Journal of Hazardous Materials B125 (2005) 80–88

Journal of Hazardous Materials

www.elsevier.com/locate/jhazmat

Kinetics study on separation of cadmium from tellurium in acidic solution media using ion-exchange resins

Wenming Wang, Vasilis Fthenakis *

National Photovoltaic Environmental Health and Safety Research Center, Brookhaven National Laboratory, Upton, NY 11973, USA

Received 9 November 2004; received in revised form 18 February 2005; accepted 26 February 2005

Abstract

The feasibility of using ion-exchange resins to separate cadmium from tellurium in acidic solutions of the two metals was investigated. We studied the competitive adsorption of cadmium and tellurium in such resins under varying acid strengths and contact time. We found that low sulfuric acid strength (i.e., 0.5 M) was most effective in removing cadmium from solutions. Different ion-exchange resins were tested for their affinity for cadmium and tellurium ions. In the selected systems, the ion-exchange rate of cadmium was rapid in the first 20 min, and reached equilibrium within 2 h. The Lagergren first-order model described the kinetic data with high coefficient of determination and correlation values. At room temperatures the ion-exchange for cadmium onto the resin followed the Freundlich isotherm model. The maximum removal of cadmium obtained from batch studies using resin A was 91%. Column studies with the same resin showed a removal of cadmium of 99.99% or higher.

Keywords: Cadmium; Tellurium; Waste management; Ion-exchange; Recycling; Photovoltaics

1. Introduction

Cadmium (Cd) and tellurium (Te) are the major materials used in manufacturing cadmium telluride (CdTe) modules for photovoltaic (PV) cells. However, the content of these two metals in the PV module's glass is extremely low, around 0.06% for each, according to our intensive leaching tests. Cadmium is a potentially hazardous metal and tellurium is a rare one; thus, both need to be treated and recycled. This demands prudent scrap-material management practices throughout the PV modules' life cycle to avoid environmental contamination and heath risks, and to comply with stringent regulations on cadmium discharges to the environment. Previous studies were limited to leaching with acidic solutions and extraction of cadmium and tellurium into the liquid phase [1–7]. None of the previous studies succeeded in completely separating Cd from Te. The concentrations of tellurium and cadmium in the leachate were ∼1000–1100 ppm of each element. Then, multiple steps (including leaching, neutralization, precipitation, filtration/separation, and re-dissolving) were used to separate and recover both from solutions. Yet, the efficiency of separating cadmium from tellurium, and subsequent recovery were not satisfactorily high. The best separation was obtained from Bohland et al. who recovered about 80% of Te at 99.7% purity in lab-scale experiments [2]. Apparently, these methods were not sufficiently effective in recovering the metals from low-concentration waste solutions. We investigated alternative processes that have the potential to completely separate cadmium from tellurium in acidic solutions. Ion-exchange technology offers a viable alternative for treating such waste streams. By using an ion-exchange resin, either all metal-ions can be removed from a solution, or one specific metal ion can be selectively removed, thus, achieving their separation. By carefully choosing the type of ion-exchange resin, the heavy metal ions can be completely separated and removed from the waste solutions to meet stringent environmental regulations. Several

* Corresponding author. Tel.: +1 631 344 2830; fax: +1 631 344 4486.
E-mail address: vmf@bnl.gov (V. Fthenakis).

0304-3894/$ – see front matter © 2005 Published by Elsevier B.V.
doi:10.1016/j.jhazmat.2005.02.013

researchers studied adsorption as a means to remove cadmium from aqueous solutions [8–24]. The tested adsorbents included activated carbon, bone char, peat, lignite, vermiculite, chitin, zeolite, and treated pinus pinaster bark. These studies focused on the adsorption of cadmium from low-concentration aqueous solutions; none of them describes the potential for separating cadmium from tellurium in acidic solutions. In the present work, we explored the feasibility of separating cadmium from tellurium in sulfuric acid solutions using different ion-exchange resins. Our study focuses on the adsorption kinetics and the effectiveness of separation.

