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Apu Wood (*Pistia stratiotes*) as Phytoremediation Agent of Screen-printing Wastewater

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Abstract. The screen-printing process produces wastewater-like organic compounds that are difficult to degrade and heavy metals such as chromium, copper, manganese, and lead, which are toxic and can accumulate in the human body through the food chain. Phytoremediation is one method that utilizes plants' ability to reduce organic and inorganic pollutants, including heavy metals. This study aimed to describe the concentration of screen-printing waste that can be tolerated by apu wood plants and analyze the effectiveness of apu wood as a heavy metal remediator. The method used in this research is a combination of filtration and phytoremediation using apu wood to reduce heavy metals such as Pb and Cr,$^{6+}$ and a preliminary test of Pb and Cr^{6+} contained in the screen-printing wastewater was carried out. The results show Apu wood lives and thrive on screen-printing wastewater, with an average of 34 new individuals' tillers growth within 15 days. The propagation of apu wood in screen-printing wastewater produced total biomass with an average of 145 grams per reactor. The effectiveness of apu wood as a remediator of Pb was 13.65%, and accumulated in the leaves was 0.0911 mg/L. The accumulation of Cr^{6+} in the leaves was 0.6635 mg/L. The use of Apu wood as a phytoremediation agent to remove Cr6+ content in screen-printing wastewater has not been proven to be effective enough due to the high concentration of chromium compounds in the waste.

***Keywords*:** Apu wood; Chromium (VI); Filtration; Phytoremediation.

I. INTRODUCTION

Screen-printing wastewater contains compounds that have the potential to become pollutants in the environment. Screen printing wastewater comes from pigments, binders, diluents, drying agents, and modifiers. The wastewater contains hazardous chemicals, such as chromium, copper, manganese, lead, and organic compounds that are difficult to degrade [1]. One of the remediation technologies developed to date is using plants or phytoremediation.

The ability of plants to remediate heavy metals wastewater occurs through several possibilities, including: (1) phytoextraction, where plants filter metal compounds and release them into the environment in different ionic bonds; (2) hyperaccumulation, where metal compounds will be adsorbed in plant organs or tissues up to a certain amount; (3) rhizofiltration, where metal compounds are carried away when water is absorbed by roots and are filtered by semipermeable membranes of root organs; and (4) phytostabilization, where toxic metal compounds react with plant exudates such as enzymes and hormones so that the poisonous properties change to non-toxic form [2].

Several previous studies revealed the ability of plants to become phytoremediation agents for heavy metals, including water hyacinth (*Eichornia crassipes*), apu wood (*Pistia stratiotes*), and kayambang (*Salvinia cucultuta*) on chromium parameters in batik waste [3], bulrush (*Typha latifola*) and Indian shot (*Canna indica*) against chromium [4], and apu wood (*Pistia stratiotes*) for treating batik waste, especially copper [5].

In principle, pollutant compounds found in wastewater can be degraded. Still, phytoremediation is a secondary treatment, so it requires preliminary processing so that plants do not experience shock loading and can increase the effectiveness of treatment [6]. In this study, filtration and phytoremediation using apu wood (*Pistia stratiotes*) will be carried out to treat heavy metals contained in screen-printing wastewater. The choice of apu wood as a phytoremediation agent is because it is easy to find naturally, especially in Pontianak [7]. This processing is used for screen printing waste treatment and in similar industries such as textiles and others.

In Pontianak, screen-printing waste treatment has not been carried out optimally due to its high inorganic compound and metal content, which is difficult and takes a long time to degrade, such as chromium (Cr^{6+}), lead (Pb^{2+}), cadmium (Cd^{2+}), and arsenic (As^{5+}). Efforts to develop waste management, especially for small to medium-sized industries, continue to be carried out. Using aquatic plants such as apu wood that can be obtained in the environment becomes an effective and financially economical treatment solution [8]. This study aimed to determine the concentration of screen-printing waste that can be tolerated by apu wood plants to survive and thrive, as well as to test the effectiveness of apu wood as a phytoremediator of heavy metals Pb and Cr^{6+}. This research is essential and benefits the development of engineering technology in sewage treatment systems in remediation techniques for wastewater treatment containing metal pollution and organic compounds that are difficult to degrade quickly and efficiently.

