International Journal of Modern Chemistry, 2019, 11(1): 73-81

International Journal of Modern Chemistry

ISSN: 2165-0128

Journal homepage:www.ModernScientificPress.com/Journals/IJMChem.aspx

Florida, USA

Article

Assessment of Heavy Metals Concentration in Batteries and Printed Circuit Boards of End-of-Life Rechargeable Lamps

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Article history: Received 15 May 2019, Revised 23 June 2019, Accepted 13 July 2019, Published 31 October 2019

Abstract: Rechargeable lamps are being used as alternatives to poor state of power in Nigeria and this has made them to be serious environmental pollutants of concern owing to their short lifespan, poor management and indiscriminate disposal at the end of their usage by the consumers. This study is aimed at finding out the concentrations of selected heavy metals in the batteries and printed circuit boards of 34 end-of-life rechargeable lamps sampled from Aba, Abia state Nigeria. Lead(Pb) and copper(Cu) were analyzed for in the printed circuit boards while cadmium(Cd), nickel(Ni) and lead(Pb) were analyzed for in the batteries. The results of this study showed that the concentration of lead and copper in the batteries and PCBs exceeded the Toxicity Threshold Limit Concentration (TTLC) while cadmium and nickel were below detection limit. The rechargeable lamps from the results of this studycontain heavy metals and pose potential risks to the environment hence; recycling method should be adopted rather than disposing these end-of-life rechargeable lamps in the environment since they are non-biodegradable.

Keywords: Heavy metals, rechargeable lamps, batteries, printed circuit boards.

1. Introduction

Since the last two decades, waste electrical electronic equipment otherwise called electronic waste (e-waste) has been marked as the fastest-growing stream of solid-wastes. This is due to the presence of small consumer electronic products, such as handsets and rechargeable lamps in countries with economies in transition. (Widmer*et al*., 2005).

Short useful life-span, portability, inadequate management policies, and high costs of recycling have resulted in the indiscriminate disposal of these appliances without much concern for their adverse effects on the environment and living things. These adverse effects occur throughout the life cycle of the products - from acquisition of raw materials (Hayes *et al.*, 2003), manufacturing and to disposal at the end of their useful life.

This is especially worrisome in developing nations of West Africa especially Nigeria, which in recent years have become one major destination for obsolete or near-end-of-life electrical and electronic equipment (EEEs) worldwide (Basel Action Network, BAN 2005).

Rechargeable lamps in recent years, have replaced the disposable battery torches which were originally used. This is mainly due to the fact that the disposable battery torches provided only about 2% of the energy used in their production. In other words, they were energy inefficient; again after they have been used, they could not be recharged, hence they were disposed of, and constituted a big pollution problem (Nnorom and Osibanjo, 2009).

Over the years and most recently, there have been concerns that toxic substances commonly leach from these devices when disposed (White et al., 2003) indiscriminately into the environment.

This research is aimed at finding out the level of heavy metals concentration in these EoL rechargeable lamps and the appropriate measures to be taken in order to minimize the threats posed by these heavy metals to man and his environment as it was been argued that the carrying capacity of the earth is significantly smaller than the demands placed on it by large numbers of human populations (Gray, 2011).

2. Materials and Methods

2.1. Sample Collection and Preservation

Different types of used rechargeable lamps otherwise called EoL rechargeable lamps were randomly sampled with the main purpose of determining the levels of heavy metals in their PCBs and batteries; and FAAS instrumental method was used for the analysis. Different simple hand tools were used for the dismantling of the EoL rechargeable lamps while taking precautions to avoid cross contamination of the samples. Out of the many EoL rechargeable lamps that were sampled for this study, 34 were selected to be analyzed and this selection was based on the simple fact that all the two components of interest-battery and PCB were present. They were transported to the laboratory for preparation and analysis.

2.2. Sample Preparation

In the laboratory (lab), the thirty four (34) EoL rechargeable lamps were selected and sorted according to colour, type, name of manufacturer and country of manufacture. They were legibly and appropriately labeled and weighed with analytical balance. The weights were recorded against each of them in the record book and the lamps were individually dismantled with stainless screw drivers, a pair of pliers and a hammer into different components of plastic casings, printed circuit boards (PCBs), batteries and others (glass, wire, metals).

2.3. Grinding and Milling

PCBs: The PCBs were crushed with a ceramic mortar and pestle to particles small enough to pass through a 2.0 mm sieve. The mortar and pestle were cleaned each time a sample was pounded with a serviette to avoid cross contamination and the pounded samples were stored in polyethylene bags prior to acid digestion.

