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# Uptake of Cadmium and Zinc from Synthetic Effluent by Water Hyacinth (*Eichhornia crassipes*)

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## Abstract

In this study was conducted on aquatic plant; water hyacinth (*Eichchornia crassipes*) which has been successfully utilized for the removal of cadmium (Cd) and zinc (Zn) from aqueous solutions. The overall metal uptake by the plant was dependent upon the concentration of the metal and the duration of exposure. In general, the metal content in plants increased with the increase in metal concentrations in solution and the metal accumulation in roots was always significantly higher than that in shoots for both metals in water hyacinth. Water hyacinth treated with 4 mg/L of cadmium accumulated the highest concentration metal in shoots (148 µg/g) and roots (2006 µg/g) and water hyacinth treated with solution containing 40 mg/L zinc accumulated the highest zinc concentration in shoots (1899 µg/g) and roots (9646 µg/g).

***Keywords:*** water hyacinth (*Eichchornia crassipes*); metal uptake; cadmium; zinc; accumulation

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## 1. Introduction

Rapid industrialization and urbanization have resulted in elevated emission of toxic heavy metals entering the biosphere (Lu *et al.*, 2004). Heavy metals, industrial pollutants, in contrast with organic materials cannot be degraded and therefore accumulate in water, soil, bottom sediments and living organisms. Water contamination with heavy metals is a very important problem in the current world (Rai *et al.*, 2002). Considerable attention has been paid to methods for metal removal from industrial wastewaters because they pose serious environmental problems and are dangerous to human health (Miretzky *et al.*, 2006). Heavy metal ions such as $Cu^{2+}$, $Zn^{2+}$, $Fe^{2+}$ are essential micronutrients for plant metabolism but when present in excess, can become extremely toxic (Lu *et al.*, 2004).

Cadmium (Cd) is one of the most toxic heavy metals and is considered non-essential for living organisms (Lu *et al.*, 2004). Cadmium enters atmosphere from mining, industry, and burning coal and household wastes. Cadmium particles in air can travel long distances before falling to the ground or water. It enters water and soil from waste disposal and spills or leaks at hazardous waste sites. It binds strongly to soil particles. Cadmium can dissolves in water. It does not break down in the environment, but can change forms.

Unlike cadmium, zinc (Zn) is an essential and beneficial element for human bodies and plants (Lu *et al.*, 2004). Zinc is one of the most common elements in the earth's crust. It is found in air, soil, and water, and is present in all foods. Zinc combines with other elements to form zinc compounds. Common zinc compounds found at hazardous waste sites include zinc chloride, zinc oxide, zinc sulfate, and zinc sulfide. Zinc compounds are widely used in industry to make paint, rubber, dyes, wood preservatives and ointments. Some zinc released into the environment by natural processes, but most comes from human activities like mining, steel production, coal burning, and waste burning.

Zinc attaches to soil, sediments, and dust particles in the air. Rain and snow remove zinc dust particles from the air. Depending on the type of soil, some zinc compounds can move into the groundwater and into lakes, streams, and rivers. Most of the zinc in soil stays bound to soil particles and does not dissolve in water. It builds up in fish and other organisms, but it does not build up in plants.

Physical and chemical methods are already available to remove toxic metals from wastewater such as ion exchange, reverse osmosis, precipitation, solvent extraction, membrane technologies, electrochemical treatment, and sorption (Rai *et al.*, 2002). These methods are either too expensive to operate and maintain, produced residuals or cannot totally remove dissolved metals from wastewater thus may require additional treatment. Bioadsorption of metal using plants can be used for polishing the problematic wastewater. Some plants have the ability to accumulate non-essential metals such as cadmium and lead, and this ability could be harnessed to remove toxic metals from the environment (Tanhan *et al.*, 2006). Plants-based bioremediation technologies have received recent attention as strategies to clean-up contaminated soil and water (Lu *et al.*, 2004). The submerged macrophytes are particularly useful in the abatement and monitoring of heavy metals.

Role of aquatic plants in the abatement of heavy metals have been discussed in several studies (Lu *et al.*, 2004). The uptake of metals ion will ultimately depend upon the nature and amount of aquatic biomass, its stage of development and earlier treatment. Selection of aquatic plant species for the removal of metal from the polluted water will also depend on the ease of growth of the plant and yield of biomass under the conditions of applications. In this case, water hyacinths were chosen to be used for removing heavy metals.