II. RESEARCH METHODS

A. Sampling and Research Locations

Wastewater samples were taken at one of the screen-printing businesses in Jalan Imam Bonjol, Pontianak City. In contrast, the apu wood (*Pistia stratiotes*) was taken around small rivers and swamps in the city of Pontianak (Figure 1).

The research was conducted at the Tanjungpura University Environmental Engineering Workshop (0°03'21.8"S 109°20'49.3"E), while the wastewater quality test was conducted at the Sucofindo Laboratory, Pontianak, West Kalimantan.

Figure 1. Sampling Location

B. Tools and Materials

The tools used are slow sand filter bioreactor, plastic container, sample bottle, thermometer, pH meter.

The materials used are apu wood (*Pistia stratiotes*), *Screen Printing Waste*, aquades, gravel and sand.

C. Research Designs

Waste Sampling

Wastewater samples were taken from screen washing activities that not been mixed with domestic wastewater.

Plant Propagation and Acclimatization Stage

The propagation stage is the stage of multiplying plants. This stage serves to provide a stock of plants used during research. The propagation period was carried out until the shoots grew and were used in the subsequent analysis [9]. Plants that should be lived, fresh, not eaten by insects, and not wilted were selected for phytoremediation tests [10]. Acclimatization was carried out for seven days using distilled water before being transferred to the test reactor so that the plants could adapt to the test conditions. The reactors used were three plastic containers, each contained 100 grams of the plant (Figure 2).

Preparation of Filter Media

The media used are sand and gravel. Media acclimatization was carried out to grow microorganisms to form a *schmutzdecke* layer. The acclimatization was carried out for 14 days by soaking the sand and gravel using wastewater to be treated and observed daily. When the medium forms a layer of fine brownish fibers that gradually become thicker and is not easily separated from the media, it indicates that microorganisms have grown on the surface of the media (Figure 3) [11].

Screen Printing Waste Treatment by means of Filtration and Phytoremediation

The following process was processing screen-printing waste using a Slow Sand Filter (SSF) with a downflow system and continued with the phytoremediation process with apu wood using a batch system method on a laboratory scale. The phytoremediation test used six reactors. That's reactor contains of three for control and three repetitions for phytoremediation tests. Each reactor contains 100 grams of acclimatized apu wood plants [12].

Data Collection and Analysis Techniques

Metal concentrations obtained from the laboratory analysis results were compared with quality standards. In addition to metal testing, tissue and plant morphology tests will be carried out after the phytoremediation process.

III. RESULTS AND DISCUSSION

A. Plant Propagation and Acclimatization

Apu wood plants are obtained from waters in the Kuala area, Kubu Raya Regency. The plant roots are cleaned of contaminants from their original environment. The growing media consist of tap water which is changed regularly. Plants undergo a self-propagation stage for one month, and tillers from these plants are used as phytoremediator agents. This acclimatization stage is a stage to adjust or adapt an organism to its new environment. In the process, plants will be conditioned to the new media, then adapt and survive [13].

At the propagation stage, plants that already have tillers are separated so that they can grow well. Withered and yellowed plants are set aside to reduce plant density and provide room for the growth of other plants.

Figure 2. Plant Propagation Stage

The saplings obtained will be used for further research so that the plants can respond to the provision of wastewater and not be affected by the adaptation process of plants to new media. The second generation of tiller was acclimatized using distilled water for seven days and cleaned to avoid any contaminants attached to the roots, which play an essential role in acclimatization related to nutrient absorption [14].

