

Capacitive-faradaic fuel cells: a novel method for recovery of metals from end-of-life photovoltaic panels

S. R. Yashas*, E. B. Ruck, Y. Gendel

Faculty of Civil and Environmental Engineering, Technion-Israel Institute of Technology. Haifa 32000, Israel.

Keywords: end-of-life, PV panels, metal recycling, electrochemistry

*Presenting author email: sryashas999@gmail.com

Introduction

Waste electrical and electronic equipment (WEEE) recycling methods are now at a new stage of development. From straightforward disassembly, classification, and sorting to high value-added usage technologies, WEEE disposal techniques have advanced. A few new and modified technologies have been reported in the last few years to recover metals (e.g. Ag, Cu, Sn, Pb, etc.) from WEEE. The present research reveals the selective extraction of silver (Ag) from the end-of-life photovoltaic (EoL PV) panels by capacitive-faradaic fuel cells (CFFCs). The EoL PV modules are one of the latest defined WEEE, which could be a menace by next 10-15 years. Hence, the present research objects to propose an eco-friendly way of selectively leaching Ag with a combination of sulphuric acid (H_2SO_4), and hydrogen peroxide (H_2O_2).

Material and methods

EoL PV module was collected from an indigenous company in Israel which was a 100W-18V-P module, and dimensions of 1000*670*35 mm. The PV extract obtained were subjected to leaching to extract metals. In a typical leaching study was with 100 mL lixiviant and 1 g of solids. During the leaching study, aliquots were analyzed for metal concentrations by inductively coupled plasma-optical emission spectrometry (ICP-OES). The CFFCs (activated carbon-platinum, AC/Pt) was prepared by impregnation of platinum particles on the surface of activated carbon. The final catalyst was obtained after calcination at 300 °C for 12h under H_2 atmosphere.

Results and discussion

Pretreatment of EoL PV panel

The Al frame and the electrical connections were manually removed, and the module was cut into small, convenient sizes. The as-is fragments were soaked acetone for 4h to remove the backsheet (Tedlar®). Further, the PV module was pyrolyzed at 450°C for 1h. Post-pyrolysis, the copper strips, tempered glass, and the PV cells were manually isolated. Table 1 gives the details of the quantities of different components of EoL PV.

Table 1. Composition of EoL PV module

Surface area	Experimental average (n=9)			
	Polymers	Cu strips	Glass	PV cell extract
sq. m	g	g	g	g
0.67	460.29	105.86	5276.25	381.23

Leaching studies

H_2SO_4 at 70°C with 1% H_2O_2 was able to leach Ag efficiently. This combination was highly selective towards Ag, along with co-leaching of Cu and Pb. The Ag extraction of one particular batch reached a maximum of 63 mg/L. Reasonably, the average concentration of Ag was on par with that of conc. HNO_3 and a combination of MSA and H_2O_2 leaching. However, because of easy, safety, and eco-friendly, and suitability for further metal recovery using CFFCs, the present study was continued with H_2SO_4 - H_2O_2 combination.

Proof-of-concept: CFFC based metal recovery

A simulated leachate with 200 mg/L Ag^+ , 20 mg/L Cu^{2+} and 10 mg/L Pb^{2+} in 1M H_2SO_4 was prepared. The working column was packed with 7.5 g of Pt/AC catalyst and the system was purged H_2 and O_2 /air to test the catalytic reduction and oxidation of metals. Figure 1 simplifies the electro-redox mechanism that governs the metal separations in the PV leachate.

Figure 2 (a) and (b) shows the variation in metal concentrations during the H_2 -O/air cycles, respectively. As perceived from the initial H_2 cycle, the concentration of Ag reduced from 200 mg/L to 0.1 mg/L within 45 min as the result of catalytic reduction of Ag^+ to metallic silver (Ag^0), that gets deposited on the Pt/AC catalyst. Likewise, the Cu^{2+} gets reduced to metallic copper (Cu^0) and deposits on the catalyst. Thus, the difference in their reduction potentials, individual metals are catalyzed in series. However, the concentration of Pb attains its saturation of solubility in 1M H_2SO_4 (~4.5 mg/L). Finally, O_2 /air was purged through the system which resulted in the oxidation of metals (into a new batch of 1M H_2SO_4). Figure 1 (b) shows that Cu^{2+} trailed by Ag^+ increased

in concentrations close to their initial concentrations witnessing the oxygenation of metals to their ionic form. Thus, the Pt/AC or CFFCs offer a unique advantage of selective recovery of metals in the PV cell leachate. Finally, the electrowinning process is applied to extract pure silver metal.

