

STUDY OF METALS DISSOLUTION FROM A BRAND OF MOBILE PHONE WASTE

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Abstract

This work constitutes the first part of activities being carried out within the context of beneficiation of valuable metals from a brand of spent mobile phones by leaching process in laboratory scale. The printed circuit board of the mobile phone was employed in this study. The effects of parameters such as acid concentration, particle size and temperature on the leaching efficiency at different time intervals were investigated. With 4M HCl solution about 87.4% was dissolved within 120 minutes at a temperature of 80°C using 300rpm and a particle size of about 0.1mm. Finally, the results of this investigation showed that the rate of dissolution of the spent powdered cell phone was found to depend on the hydrogen ion concentration, the system temperature and particle diameter.

Key words: hydrometallurgy, electronic waste, hydrochloric acid

Introduction

There has been a phenomenal growth in the information and communication technologies sector in Nigeria since 2001. Presently, a greater number of Nigerians have access to mobile telephone and mobile phone is now playing huge role in the development of the nation's economy [1]. Fast electronic industry development brought the great benefits in everyday life, but its consequences are usually ignored or even unknown. Used electronic equipment became one of the fastest growing waste streams in the world. From 20 to 50 million tones of waste electrical and electronic equipment (e-waste) are generated each year, bringing significant risks to human health and the environment [2]. The major source of e-waste is the disposal of the hardware and electronic items from Government offices, public and private sectors, academic and research institutes. Household consumers are also contributing significant volume of end-of-life electronic products [3].

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Recycling, a significant factor in the supply of many of the metals provide environmental benefits such as energy savings, reduced volumes of waste and reduced emissions associated with energy savings. In addition, recycling reduces the amount of virgin metals that must be mined [4]. Currently, the majority of electronic waste is disposed in a landfill. The remainder is either processed in an energy inefficient manor, where only small amounts of the available metals are recovered. This is a problem for a number of reasons [5, 6]:

- (i) Electronic waste contains high concentration of heavy metals, brominated flame retardants and other plastic additives that have proven adverse effects on humans.
- (ii) This waste contains recoverable trace amounts of precious metals, and larger quantities of a variety of other metals and alloys, especially copper, and steel.
- (iii) The volume of electronic waste produced is high and growing fast.
- (iv) Discarding recoverable metals is energy sufficient. The energy savings possible by recoverable metals are high when compared to mining new material. The energy savings for copper 85%, steel 74%, lead 65%, and zinc 60%. Recovering other materials such as paper and plastics can reduce energy usages by 64% and 80%, respectively.

However, the sizes of mobile phones are small and so the quantity of metals contained in each cell phone is also small. When many phones become obsolete, however, the quantity and value of the metals contained in those phones become significant. Table 1 shows the market value of the metals recovered from 1000kg of printed circuit boards (PCBs).

Table 1: Market value of the metals recovered from 1000kg PCB[3].

Recovered Metal	Weight	Approximate cost (US \$)
Gold	297.93g	6115 (@685.00 per 31g)
Precious metals (Pt, Pd,...)	93.31g	3852 (@1284.00 per 31g)
Copper	190.512kg	1470 (@3.50 per 453.59g)
Aluminium	145.152kg	448 (@1.28 per 453.59g)
Lead	30.844kg	144.16 (@2.12 per 453.59g)
Silver	450.00g	213.15 (@14.70 per 31g)

Very little work has been done in this area of study. Closest to these are the works reported by Nnorom and Osibanjo [1], Kamberovic, et al [7] and Gramatyka, et al [8] to mention but a few. These authors characterized and proposed some hydrometallurgical scheme for some metal recovery from used electronic wastes. Consequently, the hydrometallurgical approach recovery of metals is still being carried out in some developed countries as a result of their concentration on the value added technology. A proposed approach for the recovery of metals from mobile phone is presented in Fig. 1.