Batteries: The casings of the batteries were carefully opened using stainless screw drivers and the battery electrodes were removed and manually crushed and stored in polyethylene bags prior to acid digestion.

2.4. Preparation of Reagents

Aqua Regia (3:1, v/v HCl: HNO_3) (ISO Standard 11466)

Accurately, 300 mL concentrated HCl was dispensed from the stock bottle into a 500 mL measuring cylinder. Another measuring cylinder was used to dispense 100 mL concentrated HNO_3 and both were prepared each time previously prepared solution was exhausted.

1:1 HNO_3 (250 mL H_20:250 mL HNO_3)

Accurately 250 mL of DDW water was measured into a 500 mL standard flask standard flask and 250 mL of concentrated HNO_3 gradually added into it.

2.5. Digestion of Prepared Samples

Aqua regia method involving two strongly concentrated acids HCl and HNO_3 in the ratio of 3:1 was used as the digestion reagent.

2.5.1. PCBs

1.0 g each of the 34 samples was weighed on the analytical balance and quantitatively transferred into the appropriately labeled digestion vessels and 10 mL of the prepared aqua regia (ISO Standard 11466) reagent was added and the digestion vessels were well stoppered and then heated for two hours on a water bathe. After the digestion was completed, the digestion vessels were removed and allowed to cool. The contents were filtered into a 50 mL beaker and made up to mark and the solutions were transferred into plastic sample bottles prior to FAAS analysis.

2.5.2. Batteries

0.5 g each of the 34 sieved samples was weighed directly into the digestion vessels and 10mL of the aqua regia (ISO Standard 11466) reagent was added to each of the digestion vessels and then heated for two hours on a water bathe. The digestion process was properly monitored and after digestion was completed, the digestion vessels were removed, allowed to cool and then filtered into a 100 mL standard flask and made up to mark. The solutions were then transferred into plastic sample bottles prior to FAAs analysis.

2.5.3. Blank

10 ml of the same aqua regia (ISO Standard 11466) reagent used for the digestion of the PCB and battery samples was measured into a digestion vessel without any sample and heated for two hours. The solution was allowed to cool, filtered into a 25 mL standard flask and made up to mark and this was transferred into a plastic sample bottle for onward analysis by FAAS.

Prior to instrumental analysis, the sample digests were spiked with some drops of conc. HNO_3 using a 20 mL pipette. This was to prevent the diminishing of the analytes of interest in the solution through leaching into the sample containers.

2.6. Sample Analysis

The prepared sample digests were analyzed at the department of Chemistry, University of Ibadan using the Buck 205 flame atomic absorption spectrophotometer (Koirtyohann, 1991).

3. Results and Discussion

Table 1 shows the results obtained for Cu and Pb in the 34 samples analyzed. The concentrations of Cu and Pb were high in the individual samples and the values far exceeded the Toxicity Threshold

Limit Concentration (TTLC) which is the standard set by the California Department of Toxic Substances Control (DTSC).

Typical motherboards (PCBs) of electrical electronic equipment (EEE) have been reported to contain approximately 50 g/m^2 of lead (Five Winds International, 2001); and it is believed that low-level metal exposure contributes towards the high cases of chronic diseases and impaired functioning of major organs far from what was previously believed (ATSDR, 2005).

Table 1: Concentration in (mg/kg) of the Cu and Pb in the PCBs

S/N	Code	Cu	Pb
1	HT1	28506.00	62206.50
2	HT2	48215.50	62066.50
3	HT3	79507.00	60515.50
4	HT4	52007.00	37113.00
5	HT5	36009.00	60501.50
6	HT6	56005.50	59162.50
7	HT7	75712.50	59344.00
8	HT8	74511.50	57819.00
9	HT9	78553.00	43781.50
10	HT10	70114.00	56613.00
11	HT11	44013.50	42882.50
12	HT12	42051.50	43806.50
13	HT13	33064.50	26208.00
14	HT14	62309.50	47245.50
15	HT15	72158.50	45551.50
16	HT16	37505.50	56095.00
17	HT17	40065.50	60228.00
18	HT18	64158.00	31728.00
19	HT19	39717.00	41211.00
20	HT20	899305.0	48719.00
21	HT21	58572.50	57163.00
22	DL1	64326.50	41211.00
23	DL2	114551.50	44965.00
24	DL3	115514.00	55154.50