B. Preparation of Filter Media

The filter media used in this study were gravel and sand. Each media is cleaned before use to avoid contaminants attached to the filter media. Silica sand is a filter media used in the slow sand filter process. On the other hand, gravel functions as a buffer so that sand does not come out or clog the outlet faucet. Between the sand and gravel, a layer is given so that the sand does not pass into the gravel media and does not damage the structure of the filter media.

Waste samples from the screen-printing washing activities were accommodated in large containers and transferred into a jerry can. The wastewater is channeled into a filter media consisting of 15 cm high gravel and 15 cm high silica. Wastewater and filter media are contacted for 14 days to form a biofilm layer attached to the filter media. The bacteria contained in the biofilm layer are expected to degrade the contaminant of parameters included in the screen-printing wastewater.

Figure 3. Filter Media in the form of Sand and Gravel

C. Screen Printing Waste Treatment with Filtration

Before processing, a leak test using distilled water was carried out on the reactor. Glue is attached to a leak-proof layer to the outlet faucet to prevent wastewater from leaking. After the reactor is ready, the screen-printing wastewater is put into the reactor to inundate the filter media. Wastewater were flowed slowly into the reactor to prevent the silica sand's structural damage. The wastewater is contacted with the filter media for 14 days. After 14 days, the bacteria grow and are ready to degrade Pb and Cr^{6+} metals in the screen-printing wastewater.

Bacterial growth in the filter surface of media forms a biofilm. Biofilm is the formation site of naturally occurring microorganisms from the waste itself that is called indigenous bacteria and affects the effectiveness of the treatment. The more microorganisms in the biofilm, the higher the waste decomposition process because the organic matter in the waste is used as a nutrient [15].

The slow sand filter system, due to its unique combination of constituent media, is capable of effectively facilitating the processes of filtration, sedimentation, and adsorption. The grains of sand are so small that they can filter out large particles and function as filters. The sand grains have bends in the pores, so the flow velocity will slow down and leave the particles in the pores, and the sedimentation process occurs—these components are utilized by bacteria settling in the pores as colloidal particles. But if the flow is slow, it causes blockages. This process is adsorption, where the particles that flow in the colloid are trapped in the sand's pores [16].

The seeding process showed some physical changes like the solution became clearer because the particles settle if left alone due to the weight of their mass. In addition, the screen-printing waste becomes odorless, whereas, before seeding, the screen-printing wastewater smells of oil mixed with paint. Previous research shows that slow sand filters can reduce the odor, taste, pH, and turbidity of the solution that passes through [16]. The given 14 days were able to form a precipitate of dye and biofilm shown by mucus on the base of the media called the *schmutzdecke* layer; in this study, no in-depth observations were made for the diversity of microorganisms.

Figure 4. Slow Sand Filter Media Acclimatization (left = before seeding, middle = beginning of seeding, right = end of seeding)

The reactor's residual screen-printing waste was removed after 14 days of medium acclimation. Before and after passing through the slow sand filter reactor, fresh screen-printing wastewater was checked for quality. Screen-printing wastewater used for testing and acclimation has physical features that vary in color; however, the waste's chemical properties are essentially the same (Figure 5).

Figure 5. Slow Sand Filter Reactor

The filtration is composed of silica sand and gravel 10 cm thick each. For the treatment of wastewater and water, silica sand is frequently employed as a filtering medium. The combination of SiO_2, Fe_2O_3, Al_2O_3, TiO_2, CaO, MgO, and K_2O in silica results in color variations in the sand. [17]. During the filtering process, gravel is utilized as a medium for filtering waste that contains particles or suspensions. The filter media's thickness will impact the efficiency of processing. According to a prior study, zeolite as a filter media reduces COD and chromium parameters with the best efficiency at 10 cm thickness, with a removal percentage of 51.04% [17]. Similarly, in earlier research, silica filter media with other media combinations demonstrated that the quality of the processing outcomes from various categories was not satisfactory. [18]. Filters using silica sand and gravel could reduce BOD, COD, and TSS content even though these are not under quality standards [19].

