reduce polutan levels in wastewater [11]–[13].

Using locally available and highly adaptable aquatic plants, Kiambang (Salvinia molesta), in a phytoremediation strategy to treat liquid waste from Indonesia's textile industry is innovative. This technology provides a sustainable and eco-friendly option when cleaning up pollutants from industrial waste. This method addresses the waste management needs of Indonesia's fast-growing industry. It opens up new possibilities for applying environmentally friendly technology tailored to the specific ecosystem in which we live by concentrating on fast-growing plants with high absorption potential.

2. Material and Methods

This study was conducted using an experimental method in the laboratory, utilizing Kiambang (Salvinia molesta) to treat batik wastewater. Testing was performed to measure the reduction in Total Chromium (Cr) and pH levels in the wastewater before and after the phytoremediation process. The sampling technique used was grab sampling, which involved using a sampling bottle and placing the sample into a jerrycan. This sampling method complies with SNI 6989.59:2008. The Kiambang samples were collected directly into the pond, selecting healthy and viable plants that would survive in the new culture container.

Materials and Equipment for the Experiment

1) Plastic Buckets 5 Reactor Containers
2) Plastic Faucets 5 Faucets (5/4)
3) Jerrycans 6 Jerrycans (5 litters each)
4) Batik Wastewater 30 Liters
5) Sand 5 Containers
6) Gravel 5 Containers

Scope of the Research

1) Batik wastewater from the Eco Print production house.
2) Reactor performance is evaluated solely based on the reduction of Chromium (Cr) and pH parameters.

Plant Preparation

The acclimatization/maintenance phase for the research plants, which were collected from their natural habitat in Pulau Kayu village, specifically from the drainage behind residential areas, involved initially maintaining the plants by placing them in plastic containers filled with 50% or approximately 20 litters of wastewater obtained from the plant collection site. Acclimatization was carried out to adjust the plants to their new environment and was performed for 7 days before the research procedures were conducted.

Research Procedure

1) Preparation of the wetland tank and control tank using plastic containers measuring 30 cm × 15 cm × 15 cm..
2) Collection of batik wastewater is performed during the day using jerrycans, then the wastewater is separated into 15-liter jerrycans for testing at the Multifunction Laboratory of UIN Ar-Raniry Banda Aceh.
3) The remaining wastewater is placed into the wetland reactor containers, which already contain gravel, sand, and plants that have been acclimatized for 7 days.
4) The wastewater is then left to stand for 9 days in the wetland reactor.

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5) Phytoremediation is conducted by observing variations in the number of plants using 3 reactor tanks. The first tank is the control tank, the second tank (BR2) contains 8 plants, and the third tank (BR3) contains 16 plants. Sampling is done on days 3, 6, and 9.
6) Laboratory analysis is conducted to measure the reduction in wastewater parameters, specifically Cr and pH. Testing is performed at the Standardization & Industrial Service Center (BPSJI) Laboratory in Banda Aceh.

Analysis Method

1) pH Measurement (SNI 06-6989.11-2019)
2) Total Chromium (Cr) Measurement (SNI 06-6989.17-2004)

Data Processing

1) Measurement of Effectiveness

The effluent results from the batik wastewater treatment are taken to the designated laboratory for testing. The laboratory test results are then analyzed to determine the effectiveness of the plants in degrading the batik pollutants based on the wastewater effectiveness formula and compared to the established quality standards. To calculate effectiveness, the following equation is used

$$\text{\% Effectiveness} = \frac{a-b}{a} \times 100\ \%$$

2) Data Processing Using SPSS

Multiple linear regression analysis is the linear relationship between two or more independent variables (predictor variables) and a dependent variable (response variable) [14], [15]. To determine the linearity of the data, the test of linearity can be used with a significance level of 5%. If the significance value of linearity is greater than 0.05, the data is considered linear; if it is below 0.05, the data is considered non-linear [16], [17]. The analysis used to determine the effect of independent variables, such as time variation, on the dependent variables, including the reduction in chromium levels and changes in pH values.

3. Results and Discussion

The treatment process was initially conducted using a wetland system based on the differences or variations in the number of plants. In this study, there were 2 variations in the number of plants: Tank 1 contained 8 plants, and Tank 2 contained 16 plants. The type of plant used was Kiambang or Salvinia molesta. Preliminary Test Results.

