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Reduction of Copper Metal (Cu) Content in Screen Printing Wastewater with Phytotreatment System

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Abstract: Bleaching is one of the activities in the convection industry that produces liquid waste and is disposed of directly into water bodies without any treatment. Based on the test results, the liquid waste of the convection industry in Denpasar contains a very high amount of copper metal (Cu), which is 396.3 mg/L. It is necessary to process the liquid waste so as not to cause pollution to water bodies. An alternative treatment that can be done is phytotreatment with an intermittent exposure system with a ratio of F/D (Flood/Dry) cycles of 1:2 and F/D 2:1. The plant used is Pacing Pentul (Costus spicatus) because it is a hyperaccumulator that is able to absorb heavy metals in high concentrations and accumulate in roots, stems, and leaves. The media used is gravel and sand. The research started from the propagation, acclimatization, Range Finding Test (RFT), and phytotreatment test. to determine the ability of Costus spicatus to absorb copper metal (Cu) in the F/D 1:2 and F/D 2:1 cycles in reducing copper metal (Cu) in liquid waste. The results showed that Pacing Pentul (Costus spicatus) was able to absorb copper metal (Cu) in liquid waste until it became 32.41 mg/L in the F/D 1:2 reactor and 33.67 mg/L in the F/D 2:1 reactor. The largest percentage of removal is owned by reactors with a 2:1 F/D exposure cycle that are able to reduce copper metal (Cu) by 91% within 18 days.

Keywords: copper metal, costus spicatus, intermittent, pacing pentul,

1. INTRODUCTION

The convection industry is one of the industries that produces waste in its production process. The waste produced in this industry is in the form of liquid waste that can pollute the environment if not treated properly. The convection industry often does a job in producing apparel or fabrics. Copying is a stage in the production of clothing by printing previously designed images and writings (Safaruddin et al., 2022). This printing liquid waste consists of contents that can have a bad impact on the environment that are usually produced by screen printing washing, printing equipment washing in the form of ink residues, printgen, bremol, or afdruk drugs in screen making, as well as ink solvent oil used in washing tools (Violita et al., 2022; Jabbar et al., 2024).

The liquid waste contained heavy metals that were very harmful to the environment and living things. The heavy metals waste produced includes heavy metal arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), copper (Cu), zinc (Zn) (Komarawidjaja, 2017). Based on tests that have been carried out in 2023, liquid waste from a convection industry in Denpasar contains heavy metal copper (Cu) of 396.3 mg/L. The content of this heavy metal exceeds the quality standard limit for businesses and or activities that do not have wastewater quality standards stipulated in the Regulation of the Minister of Environment of the Republic of Indonesia No. 5 of 2014 concerning Wastewater Quality Standards, which stipulates a maximum level of copper (Cu) of 2 mg/L. Cu concentrations of 2.5–3.0 mg/L in water bodies can kill fish; a concentration of solution above 0.1 mg/L is toxic to all plants (Rahawarin, 2011). Therefore, it is necessary to carry out processing to reduce the level of heavy metal copper (Cu) contained so as not to pollute the environment.

One alternative treatment that can be used is phytotreatment, which uses plants with the help of plants in a medium so that it can reduce contaminants contained in wastewater (Evitasari et al., 2020; Yusuf, 2008; Sukono et al., 2020). The treatment of liquid waste with this phytotreatment system can be carried out with an intermittent exposure pattern with a time lag in wastewater flow. In this study, the plant used was *Costus spicatus*. This plant is a hyperaccumulator that can absorb pollutants, especially heavy metals with high concentrations that will accumulate in roots, stems, and leaves (Titah et al., 2018). In this study, the ability of *Costus spicatus* will be tested in reducing the content of heavy metal copper (Cu) contained in liquid waste by phytotreatment system. Water spinach (Ipomoea Aquatica) and eceng gondok (*Eichhornia crassipes*) are types of aquatic plants other than *costus spicatus* has been researched to be very efficient in reducing the metal content in printing waste (Violita et al., 2022; Marya Mistar, 2022; Vidyanti et al., 2020; Novita & Pradana, 2022).