The wastewater tested in the laboratory is before and after passing the filter media. The filtration method is a straightforward procedure that can reduce or eliminate pollution levels while saving money and energy. When paired with phytoremediation methods, the study of a simple filter made of silica sand and activated carbon applied to household trash revealed that the results did not match the standards for quality [20]. An apu wood phytoremediation procedure followed the filtering approach with silica sand and gravel media. Table 1 displays the results of testing the filtration process.

In Table 4.1. the Cr^{6+} parameter after filtration decreased to 98.26%, the Pb parameter decreased to 89.41%, and the pH increased to 7.81. This result is in line with previous research that kale-based phytoremediation could lower the waste's temperature, boost dissolved oxygen levels, and raise pH [21]. These indicate that the bacteria contained in the slow sand filter can remove the metal parameters included in the screen-printing wastewater.

D. Screen-Printing Waste Treatment with Phytoremediation

Screen printing waste that has passed filtration is processed again by a phytoremediation process using apu wood. Several studies have shown that apu wood can reduce pollutant levels in wastewater with high organic and heavy metal content, such as elements of Hg, Cd, Zn, Pb, Cr, Ni, and Co that are toxic to organisms in the environment [24]. pH measurements were carried out daily on the apu wood reactor with distilled water; the apu wood reactor was in contact with wastewater and repeated three times.

The pH values fluctuated slightly during the filtration-phytoremediation process, although the overall values were near neutral. This pH level is often conducive to the growth of apu wood plants. Compared to the treatment without apu wood, the average pH value of the treatment with apu wood was greater than seven. This data illustrates the role of plants in regulating dissolved oxygen levels. The entering oxygen from the plant roots will affect the hydrogen bonding, altering the water's pH. The presence of plants in the water will meet its oxygen requirements. According to current research, the pH value in the phytoremediation process changes from 5 to 6 or 7 after seven days [20]. The measurement of each reactor pH is presented in Table II.

The production of new plants depends on media suited for these plants, meaning that the screen-printing wastewater growing medium has ingredients that apu wood plants may utilize. Screen-printing waste often contains oil, chlorine, nitrogen, and phosphorus obtained from a mixture of dyes, adhesives, and detergents, along with B3 elements that contribute to the makeup of these compounds [24]. Similarly, an earlier study demonstrates that soil contaminated with screen printing effluent has a neutral pH, moderate levels of organic carbon, deficient levels of total nitrogen, very high levels of phosphorus, and high levels of accessible potassium [25]. Nitrogen, phosphorus, and potassium are macronutrients for apu wood, although metal elements dissolved in the waste will also be absorbed into plant tissues, such as chromium and lead [26]. Plants can tolerate pollutants such as metals despite the fact that, in principle, these metals will concentrate in plant organs if they are present in apu wood.

At the beginning of each treatment, the plant's mass was 100 g, and the mass changed at the end of each treatment. The waste treatment increased mass in each replication by an average of 45 g, comparable to the increase in the number of tillers generated, which was 37 in the waste treatment. During the control or treatment with distilled water, the biomass of apu wood decreased by 12 grams, resulting in an average of 88 grams per reactor.

The mineral content of distilled water is generally beneficial for plant growth. For instance, research indicates that high-quality distilled water is frequently used as plantlets' growth medium. Still, the price is high enough that comparable water alternatives, such as rainfall, clean well water, and refillable drinking water, are sought [27]. Despite the availability of nutrients in the distilled water medium, the plants in this study exhibited poor growth, including fading leaves and very few offspring. Plant biomass production is strongly linked to photosynthesis, during which plants create carbohydrate molecules and store them as tissues [28]. Thus, there may be non-uniform light reception since the storage location with the roof permits light to be received variably [29].

Figure 6. Plants Observation

The effluent sample from screen-printing was placed in a tightly sealed glass bottle to prevent oxygen from affecting the sample's metal concentration. After phytoremediation, the following test findings were obtained in Table IV.