2. Materials and methodology

2.1. Tellurium–cadmium containing solutions

Solutions containing both tellurium and cadmium were prepared by dissolving known amounts of high purity (99.99%) CdTe powder in solutions of sulfuric acid and hydrogen peroxide of known volume and strength. The solutions were prepared using de-ionized water. They then were passed through a filter with a pore size of 0.70 μm to ensure that they were free of suspended particulates. The concentrations of tellurium and cadmium were determined using a Varian Liberty 100 inductively coupled plasma (ICP) Emission Spectrometer. Frequent calibrations showed that the precision of the ICP measurements were ±1.0% for cadmium, and ±3.0% for tellurium.

2.2. Ion-exchange resins

Several resins were tested and two were selected for further evaluation. Before using them, the resins were soaked in deionized water for 24 h and then were rinsed several times also with deionized water.

2.3. Batch studies

Batch studies of sulfuric acid strength, kinetics studies, and batch equilibrium isotherm studies were carried out in the same manner. In each type of studies, we prepared metal solutions containing tellurium and cadmium and transferred them into 250 mL wide-mouth polypropylene test bottles with screw closure caps using a FINNPIPETTE pipette (accurate to ±0.3% with a precision of 0.2%). Each bottle contained a known volume of the solution. A known amount of resin was then added into each bottle. Afterwards, the bottles were shaken continuously at 100 rpm on an INNOVA 2100 platform shaker manufactured by New Brunswick Scientific Co. Inc. At certain intervals of contact time, the solution samples were withdrawn and filtered through 0.70 μm filters. The tellurium and cadmium concentrations of the filtered liquid samples were measured with an ICP emission spectrometer. The experiments were conducted in duplicate, and mean values were used in analyzing the data.

The quantities of cadmium and tellurium adsorbed onto the resins at equilibrium (q_e, mg/g) were calculated using the mass balance equation:

$$q_e = (C_0 - C_e)V/M$$

where C_0 and C_e are the initial concentration and equilibrium concentration of metals (mg/L), respectively, V the volume of solution (L), and M is the resin mass (g).

2.4. Column studies

The potential of commercial separation was studied using laboratory-scale ion-exchange columns. These columns are made by graduated Perspex of 34 mm inner diameter and 150 mm height. The Perspex column was equipped with a bottom filtration device to prevent the escape of fine resin beads during processing. In general, several ion-exchange resins may be used to remove positively charged heavy metals ions in aqueous solution media. We selected two different resins for evaluation, based on cost, range of operating pH, and adsorption capacity. In each column test, the ion-exchange resin was first soaked in deionized water for at least 12 h to ensure that the resin was fully swelled prior to use. The column was then loaded with 100 mL of the swelled resin. The influent solution was prepared by the dissolution of CdTe powder with sulfuric acid and hydrogen peroxide. The matrix solution was 0.5 M H_2SO_4 with approximately 1100 ppm of tellurium and 1000 ppm of cadmium. The prepared influent solution, containing both cadmium and tellurium, was passed downward through the column at a fixed flow rate. A total of ∼2.0–4.0 L of influent solution was used in each column study. The downstream effluent was collected at different fractions with each fraction measuring about one bed volume (100 mL). The flow rate of the solution was kept at 3–6 bed volumes per hour (BV/h), which was equivalent to 300–600 mL/h. Samples of solution were taken from each fraction of the effluent and were analyzed using ICP for cadmium and tellurium.

3. Chemistry of leaching and ion exchange

Thermodynamic information on tellurium [25] and cadmium [27,28] showed the following: Cadmium is soluble in acid media, and insoluble in neutral and strongly alkaline media; tellurium(IV) is sparingly soluble in acid media, insoluble in neutral media, and soluble in alkaline media; tellurium(VI) is soluble in acid media, and insoluble in alkaline media. Other studies showed that telluride can be readily oxidized with hydrogen peroxide in acid media [1,2,25,26]. In preparing the initial tellurium–cadmium-containing solutions from the raw CdTe powder, a leaching procedure was employed. During leaching, in the presence of sulfuric acid and hydrogen peroxide, the Cd and Te are extracted and solubilized into the liquid phase based on the following