Journal of Hazardous Materials 263 (2013) 486–492

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Removal of chromium ions from wastewater by duckweed, *Lemna minor* L. by using a pilot system with continuous flow

Y. Uysal*

Department of Environmental Engineering, Engineering and Architecture Faculty, Kahramanmaras Sutcu Imam University, Avsar Campus, Kahramanmaras 46100, Turkey

HIGHLIGHTS

- Cr sorption potential of *Lemna* in different pH and concentration was determined.
- Study was carried out in ponds to simulate wetlands and wastewater treatment pond.
- Growth parameters of *Lemna* were investigated to determine toxic effects of Cr.
- Increasing Cr concentration caused to increase Cr concentration.
- Even plants suffered toxic effects; they continued to remove Cr from water.

ARTICLE INFO

Article history:
Received 4 June 2013
Received in revised form 25 July 2013
Accepted 3 October 2013
Available online 11 October 2013

Keywords:
Chromium
Biosorption
Duckweed
Lemna minor
Wastewater

ABSTRACT

The aim of this study was to determine the ability of *Lemna minor* to remove Cr (VI) ions from wastewater in a continuous flow pond system. This system was used to simulate a wastewater treatment pond and a natural wetland as habitat of plants. In order to find optimal conditions for chromium removal, ponds were operated with aqueous solutions having different pH (4.0–7.0) and chromium concentration of 0.25 mgCr^{+6}/L, then plants were exposed to different chromium concentrations (0.25–5.0 mgCr^{+6}/L) at pH 4.0. Chromium concentrations, both in biomass and wastewater, were measured and removal efficiency was determined throughout water flow. Growth factors such as growth rates, chlorophyll contents and dry/fresh weight ratios of plants were also determined to measure toxic effects of chromium. The percentages of chromium uptake (PMU) and bioconcentration factors (BCF) were calculated for each run. The highest accumulated chromium concentration (4.423 mgCr/g) was found in plants grown in the first chamber of pond operated at pH 4.0 and 5.0 mgCr/L, while the minimum accumulated chromium concentration (0.122 mgCr/g) was in plants grown in the last chamber of pond operated at pH 4.0 and 0.25 mgCr^{+6}/L.

1. Introduction

The main sources of heavy metal pollution in aquatic ecosystems are of the anthropogenic activities. Heavy metals include arsenic, antimony, cadmium, chromium, mercury, lead are of particular concern to water and soil pollution. Chromium is one of these heavy metals, and a widespread contaminant entering the air, water and soil environment by different industrial activities such as iron and steel manufacturing, chrome leather, chromium plating, wood preservation and other anthropogenic sources. It exists in the environment in two stable forms of chromium (III) and chromium (VI) through natural processes and human activities.

The intensive use of chromium for several industrial applications causes high amount of wastewater containing chromium ions, and also causes to increase its concentrations in the water sources of environment. Chromium (VI) compounds are used in industry for many purposes suh as: metal plating, cooling towers, leather tanning, wood preservation. However, these compounds are highly reactive, mobile and easily soluble in water, and these properties cause several environmental health risks. Because, chromium (VI) compounds are highly toxic to aquatic organisms and accumulated by their bodies. The problem of heavy metal contamination consists in the fact that the metals cannot be degraded like other organic xenobiotics but they must be extracted from a polluted area [1]. Methods using living plants to remove metal ions from a polluted area with organic and inorganic compounds have been commonly called phytoremediation. Phytoremediation is a cost-effective "green" technology based on the use of specially selected metal-accumulating plants to remove toxic metal ions from soils

* Tel.: +90 344 280 1684; fax: +90 344 280 1602.
E-mail addresses: yuysal@ksu.edu.tr, yagmur_uysal@hotmail.com

0304-3894/$ – see front matter
http://dx.doi.org/10.1016/j.jhazmat.2013.10.006

and water. Phytoremediation/constructed wetlands are claimed to be low-technology systems able to treat a variety of wastewaters [2] containing several heavy metal ions.

Aquatic vascular plants play an important role in the uptake, storage, and recycling of metals, so many species of them are used to remove these ions from wastewater. Live aquatic plant biomass does not require any special preparations like dead biomass, and it is typically grown in a separate chamber from the waste separation so that it can be physically separated from the wastewater [3]. One of the most using aquatic families in the phytoremediation researches is *Lemnaceae* that is distributed globally in the aquatic ecosystems. In general, these plants have been tested and used for secondary or tertiary treatment (advanced), and polishing of wastewater especially to remove metal ions and nutrients. Wastewater treatment with these plants provides effective, reliable, and affordable solutions for pond-based municipal and industrial treatment systems.