The Cr^{6+} value in Table 4 increased compared to the sample after the slow sand filter. Due to the oxidation process, which allows Cr^{3+} to be oxidized, increases the concentration of Cr^{6+}. The presence of oxygen in the test reactor can be attributed to photosynthesis, which releases oxygen into the water/waste, which can oxidize organic molecules. In addition, microbes such as bacteria will always be present during processing [30], [31]. Previous research indicates that the bacteria on the roots would aerobically degrade organic waste molecules into simpler compounds, which the apu wood will then absorb as a nutrient source [32], and indicates that during phytoremediation, plants will absorb polluting elements from the growth medium. In this study, the absorption of contaminants in the leaves of apu wood was 0.6635 mg/L for the Cr^{6+} parameter and 0.0911 mg/L for the Pb parameter.

Phytoremediation of Pb in screen printing waste by apu wood resulted in a final yield of 0.0392 mg/L and a removal rate of 13.65%; this result can be induced by the existence of apu wood plants, which, during respiration and photosynthesis, will naturally absorb water and the dissolved components. The greater the number of plants in a phytoremediation process, the greater the pollutant removal value, and vice versa; the fewer plants there are, the less pollution will be absorbed [23], [33].

The graphs of each reactor are presented in Figures 4.5., 4.6., and 4.7. the following.

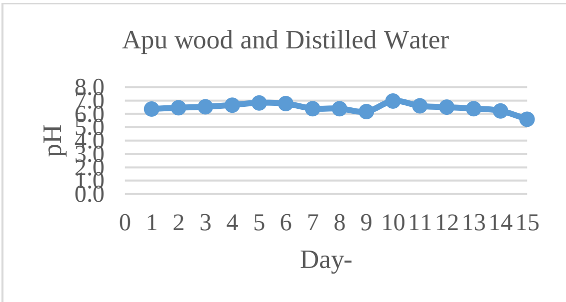

Figure 6. Measurement of pH of Apu Wood with Distilled Water

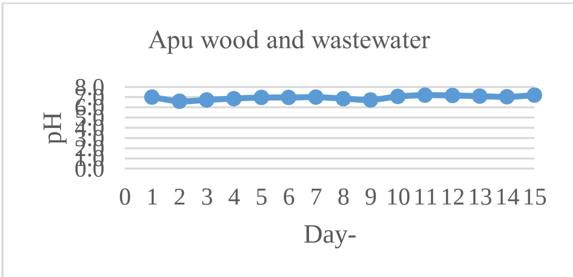

Figure 8. Measurement of pH of Apu Wood with Screen-printing Wastewater as a Growth Media

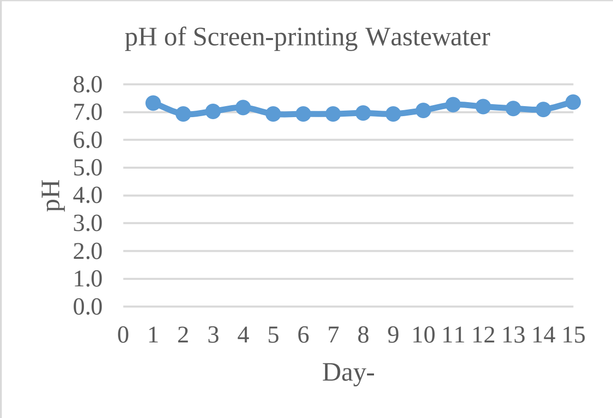

Figure 9. Measurement of pH of Screen-printing Wastewater

Figure 10. Plants Observation

IV. CONCLUSIONS

Apu wood plants may thrive and survive on waste from screen printing, producing an average of 34 young plants every 15 days. The multiplication of apu wood in trash from screen printing generated an average of 145 grams of biomass per reactor. This research also reveals that the efficiency of apu wood as a heavy metal Pb remediator is 13.65% and that 0.0911 mg/L of Pb is deposited in the leaves. The Cr^{6+} concentration in the leaves was 0.6635 mg/L. During the 15-day treatment period, the presence of Cr^{6+} did not lead to the removal of metal due to the occurrence of an increased oxidation reaction of the chromium element in the wastewater. To further investigate heavy metal properties in waste screen printing inks, additional research can be conducted. Apu wood, which has potential as a phytoremediation agent, can be combined with other plants. The concentration of screen-printing wastewater can be altered in various ways, such as using biofilters and electrocoagulation method.

