Phytoremediation of Cadmium from Contaminated Water by Pistia Stratiotes

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Abstract: Water pollution by toxic heavy metal caused due to rapid industrialisation and exploitation of natural resources is a global concern. Cadmium (Cd) is a deadly toxic, non bio-degradable heavy metal and has a tendency to biomagnify through trophic chain. Cd enters into water bodies through industrial wastewater discharge, runoff from agricultural field and mining areas and in the form of leachate generated from dumping ground of e-waste. Present study reveals removal of Cd from contaminated water by using a low cost eco-friendly technology phytoremediation. This technology is based on the use of green plants for remediation of contaminant. Aquatic macrophyte Pistia stratiotes was used for Cd phytoremediation. Cd working solution was prepared by dissolving Cd chloride salt in pond water at a concentration of 0.5 to 3 mg/L. Experiment was conducted in bench scale mode for 22 days. It was found that Cd removal decreased with increase in initial Cd concentration. At the end of treatment total Cd removal varied within the range of 55.93% to 83.4% depending upon initial Cd concentration and rate of removal gradually decreased with progress of treatment period. These indicated that Cd removal depended upon residual Cd concentration in the solution. Cd accumulation capacity was described in terms of bio concentration factor (BCF) which decreased with increase in initial Cd concentration. BCF value of 1956.37 was attained at 0.5 mg/L Cd concentration, but the same reduced to 1454.38 at 3 mg/L Cd concentration. BCF>1000 in all cases indicated that Pistia stratiotes was good Cd accumulator under current experimental condition. Most of the Cd was accumulated in plant root. After phytoremediation Cd rich plant was disposed by mixing with concrete material. Toxicity Characteristic Leaching Procedure (TCLP) test ensured this process as safe disposal method of exhausted phytoremediated plant.

Keyword: Cd, Phytoremediation, Bio concentration factor, disposal, Toxicity characteristic leaching procedure

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1. INTRODUCTION

Industrial and technological progress has exhausted natural resources in one side and on the other side generated environmental problem of pollution and degradation. This has led to the concept of sustainable development which clearly states that generation of wealth and benefits required for the present day population should not endanger the interest of the future generation. As a result eco-friendly manufacturing processes and waste treatment technologies are being explored to maintain a proper harmony between industrial development and environment protection. Further concept of developing low cost technology for these purposes is gaining popularity as a viable avenue of sustainable development. In the present research work same idea has been explored for treating waste water containing toxic contaminant cadmium(Cd) utilising some low cost eco-friendly technology.

Cd is a major environmental pollutant due to its high toxicity which was first highlighted with outbreak of itai-itai disease in Japan [1]. Cd enters into water bodies as a result of industrial wastewater discharge, runoff from agricultural field and mining areas and in the form of leachate generated from dumping ground of e-waste. Cd has been classified by U.S. Environmental Protection Agency as a probable human carcinogen [2]. In aquatic ecosystem Cd may accumulate in fish body through which it could make its way to human body. It was found that Cd level is biomagnified in each tropic level unlike other metals like copper [3]. Cd containing surface water is sometimes used in irrigation which can also lead to its accumulation in agricultural land and in crops.

Different conventional technologies like chemical precipitations, electrolysis, reverse osmosis, ion exchange, adsorption etc are already in practice for Cd removal. But most of them are complicated and costly. Hence there is a need to develop some simple eco friendly low cost technology for Cd removal [4]. Phytoremediation takes advantage of the unique, selective and naturally occurring uptake capabilities of plant root systems, together with bioaccumulation abilities of the entire plant body. This process is cost effective compared to other conventional treatment technologies as it is performed in situ, is solar driven and can function with minimal maintenance once established [4].

Aim of the present study was to determine suitability of aquatic macrophyte *Pistia stratiotes* for Cd phytoremediation from contaminated water and after phytoremediation to propose a eco-safe low cost method for disposal of toxic metal rich plants.

