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Recycling of Waste Cell Phones

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ABSTRACT

Recycling provides environmental benefits, including energy savings, reduced waste volumes, and reduced emissions associated with energy use. Cell (mobile) phones are widely used throughout much of the world. However, less than one percent of the millions of cell phones retired and discarded annually are recycled. Almost all materials used in cell phone manufacturing - metals, plastics, batteries, and packaging - can be recovered and recycled into new products. This study summarizes recycling technologies for waste cell phones and, as a case study, examines the potential for recovering valuable metals from waste cell phones using acidic leaching. The process steps include dismantling waste mobile phones, pre-processing to separate materials, and directing them to final treatment processes. In the leaching experiments, sulfuric, nitric, and hydrochloric acids were used. In the sulfuric acid leaching experiment, the effects of acid concentration, temperature, peroxide addition, and leaching time on metal dissolution efficiencies were investigated. Leaching efficiencies achieved were 97.9 % Fe in 8 mol H_2SO_4, 88 % Pb, 100 % Ni, 90.4 % Co, and 4.1 % Cu in 1 mol HNO_3 solutions, 100 % Pb, and 100 % Al in 4 mol HCl, all within one hour. Therefore, for effective leaching of all metals, a sequential leaching process using different acids is recommended.

1. Introduction

In today's society, it seems like everyone is glued to a cell phone. This results in about 100 - 120 million phones that are discarded every year (Importance of Cell Phone Recycling, 2025). With such high amounts, old cell phones have become the fastest growing form of electronic trash. This is causing a serious problem because electronic waste contains many hazardous materials. Within each mobile device, harmful chemicals and materials can contaminate soil and waterways, leading to long-term environmental effects that will eventually harm animal and human well-being (Greentec Blog, 2025). More so because many people are to throw away their phones clogging landfills, polluting air and groundwater at an alarming rate. You can make a difference and stop the pollution by recycling your cell phone instead of carelessly discarding it. With innovative technologies, up to 80 % of materials used in cell phones can be recycled and reused. Although cell phones consist of materials that differ from model to model and manufacturer to manufacturer, the guideline provides data characterizing the typical content of a mobile phone (Arslan and Arslan, 2025; MPPI - Project 3.1, 2025). The substances identified include primary constituents, minor constituents and micro or trace constituents. Figure 1 shows the weight percentages of different parts of a mobile phone (Tan et al., 2017). As for the weight in mobile phones, plastic materials are the most prominent one and additionally the batteries and printed circuit

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boards (PCBs) have a large share. Cell phones contain numerous metals, including expensive ones. The most important ones are copper, nickel, silver, gold, platinum group metals, cobalt, lithium, lead, tin, zinc, rare earth metals (REM), gallium, indium, iron, chromium, niobium, tantalum, and titanium. Table 1 lists the most important cell phone components and the metals they contain (Buchert et al., 2012; Arslan and Arslan, 2025).

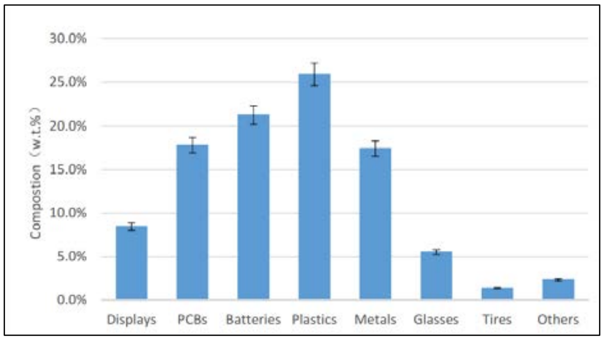

Figure 1. Mass fractions of parts of a mobile phone (Tan et al., 2017)

Table 1
Metals found in the most important parts of cell phones (Buchert et al., 2012; Arslan and Arslan, 2025)

Metals	Cell phone parts
Chromium	Shield plates
Cobalt	Batteries
Copper	Connectors, printed circuit boards (PCBs), resistors, coils, speakers
Gallium	Printed circuit boards
Gold	Connectors, printed circuit boards
Indium	LCD displays
Iron	Resistors, shield plates
Lead	Capacitors, resistors
Lithium	Batteries
Nickel	Connectors, capacitors, resistors, shield plates, batteries
Niobium	Printed circuit boards
Palladium	Printed circuit boards
REE	Permanent magnets, LCD displays, speakers
Silver	Printed circuit boards , capacitors, resistors
Tantalum	Printed circuit boards
Tin	Printed circuit boards, capacitors, LCD displays
Titanium	Capacitors
Zinc	Resistors

