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Managing Hazardous Wastes in Africa: Recyclability of Lead from E-waste Materials

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Abstract: Adaptation of the Information Communications Technologies (ICTs) is growing in many African countries determined to access the global market system driven by ICTs. As a result of high poverty level in Africa, however, the consumption of ICTs is concentrated on the inferior and used components, which soon become unserviceable and abandoned. Along with the hazardous chemical substances contained in them in significant quantity they are often discarded improperly. Moreso, as the continent weak in environmental regulation. This practice contributes to health and environmental hazards and unsustainable development. There is the need to reclaim and/or recycle components e-wastes growing in quantity in Africa. This study extracted lead from e-waste materials and converted it to an industrial good, lead (II) oxide, for recycling to the industry. Among the commonly used chemical reactor materials (metals, copper, iron, zinc, alloys glass and plastic) the metals were considered unsuitable as reactor materials on account of interfering reactions. Glass was also considered inadvisable on account of breakages and the attendant wastes while plastic (PVC) material was considered best for chemical extraction and recycling process of lead from e-waste materials. It is recommended that e-waste materials containing lead should be recovered and separated for hand-dismantling and mechanical extraction of old solder (lead) by use of soldering iron. The lead-extract should be treated in plastic (PVC) reactors to get lead (II) oxide for recycling to the industry. Also, policy should be put in place for the necessary regulation and management of e-wastes and recycling of lead from them.

Key words: Hazardous chemical components of e-wastes, lead, extraction, recycling

INTRODUCTION

Electronic waste (e-waste), also known as “e-scrap” or “Waste Electrical and Electronic Equipment” (WEEE), refers to loosely discarded surplus, obsolete, broken electrical or electronic devices (ITA, 2009). Rapid technology change, low initial cost and even planned obsolescence have resulted in a fast growing problem of increasing e-waste generation around the globe. About 50 million tons of e-wastes are generated worldwide each year. Increasing at a rate of 3-5% per year (faster than any other category of waste) the global volume of e-wastes produced annually is soon expected to double. The volume of e-wastes being generated grossly outweighs the existing capacity to manage it in an environmentally sustainable way (Walraven, 2007).

Much of the 20-50 million tons of e-wastes produced annually is shipped to developing countries with little or no sufficient legal human and technological capacity to handle them. Due to poverty pervading the continent, many African countries also import e-wastes in form of sec-hand and inferior ICTs products, which soon outlive their usefulness and are discarded as unserviceable materials. Since, regulatory infrastructure are weak in the continent, these wastes are dumped or incinerated in ways that are unhealthy and harmful to both humans and the environment (Nkamnebe, 2010).

Lack of waste management infrastructure and poor handling of e-waste are the lot of Africa where “Much ICT waste is not recycled”. When no longer needed, the majority of e-wastes materials are just dumped not reclaimed or recycled. To dispose of these materials the local government authorities and companies dump them in open fields near residences without any form of cover, or at ‘best’ incinerate them. In some cases, they are used in filling construction pits. This would appear to be most economical and convenient in the short run but poses serious health and environmental danger in the long run both on the people and the environment, because “toxic chemicals in (ICT) electronic products can leach into the

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land over time or are released in the atmosphere, impacting nearby communities and the environment" (Forge, 2007; Eneh and Agbazue, 2011; Tukura *et al.*, 2011; Alslaibi *et al.*, 2011; Uzoije and Agunwamba, 2011; Rajaganapathy *et al.*, 2011). Agreeing with this finding, Toby (1998) reports that e-waste disposal in landfills cause severe human and environmental health impacts. Plastics in electronics (commonly littered in collection points for days before they are actually collected) easily leach off in hot weather, especially when left outside.

People toss e-waste equipment into an open fire in order to melt plastics and to burn away invaluable metals. This practice obtains in sub-Saharan Africa as a method of processing and handling e-wastes. The process of burning e-wastes releases carcinogens and neurotoxins into the air, contributing to acrid, lingering smog and the attendant pollution, harm and waste. These noxious fumes include dioxin and furans, which largely consist of incineration residues or waste placed in landfill sites coming from households offices and commercial activities and may contain toxic or hazardous materials. The uncontrolled burning, disassembly, and disposal of e-wastes in Nigeria cause a variety of environmental problems such as ground water contamination atmospheric pollution and water pollution either by immediate discharge or due to surface run-off (especially near coastal areas).