2. MATERIALS AND METHODS

The tools used in this study are a 2.5 L plastic box reactor measuring 20 cm × 14 cm × 14 cm for the Range Finding Test stage, a 5 L reactor with a volume of 30 cm × 15 cm × 15 cm for phytotreatment tests, sample bottles, and rulers. The materials used in this study are artificial liquid waste that contains heavy metal copper (Cu), sand, gravel, and *Costus spicatus* plants.

2.1 Stages of research

The stages of this study were conducted as follows.

1. Sampling and Analysis of Liquid Waste
   In this study, the liquid waste used is Convection X liquid waste located in the Denpasar area. Samples are taken at the wastewater outlet in the morning, afternoon, and evening (composite sampling). After that, a test of copper heavy metal (Cu) contained in liquid waste from Convection X was carried out.
2. Propagation Stage
   Propagation is a stage carried out to homogenize plants so that the plants used during the main research have the same ability. This stage is carried out until the plant has an optimal size and shape. During the propagation period, the growth rate of plants will be observed and they will be left until the buds grow (second generation). The height of the *Costus spicatus* plant used in this study ranged from 35 to 40 cm.

3. Acclimatization Stage
   The acclimatization stage is the stage for plants to adjust to the medium to be used. At this stage, *Costus spicatus* plants are planted in a reactor with a sand medium and added PDAM water. Acclimatization was carried out for 7 days. The *Costus spicatus* plant used is around 32 cm in height. Plants that thrive (not dead and withered) will be used for the next stage, namely the Range Finding Test (RFT) and phytotreatment test.
4. Range Finding Test (RFT)
   RFT is carried out to determine how many plants are able to absorb pollutants at certain concentrations. The *Costus spicatus* plant used at this stage is the plant resulting from the previous acclimatization stage of as many as 2 plants. The RFT stage uses a 2.5 L plastic reactor box measuring 20 cm x 14 cm x 14 cm, which contains sand media with variations in copper concentrations of 0%, 20%, 40%, 60%, 80%, and 100%. The RFT stage was carried out for 7 days, and observations were carried out to determine the changes experienced by each plant with the variation in the concentration of heavy metal copper (Cu) given.
5. Phytotreatment Test
   The main research is the phytotreatment test stage with an intermittent exposure system. Intermittent exposure is when the reactor is given wastewater (flooding) intermittently with a time lag where the reactor is left dry and not given wastewater (drying). The variation of the cycle used is F/D 1:2 (flooding period for 1 day and drying for 2 days) and F/D 2:1 (flooding period for 2 days and drying for 1 day), which is carried out for 18 days. At this stage, what must be done is to prepare artificial waste that already contains copper metal (Cu) with a concentration based on the results of the RFT test. The reactor used is a 5L plastic box with a volume of 30 cm × 15 cm × 15 cm. Each reactor is given sand and gravel media measuring 20-30 mm on the right and left sides, then artificial waste that has been prepared in advance is added. The plants used are *Costus spicatus* plants with a height of 35 cm, as many as 3 plants in each reactor.

3. RESULTS AND DISCUSSION

3.1. Liquid waste analysis

The average results of the Convection X waste test showed copper (Cu) concentration of 396.3 mg/L. Based on the obtained results, the concentration of copper (Cu) exceeded 2 mg/L, the standard according to the Indonesian Regulation of the Minister of Environment No. 5 of 2014 concerning Wastewater Quality Standards. Therefore, it is necessary to carry out further processing of Convection X waste so that it does not pollute the environment and is safe when disposed of into water bodies.

