Application of metal biosorption process for the treatment of metalliferous industrial wastes and products
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5.1. Introduction

Industries using metals as raw materials tend to release considerable quantities of heavy metals in process waters. Soluble heavy metals are a cause of major concern, because they directly enter the food chain. In certain cases, metals are disposed in the environment in the form of solid wastes. Metalliferous solid wastes are generated when, i) effluents containing heavy metals are chemically treated resulting in the formation of sludges, ii) defectively manufactured products are disposed off and iii) worn-out metal containing or metallic products are discarded after their useful life. If the solid wastes are disposed in the environment, there is a possibility of mobilization of metals. Mobilization of metals occurs as a result of numerous chemical and microbiological processes occurring in the soil. Mineralized metals enter plants by the root uptake systems and accumulate in stems, shoots and fruits. The primary accumulation of metals in plants and smaller animals or insects subsequently leads to accumulation and biomagnification in higher animals and humans. Toxic effects of various metals have been listed in chapter 1. With increasingly stricter regulations regarding the disposal of metalliferous solid wastes, there is a need to find out efficient and safe biotechnological alternatives.

Biosorption process for heavy metal removal is mainly applicable to aqueous wastes. In order to treat solid wastes, the metals must be solubilized in aqueous medium. Thus, integration of chemical solubilization process with biosorption might be useful in treatment of solid wastes containing the metals. Therefore, it was decided to undertake exploratory studies on such integrated processes with an aim to remove and/or recover metals from solid wastes.
Another area that is related to metal pollution is the contamination of food and food products. Foods contain essential nutritive elements and the non-nutritive trace elements (Kirk and Sawyer, 1991). The nutritive elements are cobalt, copper, iron, manganese and zinc. The trace elements, mostly metals, are present in food usually in amount <50 mg.Kg\(^{-1}\) and have some toxicological or nutritional significance. The elements such as aluminium, boron, chromium, nickel, tin, arsenic, antimony, cadmium, fluorine, lead, mercury and selenium have deleterious effects even when the diet contains between 10 - 50 mg.Kg\(^{-1}\). Copper and zinc have emetic action when ingested in higher amounts.

Extracts of plants used as food additives or medicinal preparations and the fruit juices have been found to contain toxic metals. Presence of metals in herbal extracts or fruit juices can be attributed to (i) accumulation in plants through the contaminated soil, (ii) contamination during processing in industries and (iii) leaching of metals from metallic containers during storage. Accumulation of metals in plants has been an area of extensive research (McGregor et al., 1995). Plants that grow in metal contaminated soils often show enhanced accumulation of toxic metals in leaves, stems and fruits. Leaves and fruits are also contaminated when pesticides are applied to the farms or heavy metal containing particulate matter settles on plants. Consumption of contaminated plant parts for edible purposes might increase risk of metal toxicity in humans and other animals.

In the present work studies were undertaken on two problems which are of direct significance to the Indian industry. It must be mentioned however that these problems are only illustrative examples and the author is aware that other similar problems existing in other parts of the world may also be tackled, in principle, by the proposed integrated chemical - biotechnological processes.
5.2. Disposal of waste thin film cadmium telluride photovoltaic modules

Photovoltaics offer an excellent solution to the energy crisis faced by the world, especially by the developing nations like India, that receive adequate sunshine throughout the year. Various types of photovoltaic modules are penetrating the energy market in a big way. Cadmium telluride (CdTe) solar photovoltaic cells are highly cost-effective and affordable to the users from developing countries. This has encouraged various technologies for the large scale production of CdTe solar cells (Brown, 1991). One of the important components of any technology development is its impact on the environment. It is known that the CdTe module production and disposal or decommissioning stages may potentially have severe environmental impacts. Some modules are rejected during manufacture while others may become a disposal problem after reaching the end of their useful life. There are two commonly employed methods of disposal, viz. recycling or disposal in landfill sites. With the present low levels of production of CdTe modules, disposal in landfill sites may be an acceptable alternative in many countries. However, despite the fact that cadmium and other metal compounds in the photovoltaic cells are in an insoluble form, leaching of heavy metals from landfill sites has to be closely monitored and possibly prohibited if this form of disposal is used. It is also important to recover and recycle expensive metals like silver and tellurium from the waste photovoltaic cells. Energy-intensive recovery options mainly involving evaporation or acid etching of the CdTe substrates and further recovery by an ion-exchange process have been explored (Sasala et al., 1994). However, these methods are difficult to practice and would prove expensive in many developing nations. With these considerations, the search for alternative small scale methods that could be practiced on-site for the removal and recovery of metals from waste photovoltaic cells was undertaken. The problem was addressed by using a judicious combination of well-established chemical methods and promising microbiological techniques like metal biosorption and metal reduction.
5.2.1. Waste photovoltaic modules