2. MATERIALS AND METHODOLOGY

Pistia stratiotes from nearby pond was collected, washed with tap water to eliminate remains of pond sediments. They were then acclimatized for 7 days in same pond water and thereafter transferred to experimental unit containing 20 L of Cd spiked pond water as working solution and 1234.57g/m^2 *Pistia stratiotes* (fresh weight). Heavy metal concentration in pond water and acclimatised plant was analysed and it was found it was found to be below detectable limit. Cd chloride ($CdCl_2.H_2O$) salt was used for preparation of Cd spiked solution. The initial concentration of Cd was varied within the range of 0.5 to 3 mg/L with an increasing interval of 0.5 mg/L. A control set up was also fabricated where specified amount of plant was cultured in pond water but without addition of any metal. Everyday evaporative water loss was compensated by addition of pond water. The experiment was continued for 22 days. Periodically water sample was collected for estimation of residual Cd content using the process specified by APHA (1998)[5]. After completion of experiment plants were harvested from the tubs and Cd content in plant shoot and root was estimated separately using Atomic Absorption Spectrophotometer (AAS).

After harvesting Cd rich plants were dried completely to reduce its volume and then solidified by mixing with concrete mix. Principal constituents of concrete mix i.e. water, cement, fine aggregate (sand) and coarse aggregate (stone chips) was mixed at a ratio of 0.45:1:1.47: 3.49 respectively. Dry plant biomass was added @ 0.4% and 0.6% of cement weight. Possibility of leaching out Cd from these concrete after disposal or during other uses was evaluated by performing Toxicity characteristic leaching procedure (TCLP) test following the standard procedure mentioned by EPA [6].

All experiments were conducted in triplicate and there average was considered.

Bio-concentration factor (BCF): It was used to determine Cd accumulation capacity of *Pistia stratiotes*. BCF was calculated as the concentration of heavy metal in the plant tissue to initial metal concentration in aquatic environment [7].

$$BCF = \frac{Metal\ concentration\ in\ plant\ tissue\ at\ harvest\ (\frac{mg}{kg})}{Initial\ metal\ concentration\ in\ external\ aqueous\ solution\ (\frac{mg}{l})} \quad \text{(Equation 1)}$$

Translocation Factor: This indicated the ability of *Pistia stratiotes* to translocate Cd from root to shoot tissue at respective solution Cd concentration. It was calculated as follows:

$$Translocation\ Factor = \frac{\text{Cd BCF of shoot tissue}}{\text{Cd BCF of root tissue}} \quad \text{(Equation 2)}$$

Relative Growth Factor (RGF): Relative growth factor of control and treated plant (for each concentration) was calculated as follows [8]:

RGF= (ln (final fresh weight of plant)) - (ln (initial fresh weight of plant))/time (Equation 3)

3. RESULT AND DISCUSSION

Cd removal percentage:

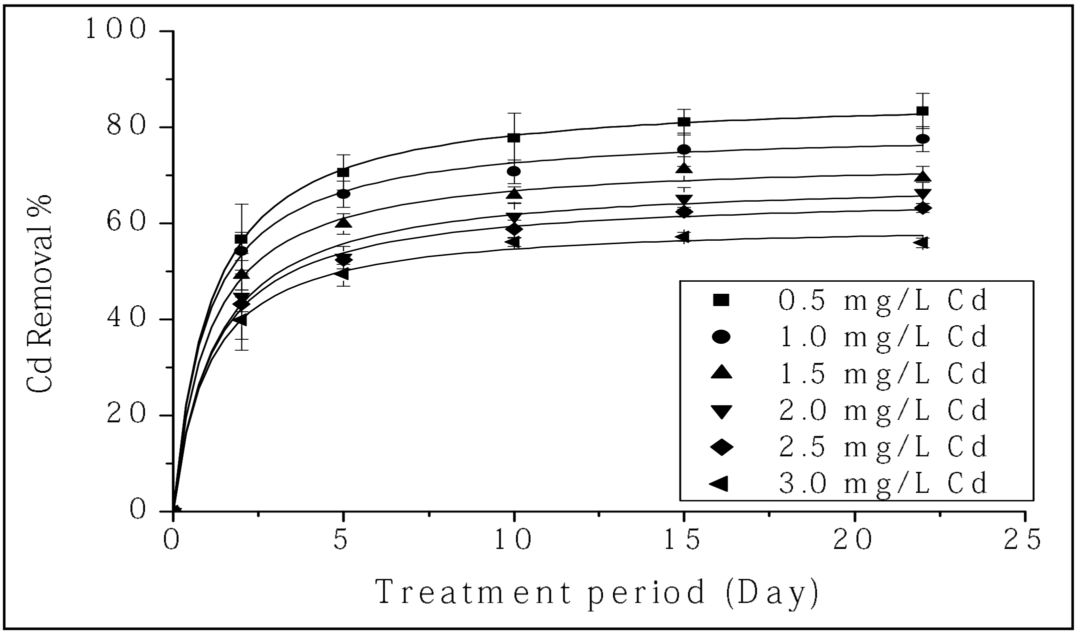

Figure 1. Cd removal % with respect to treatment period by *Pistia stratiotes*

Cd removal by *Pistia stratiotes* exposed to six different initial Cd concentrations against treatment period has been graphically presented in Figure 1.Cd removal percentage gradually increased with progress of treatment period, but it was also observed that rate of removal decreased with time. Initially Cd was removed rapidly and within first two days of treatment period 40 to 56.8% Cd was removed, depending upon initial Cd concentration in solution. Removal of Cd increased moderately in between 2nd and 15th day of treatment period and beyond that Cd removal did not change considerably. Cd removal percentage decreased with increase in initial Cd concentration. After 22 days of treatment *Pistia stratiotes* removed 83.40% Cd from 0.5 mg/L initial concentration which decreased to 55.93% for 3 mg/L initial concentration. Thus it was found that Cd removal by *Pistia stratiotes* was dependent upon residual Cd concentration. Saturation of Cd accumulating sites of *Pistia stratiotes* may influence such decrease in rate of metal removal [9].

Bio concentration factor:

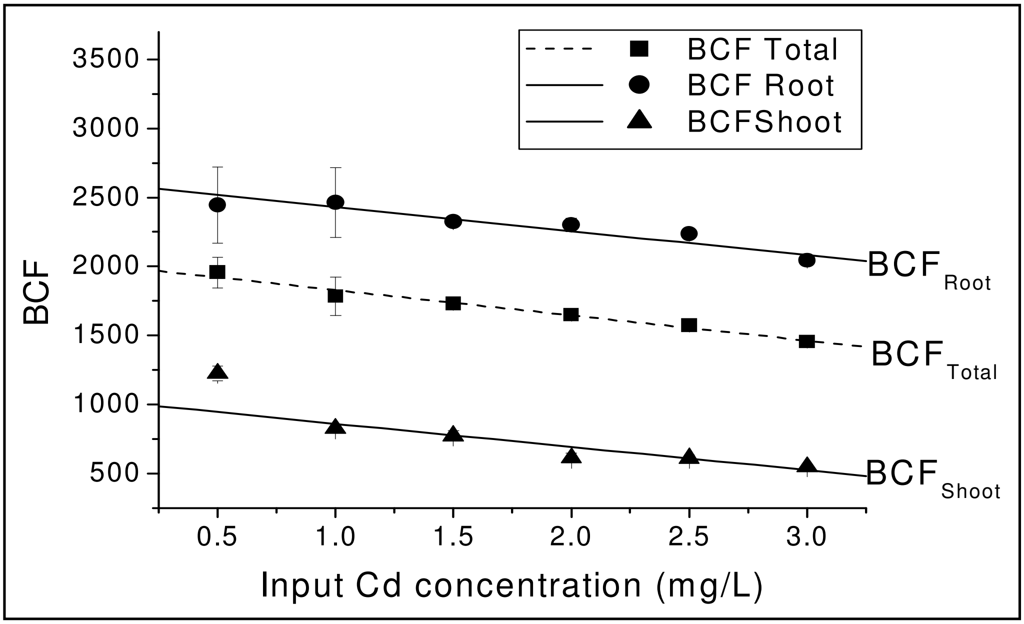

Figure 2. Change in BCF with respect to input solution Cd concentration

BCF value for Cd accumulation by *Pistia stratiotes* with respect to initial aqueous Cd concentration has been graphically presented in Figure 3. BCF of shoot and root tissue decreased from 1224.8 to 547 and 2446.2 to 2043.49 with increase in initial Cd concentration from 0.5 mg/L to 3 mg/L. Cd accumulation capacity of shoot and root of *Pistia stratiotes* was found to decrease with increase in initial Cd concentration in solution. It was also found that BCF attained by root was significantly higher ($p<0.05$) than that of shoot. Similar trend was also reported by Hasan *et al.* (2007) [10] for Cd and Zn accumulation by *Eichornia crassipes*. Root system was recognised as the main route of heavy metal uptake in case of emergent and surface-floating wetland plants also in other research work [11].