2. Recycling Processes

Waste cell phones are useful sources of metals, including copper, gold, silver, and palladium, among others. The material recovery and recycling chain consists of the following main steps: collection, segregation (sorting out cell phones from other electronic wastes, separation of components, separation of accessories, battery removal from handset, manual or mechanical disassembly of other parts, recycling of batteries, recycling of accessories, recycling of handsets, shredding or shredding and separation of materials, sampling and analysis for the determination of the individual material composition, smelting, i.e. upgrading of metal contents, and metals refining, i.e. separation and purification of metals to marketable products (MPPI - Project 3.1, 2025). A prerequisite step in the material recovery and recycling of end-of-life cell phones is the manual separation of batteries, in order to minimize contamination of other materials in subsequent material recovery and recycling stages as well as to maximize recovery of the substances contained in the batteries. Manual separation may also be used to separate certain accessories from mobile phone handsets and, in some cases, plastic parts may be separated for recycling. Mechanical separation, including shredding, crushing and size reduction, followed by various separation techniques, can also be used.

Two main techniques are applied to recycle the PCBs of waste cell phones (WCP); pyro-metallurgical and hydrometallurgical processes. During the pre-processing phase of the material, the battery and hardware parts are dismantled manually and only the PCBs are collected (Okwu and Onyeje, 2014; Arslan et al., 2022). Then, it is shredded and ground to make it ready for chemical processing. Hydrometallurgical technologies are predictable and controllable methods for material extraction (Cui and Zhang, 2008; Abdelbasir et al., 2018; Arslan et al., 2022; Arslan and Arslan, 2025).

2.1. Smelting and Refining

The environmentally sound recovery and recycling of waste cell phones (excluding batteries and accessories) can be achieved through manual or mechanical component separation, followed by processing in specialized smelters (Wang et al., 2017). After mechanical separation, the circuit board and other remaining parts are most efficiently recycled in a smelter, where valuable metals such as copper, gold, silver, and palladium are recovered. Direct smelting also recovers most metals, except iron, magnesium, and aluminum, while plastics serve as both a heat source and a reducing agent. (Arslan and Arslan, 2025)

Smelting electronics, including cell phones, requires specialized equipment, yet many smelters lack proper pollution control. However, with adequate controls, metals can be safely recovered and recycled. Metal recovery from separated batteries involves smelting, which may release metal fumes and particulates, posing risks to workers and communities (Arslan and Arslan, 2025; MPPI - Project 3.1, 2025).

Following smelting, electro-refining, dissolution, and precipitation processes further purify the metals. If the resulting slag contains significant metal content, it is either returned to the smelter or processed through selective leaching and precipitation. Only a limited number of smelters and refiners worldwide possess the necessary material handling capabilities and pollution control systems for efficient metal recovery from end-of-life cell phones (Arslan and Arslan, 2025; MPPI - Project 3.1, 2025).

2.2. Hydrometallurgical processes

Among hydrometallurgical processes that can be applied, leaching is the leading technique based on the principle of solid component solubility through contact with leaching agent. Different factors can influence the leaching process, such as pH, temperature, concentration and oxidation-reduction potential (ORP). Hydrometallurgical processes use cyanide and/or strong acids such as aqua regia, nitric acid, sulphuric acid, and hydrochloric acid, ionic liquids, and bacteria to selectively dissolve metals and separate them from other substances (Yazici and Deveci, 2015; WasteCare Corporation, 2025). Addition to these acids, a wide variety of reagent systems (e.g. iodide, ammonia, cyanide, thiourea and thiosulfate) in the presence of a suitable oxidant (e.g. ozone, H_2O_2, O_2, Cu(II), Cl_2 etc.) have been tested for leaching of metals from PCBs (Salinas-Rodrigez et al., 2022). Hydrometallurgical processes normally firstly require removal of plastics and grinding to a small particle size with a high surface area. Thus, hydrometallurgical process for cell phones will take place at later stages of selective metal recovery, to extract specific desired metals. (Arslan and Arslan, 2025)