Table 1. Preliminary Test Results

Parameter	Highest Concentration (mg/l)	Day-0
pH	6,0 – 9,0	9,0
Krol Total (Cr)	1,0	1,0
COD	150	350
TSS	50	200

Source: Permen LHKRI No.16 Tahun 2019

Table 2. Wastewater Quality Standards for the Textile Industry

Parameter	Highest Concentration (mg/l)	Highest Pollution Load (kg/ton)
BODs	60	6
COD	150	15
TSS	50	5
Fenol Total	0,5	0,05
Krom Total (Cr)	1,0	0,1
Amonia Total (NH3=N)	8,0	0,8
Sulfide (as S)	0,3	0,03
Minyak and Lemak	3,0	0,3
pH	6,0 – 9,0	
Highest Wastewater Flow Rate	100 m^3/ton Textile Products	

Source: *PERMEN LH No.16 Tahun 2019*

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The quality standards for batik industry wastewater can be seen in PERMENLHKRI No.16 Tahun 2019 **Table 1**. At a glance, the appearance of Kiambang (Salvinia molesta) resembles roots, but it is actually modified leaves that function as roots. The habitus of S. molesta can be seen in **Fig. 1**.

Fig. 1. Salvinia molesta

a. Sample Collection Location and Sample Research

The objects of this study are batik wastewater and Kiambang (Salvinia molesta). Approximately ±30 litters of batik wastewater were collected from the Eco Print batik SME located in Bineh Krueng village, Tangan-Tangan District, Aceh Barat Daya Regency. The collected wastewater comes from the holding tank; the samples were placed in sealed containers with a temperature below 20°C to prevent biodegradation. The sampling location map for batik wastewater can be seen in **Fig. 2**.

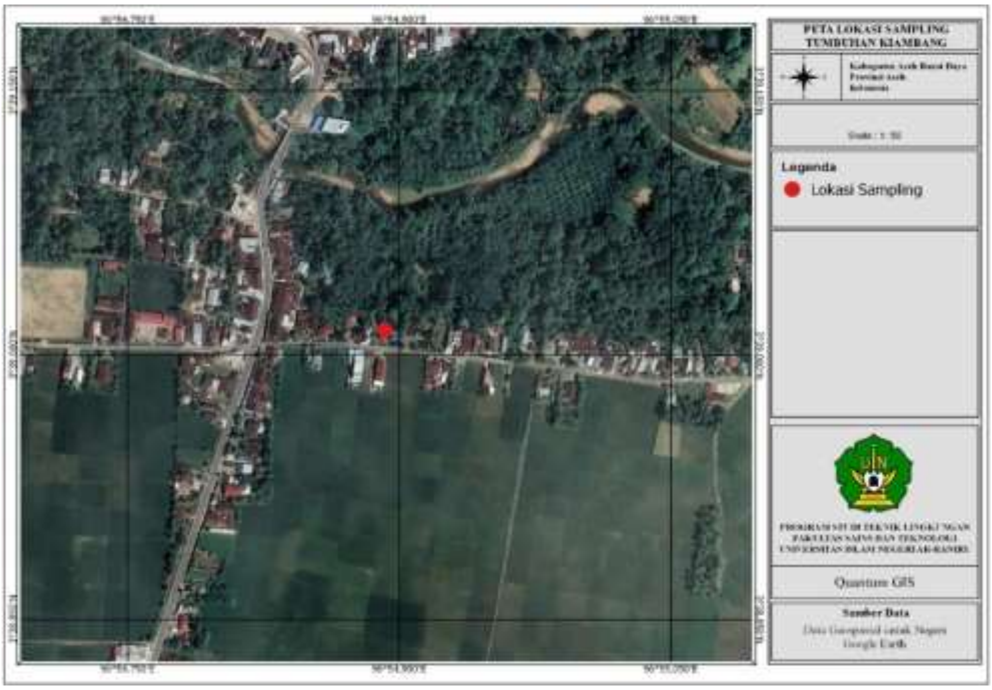

Fig. 2. The sampling location map for batik wastewater

b. Plant Morphology After Treatment

After 9 days of treatment, the morphology of each Kiambang plant in the treatment tanks was observed for symptoms, such as yellow spots caused by chlorosis. In severe cases, the leaves even fell off from the stems. Additionally, a small portion of the fibrous roots showed signs of detachment.

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(a) (b) (c)

Fig. 3. a) Control Tank, b) Reactor Tank 1 (8 Plants), and c) Reactor Tank 2 (16 Plants)

c. Chromium Levels After Treatment

Fig. 3 shows that as the concentration of the solution increases, the amount of chromium absorbed also increases.

