The potential of water hyacinth in the phytoremediation of industrial wastewater

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Abstract. In this study, the potential of water hyacinth in the phytoremediation of simulated wastewater containing copper (Cu) and lead (Pb) was studied. Locally available water hyacinth was collected from an uncontrolled environment. The prepared samples were segregated into three different parts (i.e., leaf, stem, and root), ground into powder, and used as the adsorbent for heavy metal removal. Acid digestion method was utilized for the preparation of the samples prior to atomic absorption spectrometry (AAS), and AAS was performed to determine the heavy metal concentration for each plant part. Based on the baseline study for identifying the heavy metal content in raw water hyacinth, Cu and Pb mostly accumulated in the root. The pH of simulated wastewater dropped upon the addition of Cu, and the pH gradually increased to 7 after day 7 onward. The overall removal efficiency of Cu decreased from 98.7% to 91.6% as the Cu concentration increased from 1 mg/L to 5 mg/L. Meanwhile, the overall removal efficiency of Pb decreased from 73.6% to 31.3% as the Pb concentration increased from 250 mg/L to 750 mg/L. Thus, water hyacinth is useful for treating wastewater containing heavy metals, particularly Cu and Pb.

1. Introduction

In recent years, rapid industrialization has increased waste production. The increase of heavy metal contamination in agricultural land and freshwater sources is due to higher agricultural inputs, mining, industrial waste, and contaminated irrigation water. The rapid growth of industrialization and urbanization are considered as the major anthropogenic activities that discharged potentially toxic elements (PTEs) into the environment. High concentrations of PTEs, such as cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), and copper (Cu), are discharged into wastewater from various industries. These heavy metals will accumulate at the food chain and impose a serious impact on health and the environment. This situation has raised public concern about the importance of treating wastewater from different industries.

Several chemical treatment methods have been used to remove heavy metals from wastewater, such as chemical oxidation and chemical precipitation. For instance, in chemical precipitation method, chemical precipitation agents, such as hydroxide, carbonate, and sulfide reagents, are added to precipitate heavy metals, where the solids formed are removed through filtration or sedimentation. However, this method produces a large amount of toxic sludge that requires chemical stabilization, which is disposed as scheduled waste after treatment. Furthermore, the operation of the method requires
skilled labor and has high cost for unit operations and chemical precipitants used. Therefore, it is important to apply alternative methods for the removal of heavy metals from wastewater.

Several alternatives for treating wastewater are membrane process, precipitation, and adsorption [1]. Among these methods, adsorption is considered as a low-cost and effective method to remove heavy metals from wastewater. This is due to the simple treatment process, environmentally friendly, and efficient in removing heavy metals in industrial and municipal waste. One of the available options for adsorption is phytoremediation. Phytoremediation is a biological treatment method that directly uses green plants to clean up contaminants from water, including organic and inorganic pollutants, as well as heavy metals. Various factors affecting this method, including the concentration of heavy metals, pH, and contact time.

Water hyacinth is an aquatic plant with high growth rates in tropical and subtropical regions, and also in Malaysia. This type of plant removes heavy metals using its roots through phytoremediation. Water hyacinth is also considered as a low-cost adsorbent, least harmful, and more environmentally friendly method compared to chemical methods. An advantage of using water hyacinth as an adsorbent is the plant doubles its population in 14 if the water temperature is in the range of 27–33 °C [2].

In this study, the potential of water hyacinth for the phytoremediation of simulated wastewater was conducted. The wastewater was prepared using Cu and Pb, representing among the common heavy metals in industrial wastewater. Baseline and parametric studies were performed for 28 days. Acid digestion method was chosen as the preparation step prior to using atomic absorption spectrometry (AAS).

2. Methodology

2.1. Chemicals
Nitric acid was purchased from Merck Sdn. Bhd. under EMD Milipore Corporation for acid digestion method. Meanwhile, copper (II) sulfate and lead (II) nitrate were purchased from Fisher Chemicals for the preparation of simulated wastewater. All chemicals were used as received without further purification.

2.2. Sample collection
Water hyacinth was obtained from the uncontrolled environment in Bintong, Perlis. All the plants were taken from the same place and collected randomly from a river using a systematic sampling procedure. After collection, the samples were segregated and divided into three parts (i.e., leaf, stem, and root). The parts were washed ten times with deionized water, cut into small pieces, and dried under sunlight for 3 h. After drying, the samples were dried in an oven at 105 ± 5 °C for 24 h and then ground using a blender into powder form. The powder was then stored in a container for acid digestion purpose.

2.3. Synthetic wastewater preparation and phytoremediation of heavy metals
Three sets of 35 L simulated wastewater were prepared using the concentrations shown in Table 1. In each basin, six water hyacinth plants with approximately similar size were used. The arrangement and setup of the plants are shown in Figure 1. The phytoremediation using water hyacinth was conducted for 28 days. The pH of the synthetic wastewater was monitored throughout the study using a pH meter. Meanwhile, the plant samples were sampled every seven days for heavy metal content monitoring.
Table 1. Copper and lead concentrations for simulated wastewater preparation.

| Sample | Cu Concentration (mg/L) | Pb Concentration (mg/L) |
|--------|-------------------------|-------------------------|
| 1      | 1                       | 250                     |
| 2      | 2                       | 500                     |
| 3      | 5                       | 750                     |
| Control| 0                       | 0                       |

Figure 1. The arrangement and setup of water hyacinth for the phytoremediation of simulated wastewater.