3.2. Acclimatization stage

Acclimatization is the process of adapting plants to new environmental conditions (Japar et al., 2021). The *costus spicatus* plant is a hyperaccumulator aquatic plant that is widely used to reduce pollutants in wastewater and is also researched for its benefits in the field of pharmacology (Picanço et al., 2016). After acclimatization for 7 days, the *Costus spicatus* plant can live vigorously and not wither. Therefore, *Costus spicatus* plants can grow on sand media that will be used for RFT testing and phytotreatment. The acclimatization process can be seen in Figure 1.

Figure 1. Acclimatization Process

3.3. Phase Range Finding Test (RFT)

Range Finding Test (RFT) is the initial stage in the series of screen-printing wastewater treatments. RFT is carried out to find out the concentration of waste at which plants can still survive (Damanik & Purwanti, 2018), while reducing pollutants (Tangahu et al., 2022). At the RFT stage, the concentration variations used were 0% (control), 20% (79.26 mg/L Cu), 40% (158.52 mg/L Cu), 60% (237.78 mg/L Cu), 80% (317.04 mg/L Cu), and 100% (396.3 mg/L Cu). The number of plants used was 2 *Costus spicatus* plants in each reactor that were given different concentrations. For 7 days, observations were made of physical changes that occurred in plants. The results of the RFT can be seen in Table 1.

Table 1. Range Finding Test Results

Waste concentration (%)	Plant Count	Live	Effects of Plant Death (%)
0	2	2	0
20	2	2	0
40	2	2	0
60	2	2	0
80	2	1	50
100	2	-	100

Based on observations made for 7 days, it was found that *Costus spicatus* plants could survive at a concentration of 60%, which did not show the effect of plant death. At a concentration of 80% on the 4th day, the plants began to wither, and at a concentration of 100% on the 2nd day, the plants began to wither. Plant conditions on day 7 at concentrations of 80% and 100% are shown in Figure 2. *Costus spicatus* plants cannot live at concentrations of 80% to 100%, indicating that the plant is unable to accept the Cu metal load at that concentration. Therefore, at the phytotreatment test stage, the concentration used was 60%, which was 273.78 mg/L Cu.

Figure 2. Plant condition of *Costus spicatus* on Day 7 at 80% waste concentration (left) and 100% waste concentration (right)

3.4. Ability of Pacing Pentul (*Costus spicatus*) in Absorbing Copper Metal

The main research is the phytotreatment test stage with an intermittent exposure system to determine the ability of *Costus spicatus* plants to absorb Cu metal. The waste used is artificial waste that already contains copper metal (Cu) with a concentration based on the results of the RFT test, which is 237.78 mg/L. Based on this concentration, feeding is carried out 6 times with each pollutant load of each feeding around 42.08 mg/L of Cu metal concentration. The plant requirements for the phytotreatment test reactor are as many as 3 *Costus spicatus* plants with a height of 35 cm for each reactor with sand and gravel media measuring 20–30 mm on the right and left sides with reactor conditions as shown in Figure 3. After 6 drying times in the 1:2 F/D reactor and the 2:1 F/D reactor, the *Costus spicatus* plant was able to absorb Cu metal, as shown in Table 2.

Figure 3. Reactor condition

Table 2. The ability of the *Costus spicatus* plant to absorb Cu Metal

Reactor	Absorbed Cu (mg/L) in Various Drying times					
	1	2	3	4	5	6
A	28.25	29.26	31.29	33.73	35.92	35.99
B	30.87	31.00	33.01	34.84	36.09	36.19

Note: A = 1:2 F/D exposure cycle with *Costus spicatus* plant
B = 2:1 F/D exposure cycle with *Costus spicatus* plant

Referring to Table 2, the highest absorption of Cu metal by *Costus spicatus* plants is 35.99 mg/L in the 1:2 F/D reactor and 36.19 mg/L in the 2:1 F/D reactor. After 6 drying times for 18 days, the average accumulation of copper metal (Cu) by *Costus spicatus* in the 1:2 F/D reactor was 32.41 mg/L, and the 2:1 F/D reactor was 33.67 mg/L. *Costus spicatus* plants can absorb Cu metal in wastewater because it is a hyperaccumulator that is able to absorb heavy metals with high concentrations and accumulates in the roots, stems, and leaves. The absorption and accumulation of Cu metals by the plant *Costus spicatus* starts from the absorption of metals by roots, the translocation of metals from roots to other plant parts, and the localization of metals in certain cell parts to keep them from inhibiting plant metabolism (Irhamni et al., 2017).