Table 3. Effectiveness of Chromium (Cr) Reduction in Batik Wastewater

Parameter	Variation		After Treatment (mg/l)	Treatment Effectiveness (%)
Crom	Control Tank	Day-0	2,0	-
		Day-3	1,90	5
		Day-6	1,85	7,5
		Day-9	1,79	10,5
	Tank 1 (8 Plants)	Day-0	2,0	-
		Day-3	1,65	17,5
		Day-6	1,40	30
		Day-9	1,10	45
	Tank 2 (16 Plants)	Day-0	2,0	-
		Day-3	1,05	47,5
		Day-6	0,90	55
		Day-9	0,60	70

Table 4. Chromium Concentration (mg/l) Over Time

Day	Control Tank	Tank 1 (8 Plants)	Tank 2 (16 Plants)
Day 0	2.0	2.0	2.0
Day 3	1.90	1.65	1.05
Day 6	1.85	1.40	0.90
Day 9	1.79	1.10	0.60

Table 5. Treatment Effectiveness (%) Over Time

Day	Control Tank	Tank 1 (8 Plants)	Tank 2 (16 Plants)
Day 0	0	0	0
Day 3	5	17.5	47.5
Day 6	7.5	30	55
Day 9	10.5	45	70

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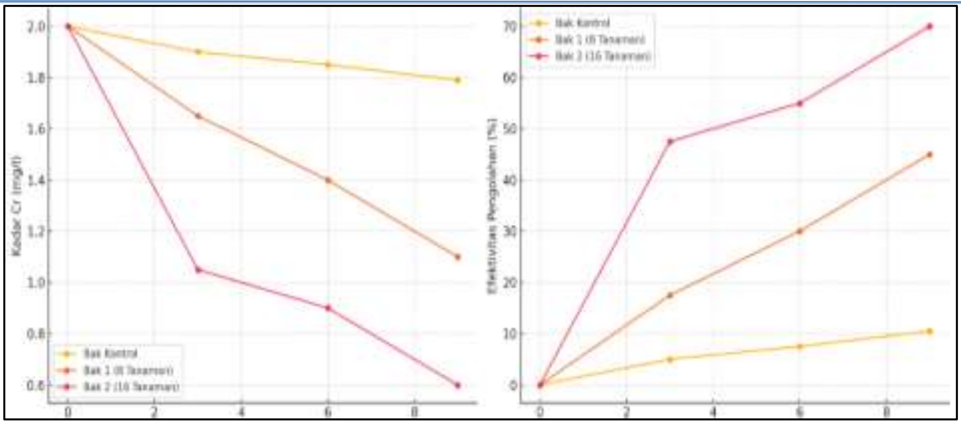

Fig. 3. Graph of Chromium (Cr) Concentration (mg/l) Changes After Phytoremediation Treatment

This graph shows the changes in chromium (Cr) levels in batik wastewater over a 9-day period following phytoremediation treatment. The three variations displayed are Control Tank, Tank 1 (8 Plants), and Tank 2 (16 Plants).

1) **Control Tank**: Shows a slight decrease in Cr levels from 2.0 mg/l on Day 0 to 1.79 mg/l on Day 9.
2) **Tank 1 (8 Plants)**: Shows a more significant decrease from 2.0 mg/l on Day 0 to 1.10 mg/l on Day 9.
3) **Tank 2 (16 Plants)**: Shows the most significant decrease from 2.0 mg/l on Day 0 to 0.60 mg/l on Day 9.

Graph of Cr Reduction Effectiveness in Batik Wastewater

This graph shows the effectiveness of Cr reduction in percentage over a 9-day period after phytoremediation treatment for the three variations.