2.4. Acid digestion of plant samples
Acid digestion method was conducted in a fume hood. About 1.2 g of plant samples were weighed for the stem, leaf, and root of water hyacinth and placed in beakers. 20 ml of 1:1 65% nitric acid was added to all samples in the beakers and mixed well. The samples were heated on a hot plane at 75 °C, and the temperature was monitored to prevent vaporization of nitric acid at 86 °C (i.e., boiling point of nitric acid). The digestion was conducted for 90–120 min until the decomposition of plant matrix occurred, where the color of the samples changed. The samples were allowed to settle overnight. After that, the samples were filtered 2–3 times to completely remove suspended particles and diluted using 1:10 ratio of deionized water. Syringe filters were used in the final step to filter the samples prior to AAS heavy metal analysis.

2.5. Heavy metal analysis
About 0.1 mole of nitric acid was added to a volumetric flask until half of its volume. After different concentrations of Cu and Pb standard solutions were added to the volumetric flask at room temperature, nitric acid was added to the sample up to the mark of the flask. Then, the samples were preserved for the determination of Cu and Pb. The AAS was calibrated for Cu and Pb by running different concentrations of standard solutions. Each sample was tested three times and the average values for three replicates were taken for each sample. The heavy metal concentration in mg and the absorbance values were obtained through AAS analysis.

3. Results and Discussion
3.1. Baseline study of water hyacinth
The baseline study was conducted to determine the heavy metal content in the raw water hyacinth plant obtained from an uncontrolled environment. The average heavy metal content in the raw water hyacinth plant is presented in Table 2. Based on the results, the highest Cu and Pb content occurred in the root,
followed by the stem and leaf. Furthermore, Pb concentrations in the plant were higher than Cu concentrations. This is because Pb is more common in some waste, such as tires and rubber-based materials.

Table 2. Average heavy metal content in raw water hyacinth samples.

| Plant Part | Cu Concentration (mg/L) | Pb Concentration (mg/L) |
|------------|-------------------------|-------------------------|
| Leaf       | 0.2228                  | 4.2780                  |
| Stem       | 0.2481                  | 2.1002                  |
| Root       | 0.5938                  | 6.2591                  |

3.2. Parametric study on pH

Figure 2 presents the pH changes over 28 days of experiment. Upon the addition of Cu, the pH of the simulated wastewater dropped from pH 6.8–7 to pH 4.5 after 7 days. The release of metal cations into the water forms metal oxides with oxide ions and releases hydrogen ions. At this stage, the level of free hydrogen ion increases and decreases the pH of wastewater. Then, the pH values increased gradually to the neutral pH range of 5.8–7.2 after day 7 for different Cu concentrations. The higher the heavy metal concentration in wastewater, the longer contact time is required to recover the neutral pH, where water hyacinth will slowly remove Cu through phytoremediation. For pH changes, water hyacinth plays a major role to alter and change the pH of the wastewater from acidic to neutral pH by decreasing the number of free hydrogen ions when the plant uptakes metal ions.

![Figure 2. pH changes along 28 days of experiment.](image)

3.3. Parametric study on copper removal

The copper uptake efficiency was examined for 28 days. Figure 3 shows the overall copper uptake efficiency. The higher the copper concentration, the lower the total uptake efficiency. Cu mostly accumulated in the root, followed by the stem and leaf. In this study, the overall uptake efficiency decreased from 98.7% to 91.6% as the Cu concentrations increased from 1 mg/L to 5 mg/L. From the study, the total uptake efficiency exceeded 90%, even at the highest Cu concentration. The uptake efficiency from this study is comparable with a previous study, where the uptake efficiency of 90% for different metal removal was achieved within 15 days of experiment [3].
Figure 3. The overall uptake efficiency of water hyacinth at different Cu concentrations

3.4. Parametric study on lead removal
The lead uptake efficiency was also examined for 28 days. Figure 4 shows the overall lead uptake efficiency. The higher the lead concentration, the lower the total uptake efficiency. The highest Pb accumulation occurred in the root, followed by the stem and leaf. In this study, the overall uptake efficiency decreased from 73.6% to 31.3% as the Pb concentrations increased from 250 mg/L to 750 mg/L. At a lower concentration, the plant grows at a normal rate and the removal efficiency is greater [4].

Figure 4. The overall uptake efficiency of water hyacinth at different Pb concentrations

4. Conclusion
The removal of Cu and Pb in the simulated wastewater was studied using water hyacinth. Three different concentrations of lead and copper wastewater were prepared, and the heavy metal removal was conducted through phytoremediation for 28 days. From the results, the pH of simulated wastewater decreased upon the addition of Cu, and the pH gradually recovered to the neutral value after day 7 as water hyacinth removed Cu through phytoremediation. The overall uptake efficiency of Cu and Pb decreased with the increase of Cu and Pb concentrations, and the highest heavy metal accumulation occurred at the root of water hyacinth. Overall, water hyacinth has demonstrated the potential for treating wastewater containing heavy metals, especially Cu and Pb.

References
[1] Uang R S and Shiau R C 2000 J. Membr. Sci. 165 159–67.
[2] Center T D, Hill M P, Cordo H and Julien M H 2002 Water hyacinth. Biological control of invasive plants in the Eastern United States USDA Forest Service Publication 1–5.
[3] Mishra V K and Tripathi B D 2009 Bioresour. Technol. 99 7091–7.
[4] Ingole N W and Bhole A G 2003 J. Water Supply Res. Technol. AQUA 52 119–28.
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