The water hyacinth (*Eichhornia crassipes*) is a prolific free floating aquatic weed found in tropical and subtropical areas of the world and recognized to be very useful in domestic wastewater treatment (Mahmood *et al.*, 2005). They float on bloated air-filled hollow leaf stalks which give them their Malay name that means “pregnant tuber” (Ivan Polunin, 1987). Their roots trail underwater in the dense mat (Talalaj, 1991). They can withstand extremes of nutrient supply, pH level, temperature, and even grow in toxic water (Mahmood *et al.*, 2005). They grow best in still or slow-moving water.

Water Hyacinths are difficult (if not impossible) to destroy (Mahmood *et al.*, 2005). In the US, arsenic was used on a large scale which only partially cleared the weeds but poisoned the ecosystem. Fire and explosives were also attempted, but the plants reproduce rapidly even from the tiniest fragment and simply grew back (Ivan Polunin, 1987). Water hyacinth has long been used commercially for cleaning wastewater. The luxuriant plant’s tremendous capacity for absorbing nutrients and other pollutants from wastewater has long been overlooked by many wastewater engineers. In recent years, the plant has been used to treat a variety of wastewaters and to produce high protein cattle food, pulp, paper, fiber, and more importantly, biogas as energy source (Mahmood *et al.*, 2005).

The objectives of this study are to determine the amount of selected heavy metals (cadmium and zinc) absorbed by water hyacinth after certain duration of exposure and to determine the part of water hyacinth (shoots or roots) that accumulates higher concentration of heavy metal.

## 2. Materials and Methods

### *2.1. Experimental Procedures*

Few samples of water hyacinth or *Eichhornia crassipes* were taken from fish ponds in Rembau, Negeri Sembilan. Then, the samples were rinsed with tap water to remove any epiphytes and insect larvae grown on the plants.

Stock solutions prepared with analytical grade $CdCl_2.2.5H_2O$ and $ZnSO_4.7H_2O$ were added into distilled water to be diluted. The plants were placed in solutions containing 0.5, 2, 4 mg/L of Cd and 5, 20, 40 mg/L of Zn. One control group of plants was also prepared where no metal ion were added. Before immersing the plants in the metal solutions, their weights were recorded. Test durations were two hours, 4, 8 and 12 days. After each exposure duration, the plants were harvested. Their weights were taken again to measure their relative growths.

After that, the plants were cut into several parts: shoots and roots. Each part was analyzed for metals content. In addition, the metals remaining in solution were also measured to assess the metal removal potential of water hyacinth.

### *2.2. Relative Growth*

Relative growth of control and treated plants was calculated as follows:

$$\text{Relative growth} = \frac{\text{Final fresh weight (FFW)}}{\text{Initial fresh weight (IFW)}}$$

### *2.3. Metals Accumulation*

The accumulation of metal in plant material was expressed in the unit g of metal per gram of dry matter. Digestion of samples in this study was performed according to the AQUA REGIA Standard. Plantûs samples; (shoots and roots) were decomposed to dry matter by heating at 60˚C in the oven. After that, about 0.5-1.0 g of the samples were taken and digested with 5ml of nitric acid. The samples were heated up to 40˚C for an hour, and later the temperature was increased to 160˚C for at least three hours. Next, the samples were diluted with 15ml of distilled water and were let cool for about half an hour. Then, the samples were filtered and analyzed using an atomic absorption spectrophotometer (AAS). The concentration of metals remained in the residual solution was analyzed using AAS.

### *2.4. Statistical Analysis*

The numbers of relative growth and metal concentration were calculated and subjected to Analysis of Variance (ANOVA) using Split-Plot Experiment method on the SAS-PC for windows program after analyses.

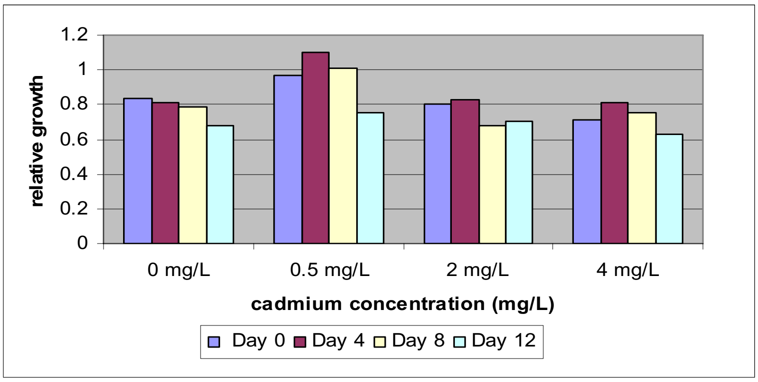

Figure 1. The effect of cadmium on relative growth of *Eichhornia crassipes* at different cadmium concentration and exposure time.

