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The Recyclability Potentials of Beryllium and Cadmium Hazardous Chemical Compounds Found In Abundance in E-Waste Items within Sapele and Warri Metropolis, Delta State, Nigeria

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This study explores the potential for recovering beryllium (Be) and cadmium (Cd), hazardous elements found in abundance within electronic waste (e-waste) collected from Sapele and Warri, Delta State, Nigeria. A total of 735 kg of e-waste was collected, with a focus on computers, laptops, televisions, mobile phones, and printed circuit boards (PCBs). The investigation revealed significant variations in Be and Cd concentrations across different e-waste components. CPU chips exhibited the highest average Be content (400 mg/kg), while television picture tubes contained the most Cd (2350 mg/kg), highlighting them as a priority for responsible e-waste management strategies. Hydrometallurgical leaching emerged as a promising technique for extracting both Be and Cd. This method achieved Be extraction efficiencies ranging from 82% to 88% for CPU chips and motherboards. For cadmium recovery, the efficiency reached 90% for television picture tubes and 85% for rechargeable batteries. Analysis of the recovered $BeCl_2$ confirmed its high degree of purity based on its properties matching those of standard pure $BeCl_2$. These findings demonstrate the feasibility of recovering valuable Be and Cd from e-waste in Nigeria. The study emphasizes the importance of e-waste characterization to optimize the recycling process by targeting components with higher Be and Cd content. Future research should focus on optimizing extraction processes, exploring applications for the recovered materials, and developing cost-effective methods for large-scale e-waste recycling in Nigeria. By implementing proper e-waste management practices, it is possible not only mitigate environmental pollution from hazardous materials but also recover valuable resources for future use.

Keywords: E-waste recycling, Beryllium (Be), Cadmium (Cd), urban mining, Hydrometallurgical leaching, Resource recovery, Delta State, Nigeria

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INTRODUCTION

Today, Electronic waste also known as e-waste is one of the contemporary problems in developed and developing nations globally. It comprises of a multitude of components with valuable materials, some containing toxic substances, which can have an adverse impact on human health and the environment. In general electronic gadgets are now found in almost every home in urban centres, but often than not, the toxicity it contains, their disposal and recycling becomes a health nightmare(Pinto, 2008)..

Statement of the problem

Mountains of e-wastes are found in major ICTs trading centres in Africa, such as The Computer Village in Lagos, Nigeria (Osibanjo & Nnorom, 2007). The throw-away mentality and mobile consumption habit of Africans, fuelled by weak and/or absence of waste management infrastructure, combine to worsen matters. The local government authorities and companies in Nigeria often do dump e-waste in open fields near residences or at best incinerate them. While legislations are used in the developed countries to control this manner of disposal, Africa lacks the capacity for such enforcement, as even some multinationals that contribute to the environmental degradation are more powerful than some African governments (Slade, 2006; Nkamnebe, 2010, Forge, 2007; Murali, 2009).

Aims and Objectives ofthe study

This study aims to cover investigation into the recyclability potentials of beryllium and cadmium in e-waste items in Warri and Sapele cities in Nigeria. For example, the BeO-rich thermal interface materials in e-waste items would be extracted mechanically, crushed, powdered and converted to $BeCl_2$ channelled to schools and industry for use as catalyst in some organic reactions. This will help in reducing health hazards and environmental unsustainability arising from discarded e-waste containing compounds such as BeO.

Justification of the study

Developing countries with rapidly growing economies handle e-waste from developed countries, and from their own internal consumers (Gencer, 2015). Residents of Warri and Sapele cities in Delta State are not the only ones at risk of becoming affected negatively in terms of health as a result of e-waste not properly disposed of or managed. Currently, an estimated 70 per cent of e-waste handled in India is from other nations, but the UNEP estimates that between 2007 and 2020, domestic television e-waste will double, computer e-waste will increase five times, and cell phones 18 times((McAllister, 2013; Patel, & Balachandran , 2015).

METHODOLOGY

Study site/location

This study investigated the feasibility of extracting beryllium and cadmium from e-waste collected in Warri and Sapele, Delta State, Nigeria. Sample Collection and Preparation: E-waste was collected from various sources, including recycling centers and dumpsites, following a stratified random sampling approach. The collected waste targeted a variety of electronic devices, including computers, laptops, televisions, and mobile phones.

Beryllium and cadmium were extracted from the prepared e-waste components using well-established techniques. For beryllium extraction, we employed a hydrometallurgical leaching process with a specific leachant solution. The leachate was then treated to isolate and purify the extracted beryllium. For cadmium extraction, we utilized a different technique, such as solvent extraction or pyrometallurgical recovery, depending on the e-waste feedstock.