Slade (2006) reported that bonfire refuse and other e-wastes are discarded into drainage ditches or water ways that feed the ocean or local water supplies in Nigeria and other countries. They not only contaminate water bodies but also results to blockage of drainages, leading to flooding, destroying lives and properties within flooded areas causing diseases and economic wastes.

With the growing population of Africa ICTs consumers will continue to grow thereby heightening the danger posed by e-wastes generation. Also, the globalisation trend and business opportunities in Africa have combined to increase the number of global organizations doing business in the continent. These organizations contribute to the growth in ICTs culture and the attendant increase in e-wastes generation in the continent. Already, mountains of these wastes are spotted in major ICTs trading centres in the continent, such as The Computer Village in Lagos, Nigeria (Eneh, 2011b, c).

Electrical Electronic Equipment (EEE) contain about 38 separate chemical substances or elements. These chemical components are classified according to their quantities in EEE and as hazardous or non-hazardous. Accordingly, lead is not only hazardous but also found in significant quantity in EEE. Emission of toxic lead from abounding e-waste materials constitutes health hazards for the people through inhalation of the polluted air. While legislations are used in the developed countries to control and manage e-wastes Africa lacks the capacity for such enforcement, as even some multinationals that contribute to the environmental degradation are more powerful than some African countries (Eneh, 2011a, d; Murali, 2009).

The environmental significance of e-wastes calls for more research and policy on recycling and reclamation of e-waste components in Africa. This study therefore, investigated the mechanical extraction and chemical recycling of lead from e-waste materials. It sought to identify extraction and treatment methods to obtain industrial goods from lead-extract from e-waste materials and to consider the best of compatible reactor materials for the recycling process.

MATERIALS AND METHODS

Materials: Materials used in the study carried out from June 2010 to March 2011 were e-waste items, analytical reagent chemicals and laboratory equipment. E-waste materials (containing lead) were collected from vendors of ICTs spare-parts and ICTs repairers in C-To-C Business Plaza, Nkpokiti Street, Enugu, Nigeria. All chemicals (analytical reagent grade) and laboratory wares and equipment were obtained from the laboratory of the Department of Medical Laboratory Sciences, Faculty of Health Sciences and Technology, College of Medicine, Enugu Campus, University of Nigeria, Nsukka.

Methods: E-waste processing usually first involves recovery of the items from consumers and services providers. The equipment are dismantled into various parts (metal frames, power supplies, circuit boards, plastics) often by hand. This enables recognition of working and repairable parts, including chips, transistors, RAM etc. The alternative process obtained in technologically advanced countries is the bulk system practice involving sophisticated machines (shredders, separators, screens and granulators). Metal and plastic fractions are obtained sold to smelters or plastic recyclers. Magnets, eddy currents and trammel screens are employed to separate glass, plastic and ferrous and non-ferrous metals, which can be further separated at a smelter. Leaded glass from CRTs is reused in car batteries, ammunition and lead wheel weights, or sold to foundries as a fluxing agent in processing raw lead ore. Copper, gold palladium, silver and tin are valuable metals sol to smelters for recycling. Hazardous smoke and gases are captured, contained and treated to mitigate environmental threat (Walraven, 2007).

Lead is applied in electrical and electronic devices as old solder, CRT monitor glass, lead-acid batteries and some formulations of PVCs. The e-waste items were first hand-dismantled into various parts (metal frames, power supplies, circuit boards, plastics). The parts containing old solder (lead) were mechanically separated and lead was mechanically extracted from them by use of soldering iron. The CRT monitor glass and lead-acid batteries were recycled intact (as practiced in developed countries).

Reactions and characterization of lead-extract from e-wastes and its product: Common chemical reactions and physical properties of lead were used to characterise the lead-extract from the e-waste materials and its products. To this end, 800 mL of dilute trioxonitrate(V) acid was added to 100 g of the lead-extract from e-waste in 2 L glass beaker. The reactants were heated until insoluble solid stopped forming. The solid product was obtained by filtration and dried overnight in Gallenkamp oven at 120°C. The product was inspected for colour to see if it tallied with lead (II) oxide colour in the literature.