*2.5. Cleaning Procedures*

In order to avoid contamination of heavy metals from the laboratory equipments, all the glassware, polyethylene bottles and plastic materials used in the processing of the samples were washed with detergent, Deacon-90. This method was followed by soaking the equipments in 5.0% of concentrated sulfuric acid ($H_2SO_4$) for 2 days. Later, they were rinsed with distilled water to minimize external contamination and were dried in the oven. All samples were rinsed with 0.5% nitric acid ($HNO_3$) followed by distilled water prior to metal analysis.

## 3. Results and Discussion

Heavy metals contamination in soil and groundwater is a major environmental problem. The use of plants to remove heavy metal, known as "Phytoremediation", offers economic and environmental advantages and is a promising technique. The success of phytoremediation depends on plant growth rate and obtaining high metal concentrations in plant shoots.

*3.1. Relative Growth*

Fig. 1 shows the relative growth of weight of *Eichhornia crassipes* in cadmium solution after exposure time. Growth changes are often the first and most obvious reactions of plants under heavy metal stress (Lu *et al.*, 2004). In the present study, the relative growth increased in plants treated with low concentration of Cd (0 and 0.5 mg/L), but decreased with high concentration (2 and 4 mg/L). However, at higher concentrations of these metals, plant growth was inhibited. Overall, the highest value of relative growth in cadmium concentration was 1.10 for water hyacinth treated with Cd at 0.5 mg/L and the lowest value of relative growth was 0.63 for water hyacinth treated with Cd at 4.0 mg/L. Fig. 2 shows the relative growth of dry weight of *Eichhornia crassipes* in zinc solution after exposure time.

Overall, the highest value of relative growth in zinc concentration was 1.15 for water hyacinth treated with Zn at 5.0 mg/L and the lowest value of relative growth was 0.66 for water hyacinth treated with Zn at 40.0mg/L. The addition of Zn at low concentration had a favorable effect on the growth of water hyacinth, which may be attributed to the fact that the plants utilize Zn as a micronutrient for their growth (Lu *et al.*, 2004). (Miretzky *et al.*, 2006) found that in long term experiment (24 days), water hyacinth exposed to 9 mg/L of Zn resulted in 30% reduction in weight.

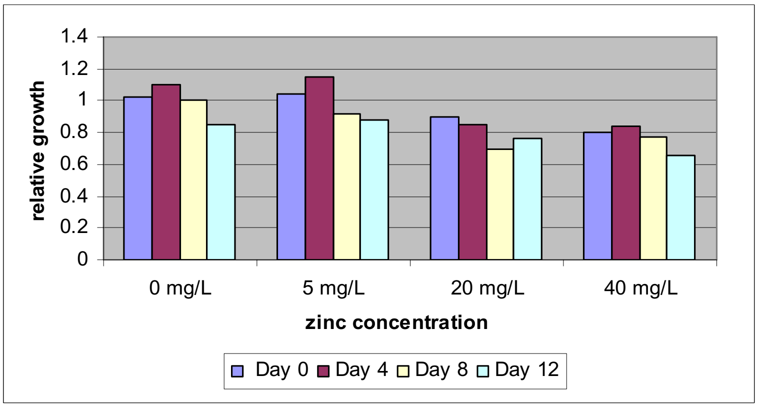

Figure 2. The effect of zinc on relative growth of *Eichhornia crassipes* at different zinc concentration and exposure time.

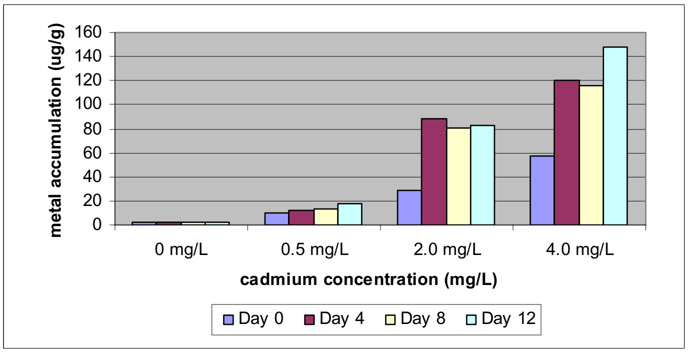

Figure 3. The accumulation of Cd in shoots of *Eichhornia crassipes* exposed to different initial cadmium concentration for several exposure duration.