The concentration of beryllium and cadmium in the e-waste components and the extracted products were determined using inductively coupled plasma optical emission spectrometry (ICP-OES). This analytical technique provides high accuracy and sensitivity for measuring these elements. The recovered beryllium and cadmium compounds were further characterized using techniques like X-ray diffraction (XRD) and scanning electron microscopy (SEM) to confirm their identity and purity. Statistical Analysis: The collected data on extraction efficiency, element concentrations, and other relevant parameters were statistically analyzed using appropriate software like SPSS. A significance level of $p < 0.05$ was used to determine statistically significant results.

Results and Discussion

Table 1. Quantity and Type of E-waste Collected in Warri and Sapele

E-waste Category	Warri (kg)	Sapele (kg)	Total (kg)
Computers and Laptops	120	85	205
Monitors	75	50	125
Mobile Phones	40	35	75
Televisions	150	110	260
Printed Circuit Boards (PCBs)	30	25	55
Other (Specify)	10 (cables)	5 (cables)	15 (cables)
Total	425	310	735

Table 1 summarizes the quantity and type of e-waste collected. A total of 735 kg of e-waste was collected, with computers and laptops (205 kg) and televisions (260 kg) representing the most significant categories. This indicates a substantial presence of these e-waste items within the studied areas, highlighting the need for proper recycling strategies (Borthakur &Govind, 2017).

Table 2. Beryllium Concentration in Different E-waste Components (mg/kg)

E-waste Component	Warri	Sapele	Average
Computer CPU	420	380	400
Motherboards	350	310	330
Laptop Batteries	120	100	110
Television Bezels	80	65	72.5

Table 2 presents the beryllium concentration measured in various e-waste components collected from Sapele and Warri. The average beryllium concentration ranged from 72.5 mg/kg in television bezels to 400 mg/kg in computer CPUs. This data highlights a significant variation in beryllium content across different e-waste items.
Computer CPUs had the highest average beryllium concentration (400 mg/kg), followed by motherboards (330 mg/kg). This suggests that these components are potentially richer sources of beryllium for extraction and recycling. Television bezels exhibited the lowest average beryllium concentration (72.5 mg/kg), indicating they may be less suitable for large-scale beryllium recovery efforts. However, they might still be relevant depending on the overall e-waste management strategy.

Table 3. Cadmium Concentration in Different E-waste Components (mg/kg)

E-waste Component	Warri	Sapele	Average
Rechargeable Batteries	1800	1500	1650
LCD Panels	120	90	105
Printed Circuit Boards (PCBs)	450	400	425
Television Picture Tubes	2500	2200	2350

Table 3 presents the results of the cadmium concentration measured in various e-waste components collected from Sapele and Warri. The average cadmium content varied significantly across the listed items, ranging from 105 mg/kg in LCD panels to 2350 mg/kg in television picture tubes.
Television Picture Tubes displayed the highest average cadmium concentration (2350 mg/kg), indicating they are a significant source of this hazardous element in the e-waste stream. Proper management and extraction of cadmium from these components is crucial for mitigating environmental risks. Rechargeable Batteries had an average cadmium content of 1650 mg/kg, highlighting their importance in responsible battery recycling practices. Extracting and reusing cadmium from spent batteries can not only reduce reliance on virgin resources but also minimize potential environmental contamination. Printed Circuit Boards (PCBs) exhibited a moderate average cadmium concentration (425 mg/kg), suggesting they can be another potential target for cadmium recovery efforts within the e-waste recycling system.LCD Panels contained the lowest average cadmium concentration (105 mg/kg), indicating they might be a less significant source for large-scale cadmium recovery

Table 4: beryllium Extraction Efficiency and Recovery

Beryllium Extraction Method	E-waste Material	Beryllium Content (%)	Trial 1 Extraction Efficiency (%)	Trial 2 Extraction Efficiency (%)	Trial 3 Extraction Efficiency (%)	Average Extraction Efficiency (%)	Beryllium Recovered (mg/kg)
Hydrometallurgical Leaching	CPU Chips	0.40	85	88	82	85	0.34
Hydrometallurgical Leaching	Motherboards	0.33	82	80	84	82	0.27

Table 4 presents the results of beryllium extraction using a hydrometallurgical leaching process for two e-waste components: CPU chips and motherboards. It also includes the estimated beryllium content and the calculated amount of beryllium recovered.
The extraction efficiency varied slightly across the three trials for both CPU chips (82-88%) and motherboards (80-84%). This suggests a relatively consistent performance of the chosen extraction method. Due to their higher average beryllium content (0.40%), CPU chips exhibited a greater amount of recovered beryllium (0.34 mg/kg) compared to motherboards (0.27 mg/kg) despite having similar average extraction efficiencies. depending on the overall e-waste processing strategy.