1) **Control Tank**: Treatment effectiveness ranges from 5% to 10.5% from Day 3 to Day 9.
2) **Tank 1 (8 Plants)**: Treatment effectiveness increased from 17.5% on Day 3 to 45% on Day 9.
3) **Tank 2 (16 Plants)**: Shows the highest treatment effectiveness, increasing from 47.5% on Day 3 to 70% on Day 9.
4) Figures 4.2 and 4.3 show that the rate of reduction in Chromium (Cr) levels decreased with each treatment and testing day. The highest degradation rate was observed in tank 2 from the first day to the ninth day, with a degradation efficiency of 70%. This was followed by treatment in tank 1, which also experienced a decrease from the first day to the ninth day, with a reduction efficiency of 45%. Testing in tanks 1 and 2 involved using the plant Salvinia molesta as a phytoremediator for Chromium (Cr). The control tank also experienced a decrease, but the efficiency of the reduction rate was lower compared to the treatment tanks with Salvinia molesta plants. Statistically, to determine the effect of the chromium solution treatment on the chromium accumulation capability of the Salvinia molesta plants, an ANOVA (Analysis of Variance) test was conducted, as shown in Table 4.1 in the appendix.
5) The measurement results indicated a significant reduction, especially for the Chromium (Cr) parameter, while the pH parameter slightly increased. The pH increase occurred in tanks 1 and 2. The Salvinia molesta plants contributed to raising the pH. This increase was due to the photosynthesis activity of the test plants. Photosynthesis converts CO_2 into C6H12O6, requiring hydrogen and energy. Hydrogen is obtained from H+ in wastewater and air. Thus, the uptake of H+ will raise the pH [18].
6) The treatment process was first conducted using the Wetland system based on the variation in the number of plants. This study included two variations in the number of plants: tank 1 contained 8 plants, and tank 2 contained 16 plants. The type of plant used was Salvinia molesta. The test results for the parameters based on Table 4.1 with varying numbers of plants indicate that the more plants used, the better the wastewater treatment. This is also explained in a study by [19] on the effect of Salvinia molesta biomass variation on Cr levels in batik home industry wastewater in Magelang.
7) In the variations of plant numbers in tanks 1 and 2, the best reduction in Chromium (Cr) parameters occurred on the ninth day with the highest number of plants, which was 16 plants. Based on Table IV.1, the Chromium (Cr) parameter value can be reduced by up to 70%. The effectiveness of this reduction occurred on the ninth day, similar to the study by [20]. The results of the linear regression

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test to determine the effect of time variation on chromium effectiveness in the control tank can be seen in the appendix. The analysis results showed that the significance value was 0.234 > 0.05, indicating that time variation did not significantly affect the total chromium effectiveness. This conclusion is supported by the T-test results, which showed that the t-count value of 2.598 < t-table 2.920, indicating no significant effect on total chromium changes due to time variation. The results of the linear regression test to determine the effect of time variation on chromium effectiveness in tank 1 can be seen in the appendix. The analysis results showed that the significance value was 0.215 > 0.05, indicating that time variation did not significantly affect total chromium effectiveness. This conclusion is supported by the T-test results, which showed that the t-count value of 2.850 < t-table 2.920, indicating no significant effect on total chromium changes due to time variation. The results of the linear regression test to determine the effect of time variation on chromium effectiveness in tank 2 can be seen in the appendix. The analysis showed that the significance value was 0.190 > 0.05, indicating that time variation did not significantly affect total chromium effectiveness. This conclusion is supported by the T-test results, which showed that the t-count value of 3.248 > t-table 2.920, indicating a significant effect on total chromium changes due to time variation.

8) The ANOVA analysis results showed an F-count value > F-table (93.18 > 3.32), indicating that the chromium solution treatment significantly affected the chromium accumulation capability of Salvinia molesta plants. The resulting KK value was 70%.

d. pH Levels After Treatment

The results of the pH parameter test after phytoremediation treatment showed a decrease, as shown in **Table 6**. The graph of the pH decrease is presented in **Fig. 4**.

Table 6. pH Parameter

Variations	Day 0	Day 3	Day 6	Day 9
Control Tank	7.2	7.1	7.0	6.9
Tank 1 (8 Plants)	7.2	7.4	7.6	7.8
Tank 2 (16 Plants)	7.2	7.5	7.8	8.1

Below is the graph of the pH parameter test results after phytoremediation treatment. This graph shows the pH changes in the Control Tank, Tank 1 (8 Plants), and Tank 2 (16 Plants) from Day 0 to Day 9. The variations in pH changes in each tank after phytoremediation treatment are evident. Next, I will create two graphs to show the effectiveness of reducing chromium (Cr) levels in batik wastewater. One graph will display the changes in Cr concentration (mg/l) after phytoremediation treatment, and the other graph will show the treatment effectiveness (%) of each tank.