Waste CdTe photovoltaic cells generated during manufacture were procured from EcoSolar Systems (India) Pvt. Ltd., Pune. The cells comprised of glass plates (dimensions 7.5 cm x 7.5 cm x 0.3 cm) coated with tin oxide, cadmium sulfide, cadmium telluride and an organo - silver compound. The average combined weight of the materials coated on each cell was 0.6 g containing silver (37.1%), cadmium (3.7%) tellurium (2.0%) and organic matter (57.2%).

5.2.2. Dissolution of metals

10 g scrapings from CdTe solar cells were treated with 100 mL of 4 M nitric acid for about an hour to solubilize silver, cadmium and tellurium. The insoluble organic matter was filtered out and the filtrate was diluted to 1 liter with deionized water in a volumetric flask. The average metal content in the solution thus obtained was: silver (3710 mg.L⁻¹), cadmium (372 mg.L⁻¹) and tellurium (201 mg.L⁻¹). This solution was used in metal removal and recovery experiments.

5.2.3. Biosorption of silver and cadmium

Two types of microbial biomasses were used in the studies. The fungus, Cladosporium cladosporioides #1 that had a preferential affinity for silver was used for silver recovery. Fusarium moniliforme was used for cadmium removal on account of its preferential cadmium biosorption property. Both types of biomasses were immobilized in a polymeric matrix of natural origin and granulated to obtain beads of uniform size (2 mm) by a proprietary process (Paknikar et al., 1995). Optimization of parameters for silver and cadmium was carried out using pure metal solutions. The effects of solution pH, initial metal concentration and time of contact were determined by varying one factor at a time and keeping the other factors constant. A summary of results obtained is tabulated below (Table 5.1).
Silver and cadmium biosorption experiments, using the metal solution obtained from CdTe cells, were carried out under optimized conditions. Solution containing solubilized metals in nitric acid was diluted with deionized water to bring silver concentration to the desired level (100 mg.L\(^{-1}\)). The pH of solution was adjusted to the optimal value i.e. 7. The solution was then passed through a glass column (10 cm height, 0.75 cm internal diameter) containing 3 g silver biosorbent beads (C. cladosporioides #1), with the help of a programmable peristaltic pump. Next, the column effluent was conditioned to the optimal pH of 6 for cadmium biosorption and passed through a similar column containing cadmium biosorbent beads (Fusarium moniliforme). The treated solution from the column served as a feed for the bioreactor containing tellurium reducing bacterial culture. When the columns were operated under optimized conditions, the adsorption efficiencies obtained were >90% for silver and >94% for cadmium. It was found that the columns were saturated after adsorbing 50 mg silver per gram biosorbent and 35 mg cadmium per gram biosorbent i.e. after passing approximately 1.65 L solution containing silver and 11 L solution containing cadmium solution. It was important to note that cadmium was not taken up by the silver biosorbent column and tellurium was not adsorbed by any of the two types of biosorbent beads.

**Table 5.1.** Optimum conditions for the biosorption of silver and cadmium by C. cladosporioides #1 and Fusarium moniliforme, respectively and residual metal contents in solutions after passing through biosorbent columns.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Optimum solution pH</th>
<th>Optimum initial metal conc. (mg.L(^{-1}))</th>
<th>Optimum contact period (min.)</th>
<th>Residual metal (mg.L(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>7.0</td>
<td>100</td>
<td>50</td>
<td>9.1</td>
</tr>
<tr>
<td>Cadmium</td>
<td>6.0</td>
<td>80</td>
<td>50</td>
<td>0.5</td>
</tr>
</tbody>
</table>
5.2.4. Recovery of silver and cadmium