2.3. Plastic recovery

Plastics from cell phones have not been widely recovered as plastics yet, because few facilities can efficiently sort plastics into clean streams of a single type (MPPI - Project 3.1, 2025). In smelters with appropriate flue gas treatment, plastics may be utilized in the metal recovering process, where they serve as a source of heat and substitute for other hydrocarbon fuels and as a reducing agent. If cell phone cases could be designed to be easily removed, and free of contaminating substances like paints, labels and metals, as well as collected in a reasonably large volume, the engineered plastics of cell phones, usually an acrylonitrile butadiene styrene-polycarbonate (ABS-PC), could be recycled with a positive economic value. Manual disassembling of mobile phones prior to precious metal recovery can produce reasonably clean streams of such plastic. (Arslan and Arslan, 2025)

2.4. Land disposal

Land disposal of mobile phones may place them in contact with co-disposed acids, and, over an extended period, the substances that are soluble in those acids may leach out. If a landfill is not bound by an impermeable barrier, substances may migrate into ground waters, and eventually into lakes, streams, or wells, and raise a potential exposure to humans and other species. The greater risk of land disposal will be from direct ingestion of contaminants, contaminated soil and water in landfills that are not controlled (MPPI - Project 3.1, 2025). If cell phones appear to be in good condition and can be reused, they may be redirected to refurbishment. One other method of recycling cell phones is to take the working parts of broken phones and combine them with the working parts of other used cell phones to make one ready-to-use cell phone (Arslan et al., 2022). The rebuilt phone can then be sent back into circulation without ever needing newly manufactured parts or natural resources. (Arslan and Arslan, 2025)

3. Material and method

As a case study, this experimental study aims to investigate the possibilities of recovering the valuable metals in the PCBs of the waste (end-of-life/used) cell phones (Arslan et al., 2022). Figure 2 represents an experimental flow sheet showing all process steps. It includes preparation, characterization, chemical analysis, and hydrometallurgical studies (Arslan et al., 2022; Arslan and Arslan, 2025).

After dismantling old cell phones as shown in Figure 3, we subjected the PCBs to size reduction using a shredder, then took cut samples for sieve analysis. Chemical analysis of the sample related to the size ranges are shown in Table 2. According to chemical analysis results, all metal contents, except Cu and Fe, do not change much with particle size ranges where Cu content decreases with decreasing size range and Fe content fluctuates without depending on size range. (Arslan et al., 2022) An average Au content was found to be approximately 250 ppm.

Before leaching experiments, we conducted dissolution tests to determine the sample's metal content. For this purpose, samples were ground below 1.0 mm in size and then dissolved in aqua regia. An average weight loss of 53.11 % was accepted as the total metal content. (Arslan et al., 2022; Arslan and Arslan, 2025)

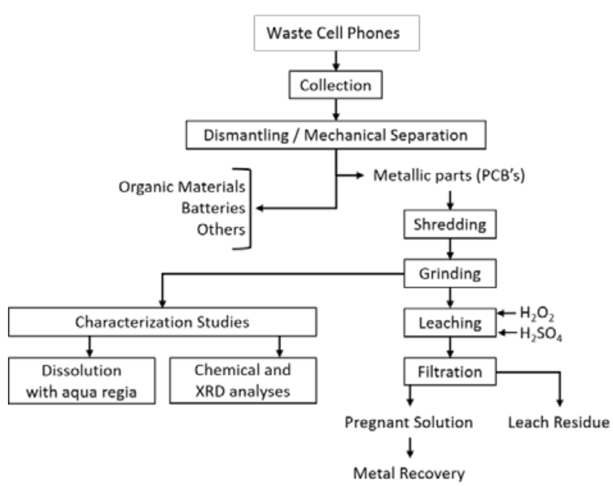

Figure 2. Experimental flow sheet for the recovery of metals from waste cell phones (Arslan and Arslan, 2025)

Figure 3. End-Of-Life cell phones used in the experimental study and pieces of old mobile phone after dismantling