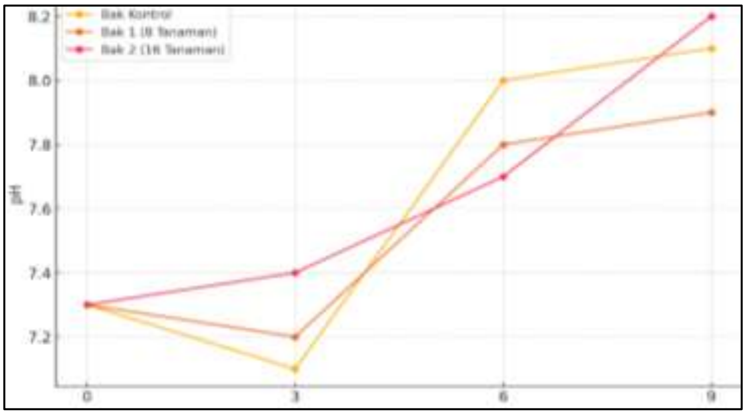

Fig. 4. Results of pH parameter results after phytoremediation

Based on **Table 6** and **Fig. 4**, it can be observed that the pH parameter value indicates that temperature affects the absorption rate because temperature is related to the metabolism and photosynthesis of plants. The higher the ambient temperature, the greater the plant's ability to absorb ions. The temperature range of 25°-30°C is optimal for the phytoremediation process. In addition to influencing the rate of transpiration, temperature also affects the oxygen levels in the water. **Fig. 4** is a graph showing the average temperature measurements in each reactor during the phytoremediation process. Based on the temperature changes in each phytoremediation reactor over 9 days with the control treatment, it shows that both the control tank and the reactor tanks with Salvinia molesta experienced temperature fluctuations during the phytoremediation process. The daily temperature variations were not significantly different and tended to be similar. This is because the temperature in each reactor was heavily influenced by the ambient temperature.

An increase in temperature affects the absorption rate, as it is related to the plant's metabolism and photosynthesis. The higher the ambient temperature, the greater the plant's ability to absorb ions. According to Rahayuningtyas et al. (2018), the absorption of metal ions is not entirely accumulated by the plants, as metal ions can move from the water through evaporation by binding with oxygen to form new ions. The temperature range of 25-30°C (mesophilic temperature) is optimal for the phytoremediation process in aquatic plants. The temperature measurements during the phytoremediation process in this study ranged between 25°C-30°C in each reactor, which is ideal for the growth and development of Salvinia molesta. The pH value was obtained by measuring the pH of the wastewater in each control and test reactor with Salvinia molesta using a pH meter every 3 days.

The initial pH measurement was 7.3, which is considered neutral. The pH value can affect plant growth during the phytoremediation process. The optimal pH range for plants is between 6.0-8.0 [21], [22]. The initial pH measurement showed that the batik wastewater still met the quality standards according to the Indonesian Ministry of Environment Regulation Number 16 of 2019.

The pH levels in each reactor tended to increase. During photosynthesis, Salvinia molesta absorbs a lot of CO_2, which is then converted into glucose and oxygen with the help of sunlight, reducing the CO_2 in the batik wastewater and resulting in an increase in pH. The following reaction occurs during the plant photosynthesis process

4. Conclusion

The Kiambang plant (Salvinia molesta) is effective in reducing Chromium (Cr) levels by 70% in batik wastewater. The treatment with the highest number of plants, specifically 16 plants, is more effective and efficient in reducing Chromium (Cr) levels compared to using 8 plants. A residence time of 9 days is more effective and efficient in reducing Chromium (Cr) levels and pH compared to 3 days and 6 days. Kiambang (Salvinia molesta) has the potential to be an effective phytoremediator for treating batik industry wastewater, particularly in reducing Total Chromium (Cr) levels and stabilizing pH. The implementation of phytoremediation using Kiambang can be an affordable and environmentally friendly alternative for wastewater treatment in the batik industry in Indonesia.

The pH levels in the wastewater increased during the phytoremediation process. This increase is attributed to the photosynthetic activity of Salvinia molesta, which reduces CO2 levels in the water and subsequently raises the pH. The temperature in each reactor was found to fluctuate within the optimal range of 25-30°C for phytoremediation, which is conducive to the growth and metabolism of Salvinia molesta. The ambient temperature significantly influenced the reactor temperatures.

The results of the linear regression and ANOVA tests indicated that the variation in time did not have a significant impact on the effectiveness of Cr removal in the control tank and Tank 1. However, in Tank 2, the variation in time did show a significant impact on the Cr removal efficiency.

5. Recommendations

Additional studies should be conducted to explore the long-term effects of using Salvinia molesta for wastewater treatment and to determine the maximum capacity of the plants for heavy metal absorption. Consider scaling up the phytoremediation process for larger volumes of batik wastewater to assess the practicality and efficiency of this method in industrial applications. Further research should investigate the optimal conditions for maximizing the phytoremediation efficiency, including variations in plant density, water temperature, and pH levels.

Explore the integration of Salvinia molesta phytoremediation with other wastewater treatment methods to enhance overall treatment efficiency and effectiveness. Encourage policymakers and industry practitioners to adopt phytoremediation as a sustainable and cost-effective method for treating industrial wastewater, particularly in the batik industry.

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