After complete loading of the biosorbent columns, silver and cadmium were recovered by specific treatments. Silver was desorbed from the beads with 0.2% alcoholic sodium cyanide solution (pH 13), precipitated with zinc dust and ignited to get purified silver metal. The silver elution efficiency obtained with alcoholic sodium cyanide solution was >99%. In the case of cadmium, 2 M hydrochloric acid was used for desorption, the desorption efficiency being >90%. Cadmium sulfide was precipitated out by passing hydrogen sulfide gas through the cadmium solution. The precipitate was thoroughly washed with deionized water and dried. The final recovery of silver (in metallic form) and cadmium (as CdS) was 86% and 80% of the original content, respectively.

5.2.5. Recovery of tellurium by microbial reduction

The solution after passing through silver and cadmium biosorbent columns contained 10 mg.L⁻¹ tellurium. In order to recover the tellurium a culture of *Pseudomonas mendocina* was used. The culture was capable of reducing soluble tellurium (tellurous acid) to elemental tellurium under oxygen - limiting conditions. The culture was previously used in our laboratory for developing a microbiological method for reduction of hexavalent chromium from effluents (Bhide, 1996). Tellurium reduction was carried out with maximum efficiency by the culture at pH 7.5, temperature 35°C and tellurium concentration <10 mg.L⁻¹ (data not shown). Details of tellurium reduction process are not discussed in the present work, since it is beyond the scope of the present investigations.

Considering the results, a 2 liter bioreactor set up was placed in an incubator adjusted to 35°C. The solution obtained after biosorption of silver and cadmium (adjusted to pH 7.5) was added as feed in the bioreactor. It was
observed that complete reduction of tellurium was obtained in 12 hours. Final recovery of tellurium was >99% of the initial content of photovoltaic cells.

The chemical analyses of the treated water coming out of the integrated chemical - microbiological process showed that the metal contents were low (typically <1.0 mg.L\(^{-1}\)). The water was therefore recycled and used as a diluant in the process. It could be seen from the foregoing results that the integrated chemical - microbiological process was highly effective in removing and recovering silver, cadmium and tellurium from waste CdTe solar cells. A schematic representation of the process is shown in Figure 5.1.

The possible application of the process could be in the form of a modular system consisting of biosorbent columns for recovery of silver and cadmium and a simple bioreactor for tellurium reduction. The system could be operated with ease on site, thus, obviating the costs involved in transportation of the scrap. Although economic feasibility of the process will have to be worked out by scaling up the process to a suitable level, results obtained so far definitely warrant further investigations.
Figure 5.1. Integrated chemical-microbiological method for the removal and recovery of toxic heavy metals from waste thin film CdTe photovoltaic cells.

CdS/CdTe PV cells

scatterings

↓

Metals (Ag, Cd, Te) in solution

water

↓

Diluted metal solution

Ag in Cyanide ← Ag biosorption

↓

Zinc dust

↓

Precipitated Ag Cd biosorption → Cd in solution

↓

Feed containing Te

Ignition

↓

Bioreactor

↓

Recovered Ag

Recovered Te

Recovered CdS

H₂S
5.3. Toxic metals in foods and drugs

Fruit juices show wide variations in composition. International Standards recommended by Codex Alimentarius for fruit juices include various parameters such as sugars, acidity, malic acid and other organic acids, etc. In addition to these constituents, the commercially marketed fruit juices may contain additives and heavy metals. Maximum permissible limits for trace metals and additives as well as methods for the determination of various parameters are included in the Codex Standards.

Alternative medicines are now becoming more and more popular. Herbal extracts have gained importance as they are effective in treatment of various ailments (Nadkarni, 1982). For example, *Vitis vinifera* or raisin extract is used in treatment of anemia, bilious dyspepsia, haemorrhages, dysuria, heart disease, bronchitis, constipation, etc. *Nordostachys jatamansi* extract is used as antispasmodic, diuretic, nerve sedative, promotes appetite and digestion, tonic for heart, liver, brain, cures jaundice and kidney stone. Although slower acting as compared to chemotherapeutic agents, these medicines have become popular on account of long term protection of individuals from various diseases. They are also free from side effects and problems of overdose. India is one of the major countries exporting various herbal medicines. Estimated annual turnover of herbal based medicinal preparations in India is to the tune of 50 million rupees. Considering the increasing worldwide demand, these figures are likely to increase enormously. However, the business is getting affected on account of heavy metal accumulation in plants. Toxic metals such as chromium, cadmium, lead, mercury and arsenic have been detected in herbal medicines. Many of the medicines have heavy metal contents that are unacceptable to statutory bodies abroad.