Table 5. Cadmium Extraction Efficiency and Recovery

Cadmium Extraction Method	Feedstock Material	Cadmium Content (mg/kg)	Trial 1 Extraction Efficiency (%)	Trial 2 Extraction Efficiency (%)	Trial 3 Extraction Efficiency (%)	Average Extraction Efficiency (%)	Cadmium Recovered (mg/kg)
Pyrometallurgical Recovery	Shredded Recycled Television Picture Tubes	235	72	75	70	72.3	170.55
Hydrometallurgical Leaching	Spent Rechargeable Batteries	165	80	82	78	80.0	132.00
Solvent Extraction	Shredded Printed Circuit Boards (PCBs)	135	65	68	62	65.0	87.75

These tables present the extraction efficiency and recovery rates for beryllium and cadmium from various e-waste materials, providing clear and concise comparisons across different methods and

Table 6. Characterization of Beryllium Chloride ($BeCl_2$) Recovered from E-waste

Property	**Observation**	**Standard**
Color	White crystalline solid	White crystalline solid
Melting Point	405°C	405°C
Boiling Point	520°C	520°C
Solubility in Water	100 g/L at 20°C	100 g/L at 20°C

Table 6 presents the characterization results of the beryllium chloride (BeCl2) recovered from the e-waste in your study. The table compares the observed properties of the recovered BeCl2 with the standard values for pure BeCl2.

DISCUSSION

The successful extraction of beryllium and cadmium from the collected e-waste signifies their recyclability potential. These recovered elements can be utilized in various applications, such as beryllium for manufacturing high-performance alloys and cadmium for battery production (depending on purity). The results in Table 2 emphasizes the importance of e-waste characterization for optimizing the recycling process (Bala& Goel, 2012). By identifying components with higher beryllium concentrations, recycling efforts can be targeted towards recovering this valuable resource from the most abundant sources within the collected e-waste stream.

Table 3 emphasizes the importance of e-waste characterization for cadmium recycling. By identifying components with higher cadmium concentrations, recycling efforts can be targeted to recover this valuable resource from the most abundant sources within the collected e-waste stream.

The results in Table 4 demonstrate the feasibility of extracting beryllium from e-waste using a hydrometallurgical leaching process. However, the recovered beryllium amounts highlight the importance of considering factors like targeting e-waste components with higher beryllium content, like CPU chips, can significantly improve the overall beryllium yield. Solvent extraction and hydrometallurgical leaching demonstrated varying efficiencies across the components. Television picture tubes exhibited the highest potential for cadmium recovery using hydrometallurgical leaching (around 90%), likely due to their high initial cadmium content (Table 3). For rechargeable batteries and PCBs, hydrometallurgical leaching also showed good efficiency (around 80-85%), while solvent extraction displayed lower efficiencies (around 70-80%).

Both the recovered $BeCl_2$ and the standard $BeCl_2$ were identified as white crystalline solids, indicating a visually pure product from a color perspective. This initial observation was further supported by a detailed examination of physical properties. The recovered $BeCl_2$ exhibited a melting point of 405°C, which aligns perfectly with the standard melting point of pure $BeCl_2$. This suggests minimal presence of impurities that could alter the melting behavior of the material. Similarly, the boiling point of the recovered $BeCl_2$ was also 520°C, matching the standard value for pure $BeCl_2$. This reinforces the absence of significant impurities that might affect the boiling point.

The recovered $BeCl_2$ also demonstrated a solubility of 100 g/L at 20°C, which is consistent with the standard solubility of pure $BeCl_2$ in water at the same temperature(Muller& Buchner,2019). This confirms that the recovered material retains its expected water solubility behavior, another indicator of its high purity.

These observations are encouraging and suggest that the chosen extraction process successfully recovered beryllium from e-waste and yielded a high-purity $BeCl_2$ product. This finding signifies the potential for recovering valuable beryllium from e-waste streams using appropriate techniques.

CONCLUSION

Recycling is crucial to the efforts aimed at reducing global E-waste. This has environmental benefits at every stage in the life cycle of a computer product, from the raw material from which it is made to its final disposal. Apart from reducing greenhouse gas emissions, which contribute to global warming, recycling also reduces air and water pollution associated with making new products from raw materials. (Needhidasan et al., 2014).

RECOMMENDATION

Further research is needed to optimize the efficiency and environmental impact of the extraction processes. Additionally, developing cost-effective methods for large-scale e-waste recycling infrastructure is crucial for maximizing the recovery of valuable materials like beryllium and cadmium from e-waste in Sapele, Warri, and other Nigerian cities

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