### *3.2. Metals Accumulation*

The amount of cadmium accumulated in the shoots and roots of *Eichhornia crassipes* exposed to different initial cadmium concentrations and several exposure durations are shown in Fig. 3 and 4, respectively. In general, there was an increase in cadmium accumulation in shoots and roots with increasing cadmium concentration and exposure times. The highest cadmium accumulation in shoots is found to be 148.0 μg/g and in roots is 2006.0 μg/g. The accumulation of metals in the roots and shoots of water hyacinth had been shown in field studies in which water hyacinth was used as a biological monitor in metal pollution (Lu *et al.*, 2004). The uptake of Cd, both by roots and shoots, increased with increasing metal concentration in the external medium but the uptake was not linear in correlation to the concentration increase (Fritioff and Greger, 2007). The results of zinc accumulation in shoots and roots of *Eichhornia crassipes* exposed to different initial zinc concentrations and at several exposure duration are shown in Fig. 5 and Fig. 6, respectively.

In general, there was also an increase in zinc accumulation in shoots and roots with increasing zinc concentration and exposure duration. The highest zinc accumulation in shoots is (1899.0 μg/g) and in roots is (9646.0 μg/g). From the experiment, water hyacinth accumulated the highest concentration of metals in roots (2006 mg/kg for Cd and 9646 mg/kg for Zn). The high metal concentrations in the plant roots is found to be similar with the results of previous studies (Lu *et al.*, 2004). The metals accumulations in water hyacinth increased linearly with the solution concentration in the order of leaves<stems<roots of water hyacinth (Hasan *et al.*, 2007). In the study conducted by Lu *et al.*, 2004 who treated 12 plant species (fuzzy water clover, iris-leaved rush, mare's tail, monkeyflower, parrot's feather, sedge, smart weed, smooth cordgrass, striped rush, umbrella plant, water lettuce and water zinnia) with 10 trace elements (As, B, Cd, Cr, Cu, Pb, Mn, Hg, Ni and Se) and reported that with the exception of B, all trace elements studied accumulated to substantially higher concentrations (from 5 to 60 folds) in roots than in shoots of all plant species.

In general, most studies reported that the higher concentrations of metals were accumulated more in the roots compared to the shoots. One of the reasons for higher accumulation factor in the plant root in the case of both metals may be due to of their absorption to the surface of root tissue. This idea was also partially supported from present studies on the mobility of the metal in plant, which showed that the rate of mobility in the root was comparatively much slower than that in the top.

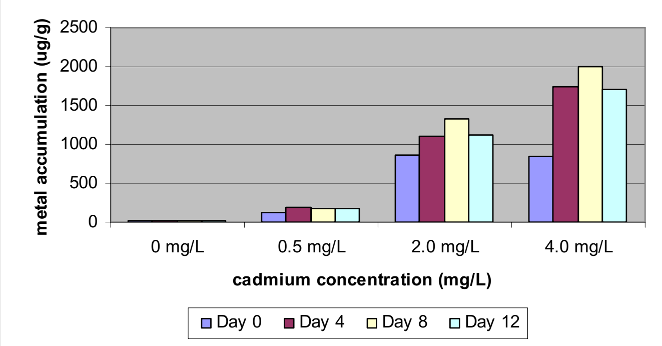

Figure 4. The accumulation of Cd in roots of *Eichhornia crassipes* exposed to different initial cadmium concentration for several exposure duration.

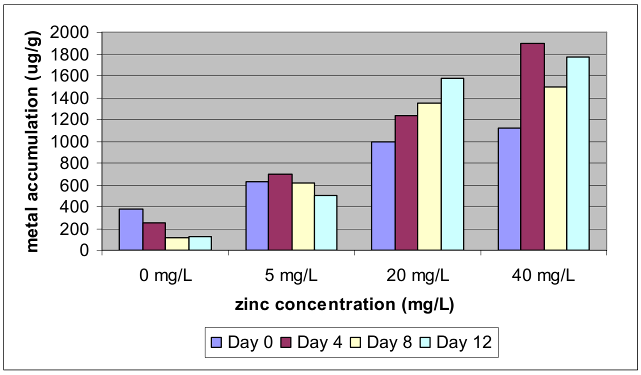

Figure 5. The accumulation of Zn in shoots of *Eichhornia crassipes* exposed to different initial zinc concentration for several exposure duration.

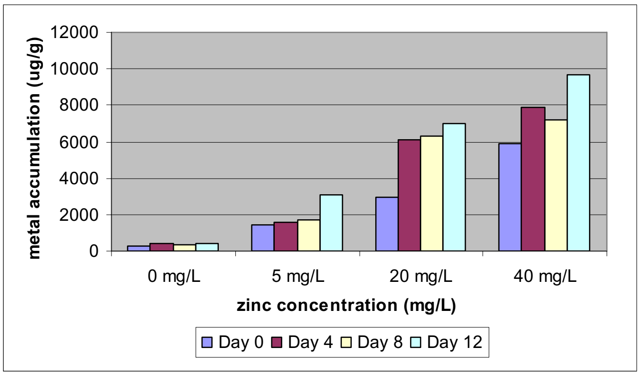

Figure 6. The accumulation of Zn in roots of *Eichhornia crassipes* exposed to different initial zinc concentration for several exposure duration.