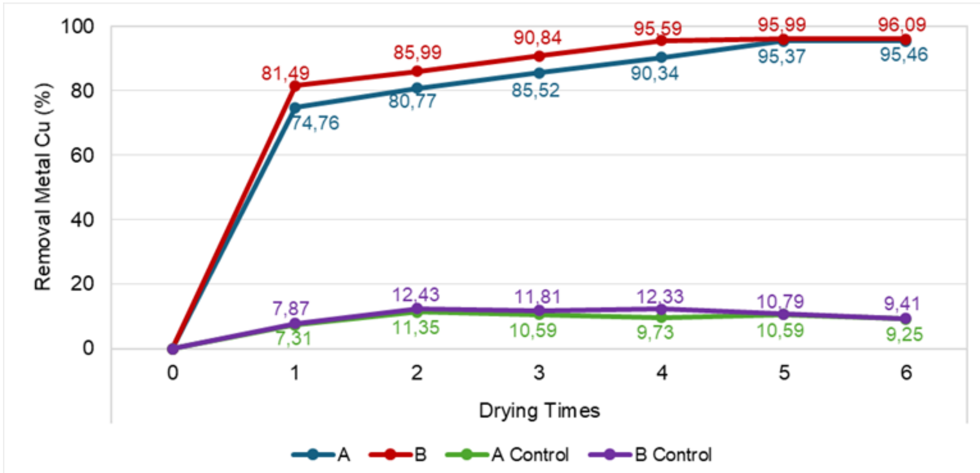
Heavy metals are absorbed by the roots in the form of ions dissolved in water in a process called rhizofiltration. During transpiration, compounds around the roots will be attracted to the rhizosphere so that contaminants are more concentrated in the rhizosphere. Microbes in the rhizosphere region will accelerate the process of absorption of contaminants by the roots. In the roots, plants change the degree of acidity and then form a chelating substance that will bind metals and then be brought into the root cells (Hartanti et al., 2013). Then, the metal is transported through the transport network of xylem and phloem to the stem or leaf part of the plant. Furthermore, metal localization is carried out in tissues that aim to prevent metal poisoning of cells, then plants will detoxify by stockpiling metals into certain organs such as roots (Patandungan et al., 2016).

The factor that causes the high cost of plants to absorb copper metal (Cu) is because copper metal (Cu) is one of the 13 nutrients needed by plants. Substances that can be absorbed by plants, such as nitrogen (N), potassium (K), calcium (Ca), phosphorus (P), magnesium (Mg), sulfur (S), chlorine (Cl), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), boron (B) and molybdenum (Mo), can be used as nutrients for plants to grow and develop (ITRC, 2009). However, at high concentrations and for a long time, copper metal (Cu) will interfere with the working activity of enzymes by modifying protein structures or replacing important elements, resulting in deficiency symptoms.

3.5. Effectiveness of the intermitten system exposure with a ratio of 1:2 (A) and 2:1 (B)

The purpose of comparing the exposure system with this cycle is to find out the good exposure system for removing copper metal (Cu). Reactors with F/D 1:2 were sampled during the drying period on days 2, 5, 8, 11, 14, and 17. Reactors with F/D 2:1 were sampled during the drying period on days 3, 6, 9, 12, 15, and 18. The percentage of copper metal removal (Cu) in the F/D 1:2 and F/D 2:1 reactors can be seen in Figure 4.