Table 2
Metal contents (%) according to particle size ranges

Particle Size Range (mm)	Weight Dist. %	Ag %	Cu %	Co %	Ni %	Zn %	Fe %	Al %	Pb %
+8	17.72	0.05	43.27	0.01	2.56	3.00	3.73	1.84	0.31
-8+6	13.65	0.04	29.95	0.04	2.52	0.49	17.93	1.46	0.20
-6+3.36	26.91	0.18	33.94	0.02	1.76	1.19	5.00	1.76	0.23
-3.36+2.36	19.81	0.14	25.20	0.06	3.44	1.67	21.91	1.50	0.38
-2.36+1.19	11.86	0.31	35.76	0.03	4.37	3.68	5.90	1.31	0.38
-1.19+0.5	3.83	0.28	27.48	0.03	4.95	1.69	6.29	1.27	1.43
-0.5+0.3	3.38	0.17	22.91	0.02	2.62	0.60	2.95	1.51	2.17
-0.3	2.84	0.27	14.63	0.02	1.39	0.52	4.03	2.64	1.71
Total	100,00	0.14	33.20	0.02	2.77	1.86	9.42	1.63	0.40

4. Experimental results

Before starting the leaching experiments, the waste mobile phone samples (collected from friends and families and supplied by Exitcom Recycling Ltd. Co., Turkey) were ground to below 1 mm in size. The experiments were carried out in four groups to study the effects of acid concentration, hydrogen peroxide (H_2O_2) addition in sulfuric acid media, leaching time, and acid type on metal dissolution efficiencies. (Arslan et al., 2022; Arslan and Arslan, 2025)

In the first group of experiments, the effect of sulfuric acid concentration on metal leaching efficiencies was studied. The experimental conditions were: solid/liquid ratio of 10 %, temperature of 60 °C, stirring speed of 600 rpm, and a duration of 1 hour at varying acid concentrations of 1 - 8 mol/L. The results are shown in Figure 4. Increasing acid concentration had little effect on most metal leaching efficiencies. (Arslan et al., 2022) Only Co and Fe showed increased leaching efficiencies above 4 mol/L acid concentration.

In the second group experiments, the effect of H_2O_2 concentration on metal leaching recoveries was investigated at the constant experimental conditions mentioned as 8 mol/L of H_2SO_4 concentration, temperature of 60 °C, 600 rpm of stirring speed, 10 % of solid/liquid ratio, and 1 hour of leaching time. According

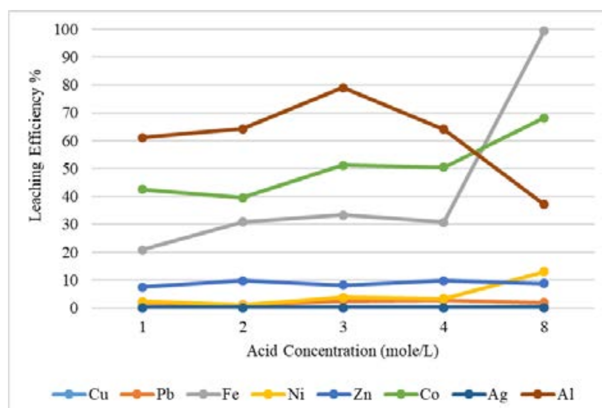

Figure 4. Effect of acid concentration on metal leaching efficiencies

to the experimental results shown Figure 5, Co and Ni leaching efficiencies are gradually increased while leaching efficiencies of other metals were not affected much with peroxide addition.

Hydrogen peroxide is a strong oxidant commonly used with acids to enhance metal extraction. In an earlier study on copper extraction from scrap TV boards, Deveci et al. (2010) reported that Cu dissolution increased with H_2O_2 addition (0.3 mol, 1 - 4 hours) in sulfide media. Similarly, Oh et al. (2003) proposed H_2SO_4 leaching of PCBs in the presence of H_2O_2 as a first-stage process, achieving

>95 % recovery of Cu, Fe, Zn, Ni, and Al. In the second stage, they targeted precious metal recovery using ammoniacal thiosulfate ($CuSO_4$-NH_4OH-$(NH_4)_2S_2O_3$). Quinet et al. (2005) also considered sulfuric acid leaching as the first-stage process, testing various oxidants including H_2O_2, O_2, and Fe^{3+} for copper extraction.