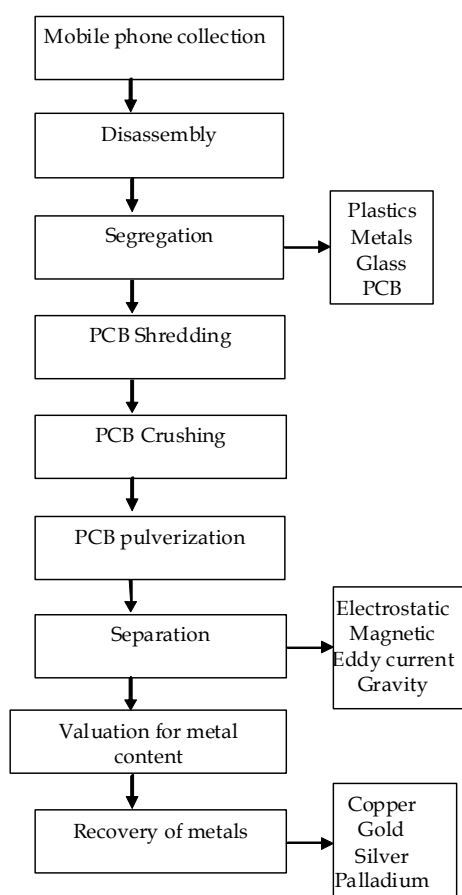


Fig.1 Proposed metal recovery approach from mobile phone [3]

The existing and potential technologies that might be used for the metal recycling from PCBs include mechanical processing, pyrometallurgy, hydrometallurgy, biohydrometallurgy or a combination of these techniques [9]. Of these techniques, hydrometallurgical approach is often used due to energy efficient and flexible to a variation in the metal contents [10].

Thus, hydrometallurgy processing consists of leaching – transferring desirable components into solution using acids or halides as leaching agents, purification of the leached solution to remove impurities by solvent extraction, adsorption or ion-exchange, then recovery of the metals from the solution by electrorefining process, chemical reduction or crystallization. The most efficient leaching agents are acids, due to their ability to leach both base and precious metals [11]. Therefore, this present aspect of study is to establish the leaching parameters that will favour the operational conditions for subsequent metal ion beneficiation from the spent mobile phone.

Experimental

Materials

A particular brand of mobile phone used for this study was collected from a mobile phone repair workshop in Ilorin, Nigeria. The reagent used for this research work is hydrochloric acid (BDH product).

Method

Physical and chemical methods were employed during the study. The physical process involved the loosening of the plastic casing and the display screen with the aid of a screw-driver after which the keypads and other parts were disassembled. The electronic circuitry, that is, the printed circuit board (panel) which was held by a Vice and was reduced to the following sized fractions: $0.09 < x < 0.15$, $0.15 < x < 0.25$ and $0.25 < x < 0.35$ mm by a filer. The $0.09 < x < 0.15$ mm sized fraction was then retained for subsequent studies by Inductively Coupled Plasma-Mass Spectrometer (ICP-MS), Yokogawa model HP-4500 and X-ray diffractometer (XRD, PHILIPS Scientific) for the elemental and phase characterization, respectively.

The leaching which is the chemical process employed during the study was done using hydrochloric acid. A 0.5g of the sample was put into 100ml of 0.5M HCl and the magnetic stirrer was introduced into the beaker containing the sample mixture on the Bibby Stuart hotplate. The sample mixture was then heated at a temperature of 55°C and stirred at a rate of 300rpm.

The same procedure was repeated for other concentrations of HCl: 1M, 2M, and 4M. Each concentration of HCl was contacted with 0.5g of the powdered cell phone sample for 10, 30, 60 and 120 min respectively.

At the end of the leaching process for a given contact time, the mixture was allowed to cool and filtered using a Whatmann filter paper and then oven dried at 60°C for about 12 hours and was then reweighed. The percentage of sample dissolved was calculated from the initial difference in mass, (m_i), amount dissolved or undissolved, (m_f), at different time intervals after oven-drying at 60°C using the relation [12]: $\alpha = \frac{m_i - m_f}{m_i}$. This calculation was done for all concentrations of HCl investigated. The concentration which gave the highest percentage of dissolution (4M) was used for the optimization of other parameters such as temperature and particle size [13]. The residue at the optimal conditions was also subjected to X-ray diffraction analysis.

Results

Result of the Elemental and Phase analysis of spent cell phone-3510 by ICP-MS and XRD

Elemental Composition by ICP-MS

The elemental analysis of the spent cell phone was done by Inductively coupled plasma-mass spectrometry (ICP-MS) and the result is as shown in Table 2.

Table 2: Elemental composition of the powdered Nokia sample by ICP-MS

Element	Ni	Pb	Ag	Cd	Fe	Sn	Cu	Mo	V	Sb	La
Conc., %	33.41	11.36	7.26	5.23	4.36	2.73	0.187	0.0367	0.0186	0.00185	<0.0005

Oxygen (O) = 34.41%, obtained by difference.