The solubility of the product in water was tested by mixing 223 g of the solid product with 250 mL distilled deionized water in 1 L conical flask which was then shaken in an electric shaker for 2 h. The solid was filtered out, dried in Gallenkamp oven at 120°C and reweighed to ascertain its solubility or otherwise in water (Ogbuanu, 2005).

The melting point apparatus was used to determine the melting point of the solid obtained in order to compare it with the literature value.

Consideration of suitable reactor material for recycling of lead from e-wastes: In consideration of cost-effectiveness, availability and inertness with reactants and stability in the conditions of the reactions, metallic materials commonly used for fabrication of chemical reactors are metals: copper, iron, zinc and alloys (Ohia *et al*., 2005). Other materials used for construction of chemical reactors are glass and plastic materials (Shreve and Brink, 1977). These materials were considered for suitability for the chemical reactor for recycling of lead-extract from e-waste materials which involved lead and dilute trioxonitrate (V) acid, as reactants and lead (II) trioxonitrate (V), nitrogen (II) oxide, lead (II) oxide, nitrogen (IV) oxide and oxygen as products.

RESULTS AND DISCUSSION

Production and caharacterisation of lead(II) oxide from e-wastes: Treatment of lead extract with dilute trioxonitrate (V) acid led to the release of gas and the formation of an insoluble solid which decripitated and decomposed on heating. The gas was suspected to be nitrogen (II) oxide, NO, while the resulting solid product was light yellow, insoluble in water and melted at 886.01°C.

This was in agreement with the report of Ababio (2005) that lead reacts with dilute trioxonitrate (V) acid to yield lead (II) trioxonitrate (V) and nitrogen (II) oxide, as shown in the chemical equation below.

The nitrogen (II) oxide, NO, went off as gas in the open reactor, while the lead (II) trioxonitrate (V) decripitated and decomposed on heating to lead (II) oxide, nitrogen (IV) oxide and oxygen.

Again, both nitrogen (IV) oxide and oxygen went off as gases, leaving lead (II) oxide as solid product. Daintith, (2000) reports that lead (II) oxide is light yellow insoluble in water and melts at 886°C. The solid product was therefore, confirmed to be lead (II) oxide.

Recycling of lead (II) oxide: Lead (II) oxide is required in the industry for making lead accumulators and lead glass and as drier in paints, varnishes and glazes, among others (Ababio, 2005; Daintith, 2000; Kneen *et al*., 1972). Recycling the lead(II) oxide product obtained from the lead-extract from e-wase materials to the industry will reduce the environmental pollution from toxic lead contained in significant quantity in e-waste materials.

The recycling is necessary because according to Woolf *et al.* (2007) lead is a very strong poison. When lead dust is inhaled some of the poison can stay in the body and cause serious health problems. Worse still it is more common for lead poisoning to build up slowly over time from repeated exposure to small amounts of lead in which case, there will be no obvious symptoms. Again, low levels of lead exposure can harm a child's mental development. Over 10 mg per deciliter is a definite concern.

Exposure to lead through occupational means or hobbies constiues the highest risk of predisposing individuals to lead poisoning. In adults, lead can increase blood pressure and can cause digestive problems kidney damage, nerve disorders, sleep problems, muscle and joint pain and mood changes. Foetuses and children up to six years of age are considered the at-risk age group for lead poisoning because young children, infants and foetuses absorb lead more readily than adults. And a small amount of lead that may have little effect on an adult can have disastrous consequences on a child. The presence of lead dust can cause difficulties during pregnancy because lead enters the bloodstream and can pass the placental barrier from the mother to the unborn child, thereby poisoning the foetus before birth.

Classification of the consequences of lead poisoning by toxicity levels has shown decreased learning decreased verbal abilit, early signs of Attention-Deficit Hyperactivity Disorder (ADHD) and low Intelligence Quotient (IQ) as general effects. Mild toxicity produces abdominal discomfort, lethargy, mild fatigue, myalgia and paresthesia. Moderate toxicity produces constipation, irritability, difficulty concentrating, diffuse abdominal pain, mild fatigue, headache, muscular exhaustibility, tremor, vomiting and weight loss. Severe toxicity produces colic, encephalopathy (seizures, coma, death) lead line on gingival tissue and paresis or paralysis.