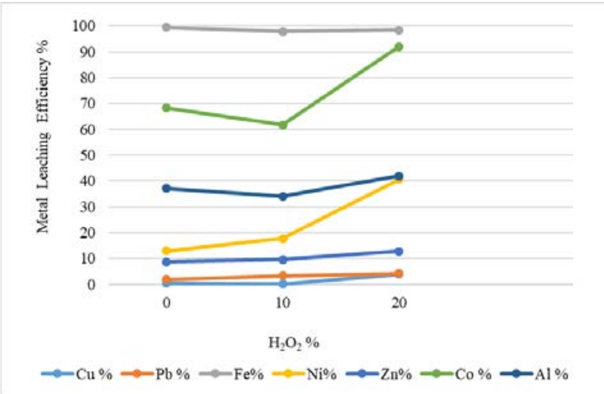

Figure 5. Effect of H_2O_2 addition on metal leaching efficiencies

In the third group of experiments, the effect of leaching time on metal dissolution efficiencies was investigated. The constant experimental conditions were: 8 mol/L H_2SO_4 concentration, temperature of 60 °C, stirring speed of 600 rpm, solid/liquid ratio of 10 %, and 20 % H_2O_2 addition. The leaching time varied from 1 to 5 hours. The results are shown in Figure 6. Increasing leaching time had a slightly positive effect on metal leaching efficiencies. At the end of 5 hours, leaching efficiencies reached 98.44 % for Fe, 40.59 % for Ni, 92.09 % for Co, and 41.90 % for Al. In contrast, Cu, Pb, and Zn leaching efficiencies were very low, with values of 3.87 %, 4.20 %, and 12.89 %, respectively.

In the fourth group of experiments, the effect of acid type was investigated using sulfuric acid (H_2SO_4), hydrochloric acid (HCl), and nitric acid (HNO_3). The results are presented in Table 3. In HNO_3 experiments, higher Co, Ni, and Pb leaching efficiencies were observed, whereas in HCl experiments, higher Pb, Co, Al, and Fe leaching efficiencies were obtained. However, Cu leaching efficiency remained low in all cases. For example, as shown in Table 3, 97.9 % Fe leaching was obtained in 8 mol H_2SO_4 solutions, 88 % Pb, 100 % Ni, 90.4 % Co, and 4.1 % Cu leaching were observed in 1 mol HNO_3 solutions, and 100 % Pb and Al leaching were achieved in 4 mol HCl solutions after 1 hour.

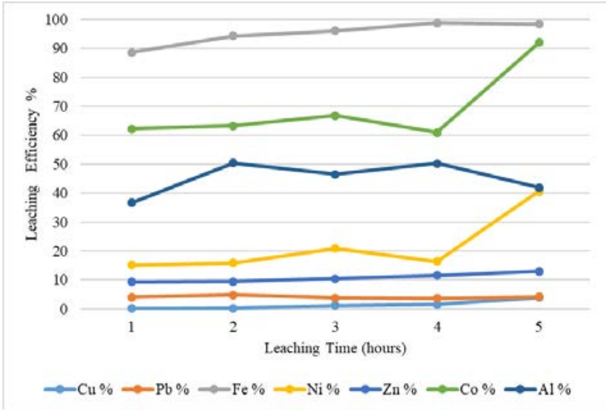

Figure 6. Effect of the leaching time on the metal leaching efficiencies

Acid leaching is often applied as the first stage of metal extraction, particularly for base metals such as copper. Numerous studies have investigated acid leaching of metals from e-waste using a variety of mineral acids and oxidants (HCl, H_2SO_4, HNO_3/H_2O_2, $HClO_4$, NaClO) (Deveci et al., 2010). Bacterial leaching has also been explored (Brandl et al., 2001) with ferric ion addition during bioleaching increasing Cu extraction to >99 % according to Yang et al. (2009). Mecucci and Scott (2002) reported high Cu and Pb extractions (>85 %) with nitric acid leaching.

In our study, 100 % Pb extraction was achieved, but Cu leaching efficiency reached only >4 %. This aligns with the findings of Castro and Martins (2009) who reported Cu extraction from PCBs of <0.01 % in H_2SO_4 leaching and about 30 % in mixed acid systems (H_2SO_4+HCl, HCl, HCl+HNO_3). XRD analysis of leach residues in our experiments confirmed the presence of Cu and Zn, supporting their low dissolution (Arslan et al., 2022). According to Madenoglu (2005) the highest Cu and Au extraction from PCBs was obtained using HNO_3/HCl media (aqua regia), as expected.