It is seen from Table 2 that the major elements present in the sample are Ni, Pb, Ag, Cd, Fe, and Sn, the minor elements is Cu while Mo, V, Sb, and La occur in traces. The remaining 34.41% obtained by difference represents the oxygen and the plastics materials possibly present in the sample. It is important to remark the high level of highly toxic metals such as Pb and Cd in the cell phone. However, the composition of electronic waste differs significantly due to the nature of the composite sample. For instance, remarkable proportion of some metals such as Cu, Ag, Sb, etc may be a representative material in printed circuit boards as reported by Ogunniyi, et al [14]. This variation may be as a result of the large assortment of populated eol printed circuit boards from the PCs, cell phones and switchboards.

Phase Characterization by X-ray Diffraction

The result of the phase characterization by XRD of the spent composite sample is presented in Fig. 2

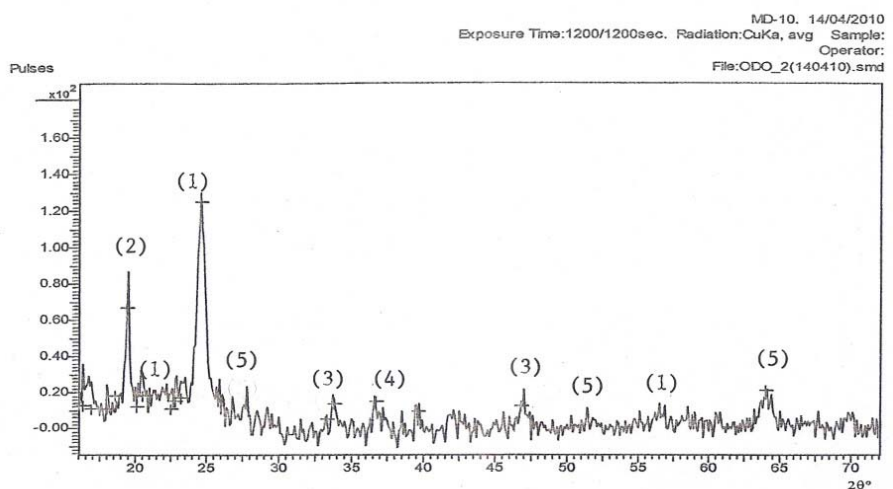


Fig. 2. The XRD pattern of the spent cell phone 3510 with compounds identified. (1) $\text{NiSO}_4 \cdot \text{H}_2\text{O}$ (dwornikite) {21-0974}, (2) PbSO_4 (anglesite) {36-1523}, (3) Fe_7S_8 (pyrrhotite) {24-0079}, (4) Mn_5O_8 (manganese oxide) {39-1218}, (5) SiO_2 (quartz) {40-1498}. Joint committee on powder diffraction standard (JCPDS) file numbers are put in curl brackets

It is evident from Fig. 2 that the predominant compound identified by XRD is Nickel sulphate hydrate, called Dwornikite ($\text{NiSO}_4 \cdot \text{H}_2\text{O}$). Other compounds identified include PbSO_4 , Fe_7S_8 , Mn_5O_8 and α -quartz. These lend support to elemental analysis by ICP-MS.

Leaching Studies

Effect of Concentration of Hydrochloric acid (HCl)

The effect of HCl concentration on the rate of the powdered cell phone sample dissolved was examined. The result of fraction of the sample dissolved was plotted against the contact time at various concentrations of HCl as shown in Fig. 3.

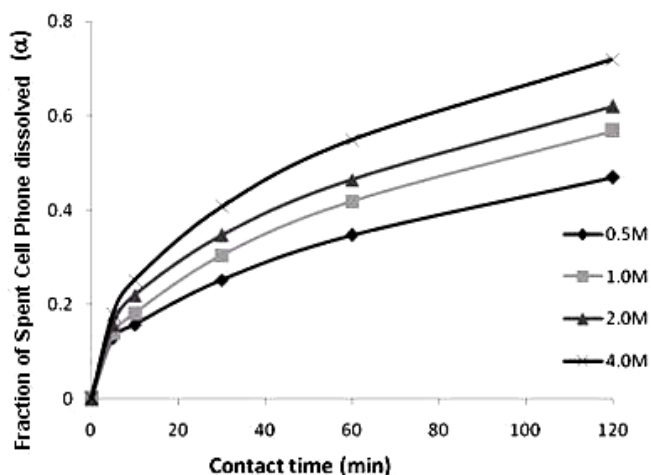


Fig. 3: Plot of α vs contact time at different HCL concentrations

From Fig. 3, it shows that increase in concentration of HCl is accompanied by an increase in the amount of the powdered cell phone sample dissolved at various time. Consequently, the concentration of the leachant has a significant effect on the leaching of the cell phone powdered sample.