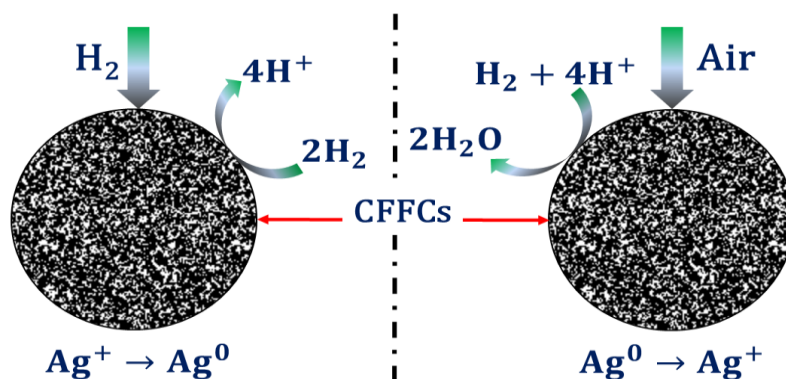


Figure 1. Schematic representing the catalytic redox mechanism for Ag recovery with CFFCs

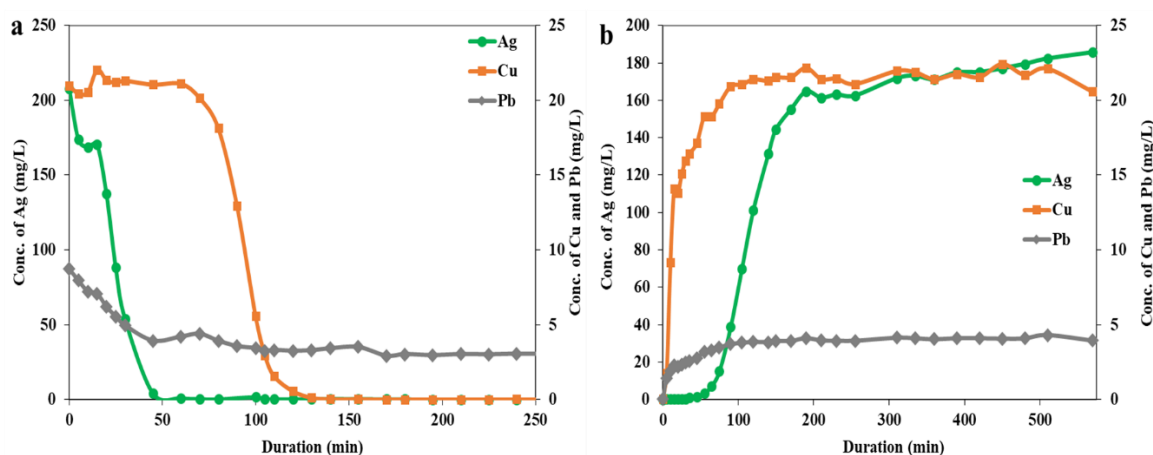


Figure 2. (a) Concentrations of Ag^+ , Cu^{2+} , and Pb^{2+} during the catalytic reduction process of CFFC process **(b)** Concentrations of Ag^+ , Cu^{2+} , and Pb^{2+} through oxidation process. Experimental conditions: 500 mL of 1M H_2SO_4 ; solution flowrate: 100 mL/min; gas flowrate (H_2 and O_2/air): 150-200 mL/min, and H_2 and air pressure: 1 atm

Conclusions

The use of H_2SO_4 as a lixiviant has an advantage for the operation of CFFCs. The platinum embedded activated carbon (Pt/AC) facilitates dual functionality of hydrogenation and oxygenation of Ag. The CFFC process is governed by the electrochemistry of metals as a function of their Nernst potentials and pH. It is evident that separation of Ag^+ ions is possible during the hydrogenation or/and oxygenation step of the CFFC due to a large difference in their standard potentials. Additionally, the Cu could be similarly recovered during oxygenation, into a fresh electrolyte, isolating the Pb. This process has highest efficiency of scaling-up and simultaneously prevents the contamination of soil and water from Pb and other metals in EoL PV. Apart from the application of CFFCs for Ag extraction from EoL PV modules, we have demonstrated Ag recovery from silver-oxide-zinc batteries, and separation of ions from water and wastewater in our previous research.

References

- [1] Amikam et al., 2022, Sep. Purif. Technol., 253, 117494. <https://doi.org/10.1016/j.seppur.2020.117494>
- [2] Darom et al., 2021, Chem. Eng. J., 421, 12995. <https://doi.org/10.1016/j.cej.2021.129950>
- [3] Amikam et al., 2021, Electrochem. commun., 124, 106945. <https://doi.org/10.1016/j.elecom.2021.106945>
- [4] Ruck et al., 2022, Sep. Purif. Technol., 285, 120303. <https://doi.org/10.1016/j.seppur.2021.120303>