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TABLE 1
SCREEN PRINTING WASTE TEST RESULTS BEFORE AND AFTER FILTRATION

Parameters	Before Filtration	After Filtration	Removal (%)
Cr^{6+} (mg/L)	0.989	0.0172	98.26
Pb (mg/L)	0.152	0.0161	89.41
pH	6.8	7.81	-

TABLE. II
SCREEN PRINTING WASTE TEST RESULTS BEFORE AND AFTER FILTRATION

Day	Apu wood + Distilled Water				Apu wood + Screen-printing Wastewater				Screen-printing Wastewater			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	6.4	6.3	6.4	6.4	6.9	7.0	7.1	7.0	7.4	7.2	7.4	7.3
2	6.5	6.4	6.5	6.5	6.6	6.7	6.5	6.6	6.8	6.9	7.1	6.9
3	6.6	6.5	6.5	6.5	6.7	6.8	6.7	6.7	6.9	7.1	7.1	7.0
4	6.8	6.6	6.6	6.7	6.8	6.9	6.9	6.9	7.1	7.2	7.2	7.2
5	6.8	6.9	6.8	6.8	6.9	7.0	7.0	7.0	6.9	6.9	7.0	6.9
6	6.8	6.8	6.7	6.8	6.9	7.0	7.0	7.0	6.9	7.0	6.9	6.9
7	6.2	6.5	6.5	6.4	6.8	7.1	7.1	7.0	6.9	7.0	6.9	6.9
8	6.4	6.4	6.4	6.4	7.0	6.8	6.8	6.9	6.9	7.0	7.0	7.0
9	6.3	6.1	6.1	6.2	7.0	6.6	6.6	6.7	6.8	6.9	7.1	6.9
10	7.1	6.9	6.9	7.0	7.0	7.1	7.1	7.1	7.0	7.1	7.1	7.1
11	6.5	6.7	6.6	6.6	7.0	7.3	7.3	7.2	7.3	7.3	7.2	7.3
12	6.4	6.6	6.5	6.5	7.0	7.2	7.3	7.2	7.2	7.2	7.2	7.2
13	6.4	6.5	6.3	6.4	6.9	7.2	7.2	7.1	7.2	7.1	7.1	7.1
14	6.3	6.3	6.1	6.2	6.8	7.1	7.2	7.0	7.1	7.1	7.1	7.1
15	5.7	5.6	5.5	5.6	7.0	7.3	7.3	7.2	7.3	7.4	7.4	7.4

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TABLE III
NUMBER OF TILLERS, PLANT WEIGHT, AND WATER VOLUME AFTER TREATMENT

Parameters	Apu wood + Aquades				Apu wood + Screen-printing Wastewater				Screen-printing Wastewater			
	1	2	3	Avg	1	2	3	Avg	1	2	3	Avg
Number of tillers	0	1	0	0.3	41	38	31	37	-	-	-	-
Weight of plant (gr)	106	68	90	88	135	144	156	145	-	-	-	-
The volume of water (mL)	1,250	1,600	1,500	1,450	2,845	2,640	2,490	2,658	3,940	3,885	3,900	3,908

TABLE. IV
SCREEN-PRINTING WASTE TEST RESULTS BEFORE AND AFTER PHYTOREMEDIATION

Parameters	Apu wood and wastewater	Wastewater	Accumulation in the Leaves
Cr^{6+} (mg/L)	0.989	0.0172	98.26
Pb (mg/L)	0.152	0.0161	89.41
pH	6.8	7.81	-