Table 3
Effect of acid type on metal leaching efficiencies (Arslan and Arslan, 2025)

Acid Type + Oxidizing Agent	Metal Leaching Efficiencies, %						
	Cu	**Pb**	**Fe**	**Ni**	**Zn**	**Co**	**Al**
1 mol/L H_2SO_4	0.09	0.54	31.45	3.30	7.69	36.09	61.09
8 mol/L H_2SO_4	0.16	3.32	97.90	7.75	9.59	61.78	24.02
8 mol/L H_2SO_4 + 20 % of H_2O_2	0.15	4.06	88.65	15.09	9.30	62.25	36.69
1 mol/L HNO_3	4.13	87.98	21.84	100.00	25.66	90.40	37.20
4 mol/L HCl	0.74	100.00	48.84	17.69	18.80	77.57	100.00
8 mol/L HCl	0.85	100.00	49.25	17.61	19.97	71.36	100.00

5. Conclusions

Less than one percent of the millions of cell phones retired and discarded annually are recycled. Almost all the materials used to manufacture a cell phone can be recovered, as metals, plastics, batteries, and packaging materials can be recycled and made into new products. Pyrometallurgical and hydrometallurgical processes are the two main techniques used to recover metals from cell phones. As a case study, acidic leaching of waste cell phones was studied. Experimental results showed 97.9 % Fe leaching in 8 mol H_2SO_4 solutions, 88 % Pb, 100 % Ni, 90.4 % Co, and 4.1 % Cu leaching in 1 mol HNO_3 solutions, 100% Pb and 100 % Al leaching in 4 mol HCl solutions within one hour. Therefore, for effective leaching of all metals, a sequential leaching process using different acids is recommended. Precious metals can be dissolved using cyanide, thiourea, or aqua regia. For metal recovery from leach solutions, solvent extraction/ion exchange, precipitation, cementation, and electrowinning processes can be used depending on the metal types and compounds. (Arslan et al., 2022; Arslan and Arslan, 2025)

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Reciklaža otpadnih mobilnih telefona

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INFORMACIJE O RADU

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Naučni rad

Ključne reči:
Mobilni telefon
Reciklaža
Kiselinsko luženje

Proširena i recenzirana verzija rada - rad prezentovan na simpozijumu XVI Međunarodna konferencija pripreme mineralnih sirovina i reciklaže (IMPRC 2025)

I Z V O D

Reciklaža donosi brojne ekološke koristi, uključujući uštedu energije, smanjenje količine otpada i smanjenje emisija povezanih sa potrošnjom energije. Mobilni telefoni su u širokoj upotrebi širom sveta. Ipak, manje od jednog procenta od milion telefona koji se svake godine povuku iz upotrebe i odbace biva reciklirano. Gotovo svi materijali koji se koriste u proizvodnji mobilnih telefona - metali, plastika, baterije i ambalaža - mogu se ponovo preraditi i reciklirati u nove proizvode.
Ova studija daje pregled tehnologija reciklaže otpadnih mobilnih telefona i, kroz studiju slučaja, ispituje mogućnosti izdvajanja vrednih metala iz otpadnih telefona primenom kiselinskog luženja. Proces obuhvata demontažu otpadnih mobilnih telefona, predtretman radi razdvajanja materijala i njihovo usmeravanje ka završnim procesima obrade. U eksperimentima luženja korišćene su sumporna, azotna i hlorovodonična kiselina. U eksperimentima sa sumpornom kiselinom ispitivani su uticaji koncentracije kiseline, temperature, dodatka peroksida i vremena luženja na efikasnost rastvaranja metala. Postignute efikasnosti luženja iznosile su: 97,9 % Fe u 8 mola H_2SO_4, 88 % Pb, 100 % Ni, 90,4 % Co i 4,1 % Cu u rastvorima 1 mol HNO_3, te 100 % Pb i 100 % Al u 4 mola HCl, sve u roku od jednog sata. Stoga se za efikasno luženje svih metala preporučuje primena sekvencijalnog procesa luženja upotrebom različitih kiselina.