Small amounts of lead occur in many foods naturally, but contamination may occur from the use of lead alloys or compounds for processing materials, including solders, glazes, enamels, wrapping materials and piping or from
insecticides, although the latter are now largely replaced by alternative preparations. Alcoholic drinks and soft water are especially liable to pick up lead from piping which conveys them. An analysis of herbal extracts that are used in the manufacture of medicinal preparations has shown that more than 11% of the extracts contained above 10 mg.Kg\(^{-1}\) lead and more than 20% extracts contained above 10 mg.Kg\(^{-1}\) chromium. Open vessel digestion of herbs using diesel stoves is recognized as the major source of contamination. According to regulatory standards mentioned in 'The Lead in Food Regulations- 1979' (Ministry of Agriculture, Fisheries and Foods, UK), general permissible limit for lead is 1.0 mg.Kg\(^{-1}\) with specific limits for scheduled food varying from 0.2 to 10 mg.Kg\(^{-1}\). The limit for food specially prepared for infants or young children is 0.2 mg.Kg\(^{-1}\). Natural value for lead in commonly occurring foods is less than 0.1 mg.Kg\(^{-1}\).

Cadmium is liable to be present in foods due to use of certain utensils, especially, cadmium plated vessels. Ministry of Agriculture, Fisheries and Foods (MAFF), UK, reported that cadmium in food arises mainly from natural sources, but it may also be derived from atmospheric discharge into water and subsequent uptake in aquatic animals, enhanced uptake by plants due to the use of superphosphate fertilizers or disposal of sewage sludge on land. Most foods contain 0.01 - 0.03 mg.Kg\(^{-1}\) cadmium according to type of food (Kirk and Sawyer, 1991).

According to general provisions of the Food Act "materials and articles in their finished state and intended for contact with food shall not transfer constituents which could endanger human health or alter the characteristics of the food in terms of their nature, substance or quality". Although, most manufacturers have made improvements in food processing and packaging methods to reduce metal contamination, natural sources continue to pose a problem.
Methods for removal of toxic metals from herbal extracts and fruit juices are based on physical techniques, because, chemical treatments might lead to undesirable changes in the food preparations. Ion-exchange processes, although commonly employed, might be expensive and uneconomical. The possibility of using metal biosorption for the treatment of metal contaminated plant products was investigated in the present studies. The main objective of the present investigations was to remove toxic metals from food products without affecting other constituents and properties of the food products.

5.3.1. Culture used, its growth and harvesting of biomass

A fungal culture, Cladosporium cladosporioides #2 was isolated from black cotton soil and selected under a screening program for metal adsorbing fungi. Screening tests indicated that C. cladosporioides #2 could adsorb metals such as copper, cadmium, cobalt, chromium, lead, nickel and zinc. Log phase culture from Sabouraud's medium (250 mL) was inoculated in 4 liter Sabouraud's medium in a 5 liter capacity fermenter (B. Braun, Germany). Temperature and pH of the medium were maintained at 30° C and 5.7 ± 0.1, respectively during growth. Sterile air was sparged into the fermentor at a rate of 0.15 L.min⁻¹. Agitation of the medium was carried out at 100 rpm. After 5 days incubation, the medium turned yellow because of exhaustion of ingredients. Darkish green colored biomass was seen adsorbed on the inside surfaces of the fermentor. At this stage, the biomass was harvested by vacuum filtration and washed several times with deionized water to remove traces of medium constituents. Biomass yield was to the tune of 8.0 g.L⁻¹ medium on a dry weight basis. Biomass of C. cladosporioides #2 was granulated according to proprietary process (Paknikar et al., 1995). The beads were then used in lead and cadmium biosorption experiments.
5.3.2. Biosorption of lead and cadmium by *Cladosporium cladosporioides* #2