Karri *et al*. (2008), Timbrell (2008), Pearce (2007), Marshall and Bangert (2008), Patrick (2006), Needleman (2004) and James *et al*. (2006) report that the symptoms and signs of lead poisoning vary according to the individual and the duration of lead exposure. They may be subtle and someone with elevated lead levels may have no symptoms. Symptoms usually develop over weeks to months as lead builds up in the body during a chronic exposure, but acute symptoms from brief intense exposures also occur. Symptoms from exposure to organic lead occur rapidly probably because organic lead is soluble in lipid and is. therefore, more toxic than inorganic lead. Poisoning by organic lead compounds has symptoms predominantly in the central nervous system such as insomnia, delirium, cognitive deficits, tremor, hallucinations and convulsions.

The main symptoms in adults are headache, abdominal pain, memory loss, kidney failure, male reproductive problems and weakness, pain, or tingling in the extremities. The classic signs and symptoms in children are loss of appetite, abdominal pain, vomiting, weight loss, constipation, anaemia, kidney failure, irritability, lethargy, learning disabilities and behavior problems. Children may also experience hearing loss, delayed growth, drowsiness, clumsiness, or loss of new abilities especially speech skills. Symptoms may appear in children at lower blood lead levels than in adults.

In acute poisoning, typical neurological signs are pain, muscle weakness, paraesthesia and rarely symptoms associated with encephalitis. Abdominal pain, nausea, vomiting, diarrhoea and constipation are other symptoms of acute lead poisoning. Lead's effects on the mouth include astringency and a metallic taste. Gastrointestinal problems, such as constipation, diarrhoea, poor appetite, or weight loss are common in acute poisoning. Absorption of large amounts of lead over a short time can cause shock (insufficient fluid in the circulatory system) due to loss of water from the gastrointestinal tract. Haemolysis (the rupture of red blood cells) due to acute poisoning can cause anaemia and haemoglobin in the urine. Damage to kidneys can cause changes in urination such as decreased urine output. People who survive acute poisoning often go on to display symptoms of chronic poisoning.

Chronic poisoning usually presents with symptoms affecting multiple systems but is associated with three main types of symptoms: gastrointestinal, neuromuscular and neurological. Central nervous system and neuromuscular symptoms usually result from intense exposure while gastrointestinal symptoms usually result from exposure over longer periods. Signs of chronic exposure include loss of short-term memory or concentration, depression, nausea, abdominal pain, loss of coordination and numbness and tingling in the extremities. Fatigue, problems with sleep, headaches, stupor, slurred speech and anemia are also found in chronic lead poisoning. A "lead hue" of the skin with pallor is another feature. A blue line along the gum, with bluish black edging to the teeth is another indication of chronic lead poisoning. Children with chronic poisoning may refuse to play or may have hyperkinetic or aggressive behaviour disorders.

Suitable reactor material for recycling of lead from e-wastes: According to Ohia *et al*. (2005) copper reacts with trioxonitrate (V) acid to form nitrates. But lead also reacts with trioxonitrate (V) acid to form lead (II) trioxonitrate (V) (Ababio, 2005). Therefore, copper is unsuitable for the reactor as it interferes in the lead-acid reaction.

Pig or cast iron contains impurities - sulphur, silicon, phosphorus and about 5% carbon. Wrought iron contains 0.1% carbon while ordinary steel (iron) contains 0.1-1.5% carbon. Iron reacts with dilute trioxonitrate (V) acid ($HNO_{3(aq)}$) to give a mixture of products, including ferric nitrate or iron(II) trioxonitrate (V) $Fe(NO_3)_2$ and ammonium nitrate or ammonium trioxonitrate(V) NH_4NO_3. The reactions with inorganic acids render iron unsuitable for the chemical reactor because of interference in the lead-acid reaction. Besides, iron rusts, because of the presence of impurities, water and oxygen in it (Ohia *et al*., 2005). Zinc belongs to the first group of transition metals with copper and iron. Therefore, zinc is similar in chemical reactions to copper and iron (Ohia *et al*., 2005). Therefore, like copper and iron zinc was considered unsuitable for the chemical reactor for lead recycling.