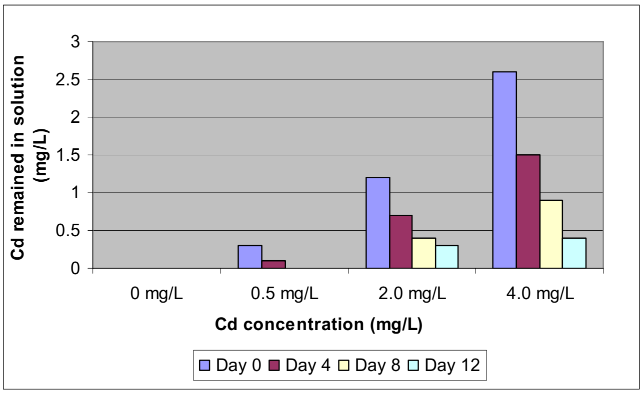

Figure 7. Cadmium concentration that remained in the solution after exposure duration.

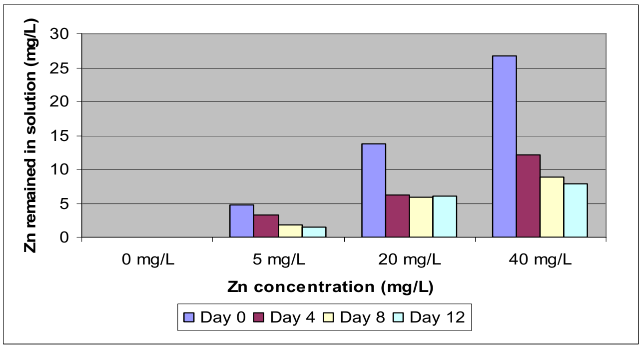

Figure 8. Zinc concentration that remained in the solution after exposure duration.

Table 1. The percentage of removing cadmium absorbed by water hyacinth

| Initial concentration/Duration | 5 mg/L | 20 mg/L | 40 mg/L |
|---|---|---|---|
| Day 0 | 40 | 40 | 35 |
| Day 4 | 80 | 65 | 62.5 |
| Day 8 | 100 | 80 | 77.5 |
| Day 12 | 100 | 85 | 90 |

Table 2. The percentage of removing cadmium absorbed by water hyacinth

| Initial concentration/Duration | 5 mg/L | 20 mg/L | 40 mg/L |
|---|---|---|---|
| Day 0 | 4 | 31 | 23.5 |
| Day 4 | 36 | 68.5 | 69.5 |
| Day 8 | 64 | 70.5 | 78 |
| Day 12 | 70 | 70 | 80.25 |

From ANOVA test, there was a significant difference between plants treated with blank and 0.5 mg/L with plants treated with 2.0 m/L and 4.0 mg/L in cadmium concentration. And in zinc concentration there was also a significant difference between plants treated with blank and 5.0 mg/L with plants treated with 20.0 m/L and 40.0 mg/L. there was also a significant difference between shoots and roots for both metals which mean for shoots were 48.9 (cadmium), 923.3 (zinc) and roots were 717.6 (cadmium), 4021.0 (zinc).

### *3.3. Metals Remained in the Residual Solution.*

The cadmium and zinc concentrations (mg/L) remained in the residual solution after exposure duration are shown in Fig. 7 and Fig. 8, respectively. From Table 1 and Table 2, it was found that water hyacinths were able to remove cadmium and zinc effectively at low concentrations. The effluent containing these metals at low concentration may be treated by continuously passing it through a bed of these plants growing in ponds. However, for effluent with higher concentration of metals, suitable batch treatments need to be designed.

## 4. Conclusion

The results of this study indicate that water hyacinth can successfully be used for the removal of low concentrations of Zn(II) and Cd(II). Water hyacinth may be used in "Ecotechnology" (environmental technology) in constructing wetlands. Wetlands help to prevent the spread of heavy metal contamination from land to the aquatic environment. High metal removal rates of close to 100% have been reported both in natural and artificial constructed wetlands. These wetlands make a suitable alternative for wastewater purification as they are easier to be constructed and operated. Apart from that, they are also cost-effective with no generation of toxic sludge which must be stabilized prior to disposal into secure landfill.

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