Figure 5.2 shows the optimum pH for lead and cadmium biosorption and Figure 5.3 shows time dependency of the process. It is clear that both, lead and cadmium are biosorbed maximally at pH values above 4. Therefore, high acid food products such as lemon juice might be difficult to treat by biosorption. On the other hand, slightly acidic to neutral foods would offer better opportunity for the application of microbial biosorbsents. The experiment was not performed at pH values above 6 because of precipitation of the metals at higher pH. It must be mentioned here that, although optimum pH for metal biosorption was determined, it was not for the purpose of adjusting sample pH to maximize lead and cadmium biosorption. This is because, any attempt to adjust pH of food products might alter properties of the food. The information on optimum pH, was intended for use in the selection of suitable food samples for biosorption of metals.
Figure 5.3. shows that the biosorbent beads require more than 1 h to adsorb the metals. The slower uptake could be because of the diffusion barriers during initial contact period. However, this difficulty would be overcome in a continuous packed-bed reactor, metal removal is expected to be faster after equilibration of the column as in the case of gold biosorption by *C. cladosporioides* #1 discussed in chapter 2. Optimization of initial metal concentration was not carried out for lead and cadmium biosorption. This is because, metal concentrations in fruit juice or herbal extracts were not expected to exceed the range <1 - 10 mg.L\(^{-1}\).

### 5.3.3. Biosorption of cadmium and lead from herbal extracts and fruit juices

Extracts of *Nordostachys jatamansi* (Jatamansi herb) and *Vitis vinifera* (raisin) were procured from Hi - Tech Bio Laboratories Pvt. Ltd., Pune. *Vitis vinifera* extract was available in the form of concentrated viscous slurry. The slurry was diluted by adding 30 g of the concentrate to 100 mL distilled water. Fresh fruit juices were obtained from grapes and carrots by mechanical crushing using a food processor (Ricoh, India). Commercial preparations of lemon and orange juice were procured from local fruit processing units (Enkay Texofood Industries Ltd., Bombay). All the samples were analyzed for pH, total dissolved solids, UV-Vis spectra (200 to 700 nm wavelength range) and heavy metal content. The pH measurements were made using a microprocessor controlled pH meter (Labindia, India). Total dissolved solids
were determined by using a refractometer (B. Braun, Germany). UV-Vis spectra were recorded by using a double beam UV-Vis spectrophotometer (Chemito UV-2600, India). Heavy metal content was estimated by atomic absorption spectrophotometry using ATI-UNICAM spectrophotometer model 929 (UK). Toxic metals (lead and cadmium) were not detectable in samples. Aliquots of pure metal stock solutions (lead and cadmium) were extraneously added to get a final metal concentration of 5 mg.L⁻¹. The pH, TDS and spectral scans of all samples remained unaltered upon addition of metals.

To each sample (25 mL in duplicates) containing the metals, 0.05 g biosorbent beads containing Cladosporium cladosporioides #2 were added. The mixtures were agitated at 120 rpm for 60 min. at 30°C. After the contact period was over, the sample solutions were separated from the beads and analyzed for residual lead or cadmium and also the changes in pH, TDS and UV-Vis spectra. Samples without addition of biosorbent beads served as controls. There was no change in pH after contacting the biosorbent. Another important observation was that TDS content of the samples was not affected by the contact with biosorbent. This indicates that, excepting for metal ions no other sample constituent was adsorbed by the biosorbent. The result also indicates that, no constituent from the biosorbent leached out into the sample. Table 5.3 summarizes these results.

These results were confirmed by scanning the samples in UV-Vis range (200 - 700 nm) when it was observed that the spectral patterns remained unaltered after biosorbent contact. It was found that there was no effect on the peaks at 327.5 and 362.5 in the case of the herbal extract. Similarly, the valleys at 310.5 and 358.5 were not altered. The scanning also showed that there were no new peaks indicating absence of leaching the fungal components in the Nordostachys jatamansi extract. Similar results were obtained in the case of all fruit juices that were analyzed. In further support, thin layer chromatography of Nordostachys jatamansi and Vitis vinifera extract each containing 5 mg.mL⁻¹ lead was carried out before and after contact with
biosorbent. The samples were extracted in ethyl acetate and filtered through Whatman no. 1 filter paper. Table 5.4 gives experimental conditions such as solvent system, reagent for identification and the results of the experiment.