Translocation Factor: It was observed that at 0.5 mg/L Cd concentration translocation factor was 0.50, which decreased to 0.34 at 1 mg/L Cd dose and finally at 3mg/L Cd concentration translocation factor reduced to 0.268 (Table 1). Cd translocation factor was found to be less than unity under the present experimental condition, which interpreted that less amount of Cd was transported and stored in shoot than that of root. Thus Cd stress hindered the physiological process of Cd translocation in plant. This finding was in accordance with that previously reported for Hg removal by *Pistia stratiotes* [12].

Table 1. Cd translocation factor and relative growth factor of *Pistia stratiotes*:

Initial Cd concentration mg/L	Translocation factor	Relative growth factor
0.5 mg/L	0.50 ± 0.01	0.025 ± 0.001
1 mg/L	0.336 ± 0.009	0.009 ± 0.003
1.5 mg/L	0.333 ± 0.01	0.006 ± 0.003
2 mg/L	0.280 ± 0.009	0.0002 ± 0.001
2.5 mg/L	0.269 ± 0.009	0.008 ± 0.002
3 mg/L	0.268 ± 0.01	0.01 ± 0.002

Relative Growth Factor: Relative growth factor of unexposed or control *Pistia stratiotes* was 0.024 which decreased gradually with increase in aqueous Cd concentration (Table 1). RGF of treated plant ranged between 0.016 and 0.001 by increasing aqueous Cd concentration from 0.5 to 3 mg/L. Thus it was observed that Cd toxicity inhibited plant growth at all the tested Cd concentration. The effect gradually became more severe with increase in aqueous Cd concentration. Cd toxicity inhibited 50% relative growth (EC50) of *Pistia stratiotes* at 1.43 mg/L external Cd concentration. This hindered plant growth may be attributed by inhibition in cell division and cell enlargement in presence of Cd [13].

Disposal: After phytoremediation Cd rich plants were dried completely and mixed with green concrete at an amount of 0.4% (marked as 0.4%PS) and 0.6% (marked as 0.4%PS) of cement weight. To investigate stability of Cd that was aimed to immobilize inside concrete, EPA recommended leachability test known as toxicity characteristic leaching procedure (TCLP) was conducted.

Table 2: Cadmium concentration in leachate of TCLP test:

Concrete sample identification	Cd concentration in filtered solution (mg/L)
Non solidified dried plant biomass	15.3±0.009
Control	BDL
0.4% PS	0.03±0.006
0.6% PS	0.041±0.003

It was found in Table 2. that Cd concentration in TCLP filtered fluid was considerably below EPA recommended maximum Cd concentration for toxicity characteristic which is 1.0 mg/L [14]. This indicated that Cd rich plant containing concrete cannot be classified as “hazardous”. Hence it can be opined that the tested disposal procedure of Cd phytoremediated plant would not create further environmental nuisance in terms of Cd pollution. It was also noted that Cd leached from non solidified dried plant biomass was much higher than EPA recommended maximum leached Cd concentration (i.e. 15.3±0.009mg/L > 1mg/L). This result highlighted importance of solidifying Cd rich plant biomass inside concrete matrix. Cementaceous plastic mass cover together with alkaline environment rendered Cd immobile inside concrete matrix and thus restricted its leachability to outer environment. Cement-based matrices produced strong buffering capacity, which neutralized the extraction solution and thus limited Cd leaching process [15].

4. CONCLUSION

Cd is a toxic contaminant for aquatic ecosystem as well as human beings. Hence its removal using low cost eco friendly process phytoremediation was considered sustainable approach in this study. Cd removal and accumulation efficiency of locally available aquatic floating macrophyte *Pistia stratiotes* was investigated in this regard. It can be summarised from the experimental observation that *Pistia stratiotes* could effectively remove Cd especially at lower concentration. Bio concentration factor of more than 1000 identified the selected plant as potentially good Cd accumulator. It was further observed that Cd toxicity hindered different physiological process of macrophyte like plant growth and Cd translocation ability etc. It was also demonstrated that after phytoremediation Cd rich plant could be disposed of by solidifying inside concrete material.Thus it can be concluded that the present study proposed a suitable Cd removal process from contaminated water and finally proposed a measure to restrict further pollution during disposal of exhausted removing media.

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