In the literature reports, duckweeds have also shown the ability to accumulate chromium ions from water substantially. In addition, duckweeds attain higher concentrations of chromium in their tissues than do other macrophytes. However, most of studies reported in the literature were carried out using batch systems like flasks or Erlenmeyer. However, these floating plants were exposed to continuous water flow both in nature and wastewater treatment plants.

Wastewater is characterized by substantial variations in pH, and may have different heavy metal ions at variety concentration range. In addition, treatment processes mostly occur in natural systems depending on the metabolic activities of plants, and pH value of water that they possibly affect the growth of plants. Thus, choosing of optimal pH value for the metabolism-dependent removal and bioaccumulation of pollutants is quietly important operation parameter in order to achieve requested treatment level. *Lemna* is a fast growing plant species and adapts easily to various aquatic conditions like pH, temperature and light. Plants are able to grow across a wide range of pH (3.5–10.5). Although this wide pH range, the optimal pH range for growth is 4.5–7.5 [4]. The plant carries on growing, but growth rate decreases at the lower or upper limits of this pH range. Thus, this study was carried out to determine the effect of different wastewater conditions such as pH (4.0–7.0) and chromium concentration (0.25–5.0 mgCr/L) on the sorption by *Lemna minor*. In order to simulate a stabilization pond for wastewater treatment and also simulate a natural wetland for plants' habitat, a laboratory scale pilot system with continuous water flow composed of three ponds was used in this study. The amount of plant biomass produced was also determined during the study period on weight and dry/fresh weight ratio basis.

2. Experimental

2.1. Terminology

In this study, differentiation between chromium oxidation states is not a concern; similarly to other works [5,6], biouptake including active incorporation into living cells as well as physical adsorption will be referred to total Cr. Two separate experiments were conducted: (1) to determine chromium removal from water by duckweed and (2) to determine the influence of Cr on duckweed growth and its biochemical parameters.

2.2. Experimental plant material

Plants were collected from freshwater canals in Kahramanmaras, and transferred to the climate chamber in the laboratory. They were first washed carefully with tap water several times to remove dirt, sludge and other debris, then were set into pilot system consisted of three plexiglas ponds with a capacity of 14 L filled with Synthetic Duckweed Nutrient Solution (DNS) [7]. No detectable levels of chromium were found in the water or sediments at the collection site.

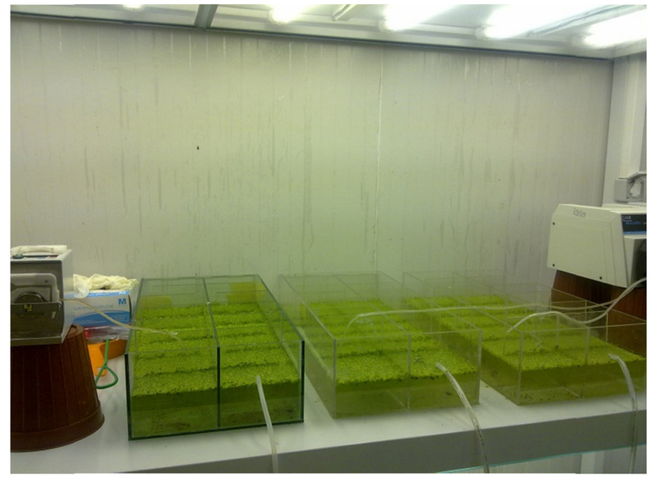

Fig. 1. Pilot system with *L. minor*.

2.3. Pilot system

This system consisted of three ponds as shown in Fig. 1. All the experiments were carried out in two ponds. One pond was used as control pond without any addition of metal. They were fed with DNS using a peristaltic pump continuously. Temperature was maintained at 23–25 °C, and 16 h of photoperiod was applied to plants at a photosynthetic photon density of 250 μmol/m^2 s at plant level. Each pond was segmented into twelve 10 × 10 cm sections connected to each other, and hydraulic retention times (HRT) for the ponds were chosen as 7 days. Water samples were collected from the effluent of chromium pond for chromium analyses periodically.

2.4. Growth parameters

In order to determine any possible toxic effects of chromium on plants, biochemical parameters such as growth rates, dry/fresh weight ratios and chlorophyll contents of plants were determined. Duckweed growth was determined by measuring fresh weight (FW, biomass) according to the Standard Methods [7]. Plants were surface-dried between layers of paper towels, and fresh weight was determined. To measure dry weight, plants were dried at 80 °C up to constant weight (usually 24 h). Since experiments were carried out in the ponds, and amount of plants was too high to count of frond number, special rings were used to limit the area of plants. These rings were set into chambers of ponds of 1st, 3th, 5th, 8th, 10th and 12th to calculate growth rates. The inner space areas of rings were about 20 cm^2 and plants (1 g) were put into them at the beginning of each experiment. Typical plant size was two to four fronds on each plant; and plant density was sufficient to exclude any significant algae or other plant growth.