25	HT22	123009.00	56914.50
26	DL4	169509.50	56508.50
27	DL5	29061.00	47311.00
28	DL6	39637.50	39274.00
29	DL7	6005.50	50602.50
30	DL8	61000.50	65156.00
31	HT23	63007.00	55607.50
32	HT24	111002.0	48427.00
33	HT25	90501.50	56357.50
34	HT26	87006.50	62313.50
35	**Mean**	**92241.00**	**51169.51**
36	**SD**	**143.7800**	**9449.160**
37	**Range**	**89.93-28506**	**65156-26208**
38	**TTLC**	**2500**	**1000**
39	**N>TTLC**	**34**	**34**

Table 2 shows that the concentrations of Cd in 23 samples and Ni in all the 34 samples were below the instrument detection limit (IDL) of 0.06 mg/L; while lead had high concentrations above the (TTLC) in all the 34 samples.The toxicity of metals most commonly involves the brain and kidney but some other complications may arise. Metals such as lead, depending on the dose, in children and adults is capable of causing coma, renal failure and even death (ATSDR, 1999). Cadmium exposure causes respiratory irritation, lung cancer as well as testicular degeneration (Morals et al., 2000). In particular, the loss of calcium caused by cadmium effect on the kidney can be severe enough to lead to weakening of bones as well the ease with Itai-itai disease-an epidermic of bone fractures in Japan from gross cadmium contamination of rice stocks. This has recently been shown to happen in more subtle fashion among a general community living in an area of relatively modest cadmium contamination (Jamp et al.,2000). Acute symptoms of copper exposure/poisoning include vomiting, hematemesis, hypotension, coma, melena, jaundice and gastrointestinal distress while the chronic effects damage the liver and kidneys (Environmental fact sheet, 2005). Nickel is one of many carcinogenic metals known to be an environmental and occupational pollutant. The New Forth University School of Medicine warns that chronic exposure to nickel has been limited to increased risk of lung cancer, cardiovascular disease, neurological deficits, developmental deficits in children and high blood pressure (Chervona et al., 2012).

Table 2: Concentration in (mg/kg) of Cd, Ni, and Pb in the Batteries

Code	**Cd**	**Ni**	**Pb**
HT1	0.35	BDL	294122
HT2	BDL	BDL	281840
HT3	0.25	BDL	344730
HT4	0.42	BDL	304293
HT5	0.28	BDL	370928
HT6	0.42	BDL	325154
HT7	0.46	BDL	323120
HT8	0.34	BDL	319970
HT9	0.28	BDL	290536
HT10	0.01	BDL	298952
HT11	BDL	BDL	371110
HT12	BDL	BDL	339936
HT13	BDL	BDL	308132
HT14	BDL	BDL	322494
HT15	BDL	BDL	325280
HT16	BDL	BDL	300294
HT17	BDL	BDL	300914
HT18	BDL	BDL	306504
HT19	BDL	BDL	309388
HT20	BDL	BDL	289864
HT21	BDL	BDL	277998
DL1	BDL	BDL	315372
DL2	BDL	BDL	333298
DL3	BDL	BDL	313148
HT22	BDL	BDL	328734
DL4	BDL	BDL	276152
DL5	BDL	BDL	307092
DL6	0.02	BDL	330712
DL7	BDL	BDL	281394
DL8	BDL	BDL	311966
HT23	0.01	BDL	291126

HT24	BDL	BDL	287944
HT25	BDL	BDL	314922
HT26	BDL	BDL	301670
Mean	**0.26**	**-----**	**311737.91**
SD	**0.16**	**-----**	**22888.60**
Range	**0.46-0.01**	**----**	**37110-276152**
TTLC	**100**	**2000**	**1000**
N>TTLC	**Nil**	**Nil**	**34**

4. Conclusion

The battery and PCB components of EoL rechargeable lamps are potential toxic substances since the concentrations of lead, (Pb) and copper, (Cu) far exceeded the TTLC limits of 1000 mg/kg for Pb and 2500 mg/kg for Cu respectively set by DTSC. Therefore, there is an urgent need to control the rate of indiscriminate disposal of this equipment into the environment by the users. Policies like the Polluter Pays Principle (PPP) and the Extended Producer Responsibility (EPR) should be strengthened and fully enforced to ensure full compliance by the manufacturers.

Potential Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgments

My sincere appreciation goes to Gilbert U., Adie (PhD), for finding time to supervise this work. I also wish to thank the Department of Chemistry, University of Ibadan for giving us the space to undertake this research; and to all other colleagues and friends particularly Mr. Agwupuye John who worked tirelessly to see to the success of this work, your supports are highly appreciated.

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