Based on the percentage of removal presented, the concentration of Copper Metal (Cu) decreased in both reactors with an exposure cycle of 1:2 and an exposure cycle of F/D 2:1 by 74-96%. The highest Cu metal clearance occurred during the 6th drying with a removal percentage of 95.46% for the 1:2 F/D reactor and 96.09% for the 2:1 F/D reactor. After 6 dryings, the percentage of copper metal (Cu) removal for 18 days in the 1:2 F/D reactor and the 2:1 F/D reactor can be seen in Table 3.



Note: A = 1:2 F/D exposure cycle with *Costus spicatus* plants
B = 2:1 F/D exposure cycle with *Costus spicatus* plants
A Control = 1:2 F/D exposure cycle without *Costus spicatus* plant
B Control = 2:1 F/D exposure cycle without *Costus spicatus* plant

Figure 4. Removal of Metal Copper (Cu)

Table 3. Copper Metal (Cu) Removal Percentage for 18 Days

Reactor	Total Copper (Cu) Metal Concentration	
	mg/L	% removal
A	32.68	87
B	22.68	91

Based on Table 3, the 1:2 F/D reactor is only able to remove Cu metal with a removal percentage of 87%, while the removal percentage of the 2:1 F/D reactor is higher, which is 91% after 6 drying times for 18 days. Based on these results, the better exposure cycle in setting aside Cu metal is with an exposure cycle of F/D 2:1.

The decrease in the concentration of copper metal (Cu) in each reactor is due to the cooperation and activity between microorganisms and plants in the reactor. The decrease in pollutant parameters in waste is highly dependent on the activity of microorganisms and the ability of plants to absorb nutrients. Exposure time is a very important factor for reactors in removing Cu metal because the length of exposure time will cause rhizosphere microbes found in plant roots to reduce Cu metal dissolved in water. Rhizosphere microbes are able to convert inorganic Cu into organic Cu, which will then be absorbed by plant roots and can be used in the process of photosynthesis (Djo et al., 2017).

The application of the 2-day flooding cycle and 1-day drying cycle is more effective because it provides a longer time for the exposure of waste to the treatment system than the application of the 1-day flooding and 2-day drying cycle. A longer exposure time makes a more perfect absorbing heavy metals process by plants and microorganisms in the roots (Putri, 2023). In addition, the

2-day flooding cycle and 1-day drying can also provide an opportunity for plants to recover their ability to accumulate metals contained in wastewater during drying. Based on the removal percentage data obtained, it shows that the reduction of Cu metal in waste can be said to be effective because it is above 50% (Djo et al., 2017). This deep decline is caused by Cu metal, which is an essential metal that in certain concentrations is needed by microorganisms as a coenzyme in the body's metabolic process (Selpiani et al., 2015). The construction of phytotreatment facilities in wastewater sewers can improve the self-purification ability of water bodies (Sotelo et al., 2021). The *Costus spicatus* plant is explored as a potential therapeutic agent in the health sector, namely the management of insulin resistance in chronic endocrine disorders (Femi-Olabisi et al., 2021).

4. CONCLUSION

Pacing Pentul plant (*Costus spicatus*) can absorb copper metal (Cu) in Convection X waste with an intermittent phytotreatment system. This is because the *Costus spicatus* plant is a hyperaccumulator. Over 18 days, the average accumulation of copper metal (Cu) by *Costus spicatus* in the 1:2 F/D reactor was 32.41 mg/L, and in the 2:1 F/D reactor, it was 33.67 mg/L. The comparison of the effective exposure system used in intermittent waste treatment was the 2-day flooding and drying cycle for 1 day because it provides a longer exposure time to the treatment system compared to the implementation of the 1-day flooding cycle and 2-day drying. Within 18 days, the 1:2 F/D reactor was able to remove Cu metal with a removal percentage of 87%, while the removal percentage of the 2:1 F/D reactor was higher, at 91%.

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