Alloys are mixtures of two or more metals. Brass alloy contains copper and zinc, stainless steel alloy is a mixture of iron and chromium and nickel, bronze alloy is a mixture of copper and aluminum and tin and magnesium, soft solder alloy contains lead and tin etc. Alloys were therefore, considered unsuitable for the reactor for lead recycling from e-wastes because of the interfering reactions of their components with the reactants (Ohia *et al*., 2005).

Since, glass has no interfering reactions it was suitable. But it is risky to use glass on account of imminent frequent breakage and replacement with

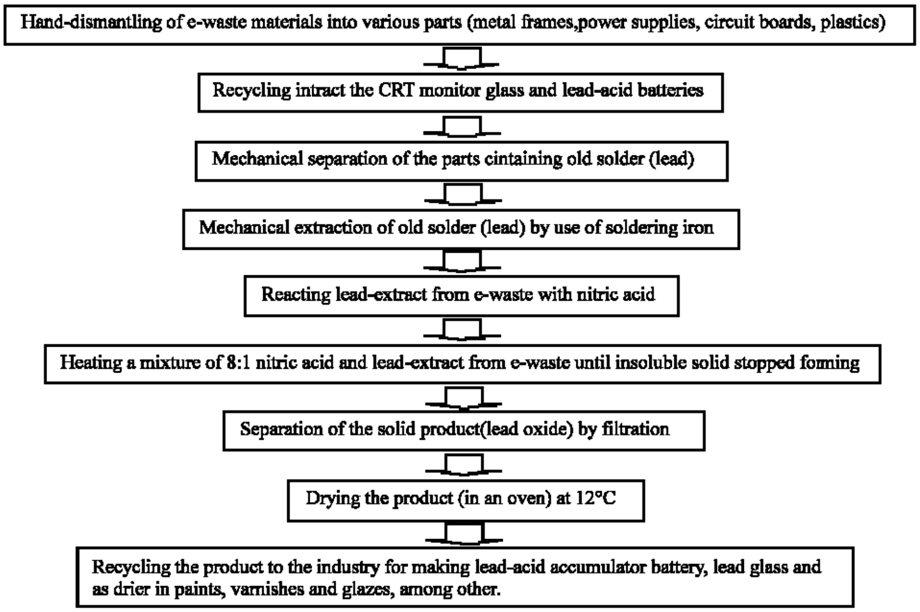

Fig. 1: Flowchart for the extraction and recycling of lead from e-wastes

attendant losses of material time and other resources. On the other hand, plastic (PVC) materials were found to be suitable for the recycling process of lead from e-waste items because it has no interfering reactions, is available and durable without the risk of breakage. This compares with earlier reports (Ababio, 2005; Daintith, 2000; Kneen *et al*., 1972; Shreve and Brink, 1977).

Flowchart for the extraction and recycling of lead from e-wastes: The flowchart for the extraction and recycling of lead from e-wastes is given in Fig. 1.

CONCLUSION AND RECOMMENDATIONS

There are unavoidable reasons for the rapid increase in the generation of e-wastes in developing countries. These e-wastes contain lead-a hazardous chemical element-in significant quantity. The emission of lead from these wastes improperly discarded in the environment lead to health hazards, as people inhale the polluted air. Therefore, it has become necessary to manage e-wastes prudently and to make policies to that effect, in order to minimize the environmental and health hazards arising from emissions of lead from e-waste materials.

The study has shown that lead can be extracted from e-waste materials and converted to lead (II) oxide demanded in the industry for making lead accumulators and lead glass and as drier in paints, varnishes and glazes. And, that plastic (PVC) reactors would be best suited for the chemical raection process. It is, therefore, recomended that:

- E-waste materials containing lead should be recovered
- They should be hand-dismantled to separate the parts containing old solder (lead)
- Old solder (lead) should be mechanically extraction by use of soldering iron from the separated waste materials
- The lead-extract should be treated in plastic (PVC) reactors to get lead (II) oxide
- The product lead (II) oxide, should be recycled to the industry for making lead accumulators and lead glass and as drier in paints, varnishes and glazes
- Plastic (PVC) reactors should be used for the recycling process
- Enabling policies should be made for the necessary regulation and management of e-wastes and recycling of lead from them

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