Effect of Temperature

The effect of temperature on the rate of dissolution of the powdered cell phone sample was also examined. The range of temperature used was 28°C – 80°C at different contact time. The fraction of the sample dissolved at the various temperatures and their corresponding contact time of leaching is presented in Fig. 4.

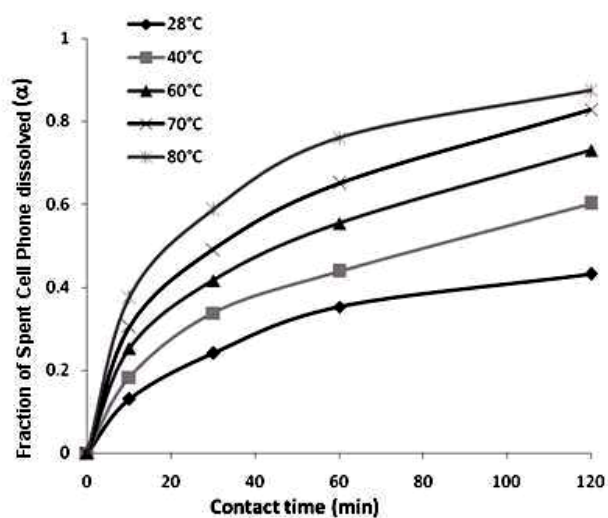


Fig. 4: Plot of α vs contact time at different temperatures

As seen from Fig. 4, an increase in temperature brings about a great increase in the reaction rate which then leads to increase in the amount of sample dissolved.

Effect of Particle Diameter

Investigation was also done to see the effect of particle diameter of the sample on the dissolution rate. The particle sizes used were $0.09 < x < 0.15$ mm, $0.15 < x < 0.25$ mm and $0.25 < x < 0.35$ mm. The result of this finding is presented in Table 3.

Table 3: Results of the effect of particle size on the filed cell phone sample dissolution

Particle size, r_0 (mm)	Amount of sample dissolved (%)
$0.09 < x < 0.15$	87.4
$0.15 < x < 0.25$	55.6
$0.25 < x < 0.35$	33.6

From Table 3, it is apparent that the fraction with the smallest particle size has the highest quantity of the powdered cell phone sample being dissolved. This is probably due to the highest surface area of the smallest particle size fraction.

Discussion

Evaluation of Post-leached residue at optimum conditions:

The XRD analysis of the reaction products obtained from the leaching experiment at 80°C (Fig. 5), showed that the residue (12.6% of the initial sample) left unreacted may be composed of α -quartz (SiO_2) and other minor impurities. It is important to note the near absence of metals such as Ni, Pb, Ag, Cd, Fe and Sn in the residual product.

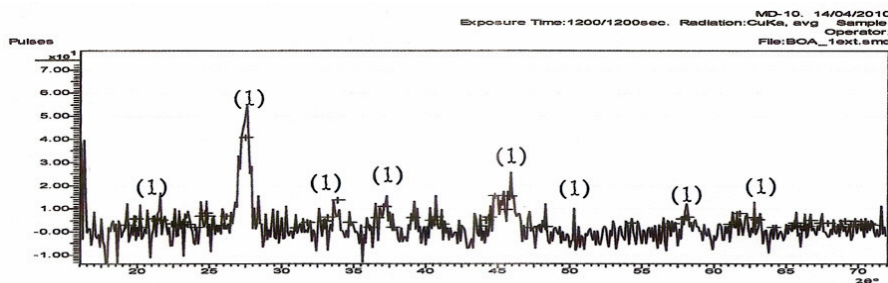


Fig. 5: X-ray diffraction data of the post leached residue at optimum condition

Conclusions

This study has shown that the spent cell phone is amenable to hydrometallurgical treatment by hydrochloric acid leaching. The rate of dissolution of the spent powdered cell phone sample was found to depend on the hydrogen ion concentration, the system temperature and the particle diameter. With 4M HCl solution, about 87.4% of the powdered cell phone-3510 sample was dissolved within 120 minutes at a temperature of 80°C using 300rpm by $0.09 < x < 0.15$ mm sized fraction.

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