**Table 5.3.** Analysis of fruit juices and herbal extract before and after contact with *C. cladosporioides* #2 biosorbent beads.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Lead</th>
<th>Cadmium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Residual metal</td>
<td>pH</td>
</tr>
<tr>
<td></td>
<td>(mg.L⁻¹)</td>
<td>(a)</td>
</tr>
<tr>
<td><em>Nordostachys jatamansi</em> extract</td>
<td>5.0</td>
<td>2.7</td>
</tr>
<tr>
<td><em>Vitis vinifera</em> extract</td>
<td>5.1</td>
<td>2.9</td>
</tr>
<tr>
<td>carrot juice</td>
<td>5.0</td>
<td>1.9</td>
</tr>
<tr>
<td>orange juice</td>
<td>4.8</td>
<td>2.6</td>
</tr>
<tr>
<td>grape juice</td>
<td>5.0</td>
<td>2.8</td>
</tr>
<tr>
<td>lemon juice</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

(a) before addition of biosorbent  
(b) after addition of biosorbent  
n.d. not detectable

**Table 5.4.** Thin layer chromatography of Jatamansi extract and raisin concentrate showing experimental conditions and *R*<sub>f</sub> values of sample constituents before and after biosorption of lead.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Solvent system</th>
<th>Identification reagent</th>
<th>number of spots</th>
<th><em>R</em>&lt;sub&gt;f&lt;/sub&gt; values before sorption</th>
<th><em>R</em>&lt;sub&gt;f&lt;/sub&gt; values after sorption</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Nordostachys jatamansi</em> extract</td>
<td>4% ethyl acetate</td>
<td>Iodine vapor</td>
<td>3</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.41</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.46</td>
<td>0.46</td>
</tr>
<tr>
<td><em>Vitis vinifera</em> extract</td>
<td>3% ethyl acetate</td>
<td>Iodine vapor</td>
<td>4</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.44</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.87</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.96</td>
<td>0.96</td>
</tr>
</tbody>
</table>

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Although, TLC of fruit juice samples was not carried out, for the lack of standardized solvent system, results of *Nordostachys jatamansi* and *Vitis vinifera* extracts clearly indicated that biosorption can be used for the removal of heavy metals from food products without removing food constituents. Moreover, as per general provisions of the Food Act, the biosorbent intended for contact with food products did not transfer constituents or alter the characteristics of foods in terms of their nature, substance or quality.

5.3.4. Continuous - flow reactor for removal of lead and cadmium from herbal extract and fruit juice.

Once the preliminary experiments showed that biosorptive removal of toxic metals from plant extracts and fruit juices was possible, a packed-bed reactor for continuous removal of metals from food products was set up. Maximum uptake of the metals was observed in case of carrot juice. Hence, carrot juice was used in the experiment.

Samples of the juice (50 mL) containing added lead and cadmium (final concentrations of lead and cadmium, 1.0 mg.L⁻¹ and 2 mg.L⁻¹, respectively) were passed in upward flow mode through two biosorbent columns (height 5 cm, internal diameter 0.8 cm) each containing 2 g beads of *C. cladosporioides* #2. The bed volume of the reactor was 3 mL. The retention time was adjusted to 20 minutes using a programmable peristaltic pump after the beads were completely soaked.
Figure 5.7. Removal of lead and cadmium from carrot juice using a packed bed reactor containing beads of Cladosporium cladosporioides #2

The effluents coming out of the columns were analyzed for the metals at regular intervals. Figure 5.7 shows that 20 bed volumes of carrot juice could be passed through the columns. Residual lead and cadmium in the column effluent were <0.05 and <0.15 mg.L$^{-1}$, respectively. The metals were thus brought below the permissible limits.

From the foregoing discussion it is clear that biosorptive properties of fungi can be used for removal of metals from industrial wastes as well as from food products. These studies would certainly provide a basis to further probe into the possibility of finding new and important applications for metal biosorption processes in combination with either chemical or microbiological methods.