Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 6 (7): 1499-1505, 2006
ISSN 1812-5654

Estimation of Consumption Emissions of Lead and Cadmium from Dry Cell Battery Importation in Nigeria: 1980-1998

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Abstract: The lead and cadmium contents of dry cell batteries imported into Nigeria were determined by atomic absorption spectrometry after acid digestion and used in the estimation of the consumption emissions of these toxic heavy metals from battery consumption in Nigeria. The average Pb and Cd content of the dry cells are 1051 mg kg^{-1} (range 42-3170 mg kg^{-1}) and 107.7 mg kg^{-1} (range 4.6-410 mg kg^{-1}), respectively. An estimated consumption emission of 1.16 metric ton lead and 0.12 metric ton cadmium are witnessed per decade from the importation of about 11000 metric ton/year of primary batteries and parts. The calculated emissions of 607 kg Pb and 62 kg Cd for 1987 accounts for about 42% of the estimated emissions witnessed for the period 1980-1998. Within this period, an estimated average of 1671 g/t Pb and 475 g/t Cd were emitted annually into the atmosphere with fly ash particulate at municipal waste minimization sites. About 3400 g/t Pb and 41 g/t Cd are released into the soil through ash and cinder at such sites with about 1% of these reaching the underground water per annum. These estimated consumption emissions calls for appropriate legislation and provision of adequate well established systems for the separation, storage, transportation and management of toxic waste materials such as primary and secondary battery wastes. The environmental and health implications of inappropriate management of primary waste are also discussed. The degradation of discarded dry cells in inhabited areas can expose children who play in such contaminated areas to low doses of Pb and Cd. Ways of halting this form of metal pollution in Nigeria were also suggested. There is an urgent need to develop an appropriate technology following the principles of waste minimization and sustainable development to handle the increasing toxic and hazardous waste generated in Nigeria.

Key words: Dry cell, battery, lead, cadmium, consumption emission, Nigeria

INTRODUCTION

Batteries represent a large volume of toxic and hazardous materials in common use and these materials must be managed to avoid or minimize dissipation into the environment, thereby avoiding harm to the environment and human health.

The manufacturing processes of dry cells have been identified as exposure route of heavy metals of which mercury, lead, manganese and cadmium, are of most toxicological significance (Bader *et al*., 1999; Semu *et al*., 1986; Onianwa and Fakayode, 2000). Exposure to carbon black dust in dry cell battery facilities results in significant loss in pulmonary function (Oleru *et al*., 1983).

The zinc anode of dry cells contains low percentages of Cd and Pb for improvement in strength and ductility. Small quantity of mercury is also alloyed with the zinc to control corrosion and provide current carrying capability. In 1991, the EU directive on batteries and accumulators (91/157/EEC) was introduced which requires that batteries containing more than 25 mg of Hg, 0.025% of Cd and 0.4% Pb by weight be collected separately from household waste for recycling or special disposal. The manufacturers of alkaline batteries ceased the addition of Hg in 1992 (Malloy, 1994).

The absence of environmental protection facilities in primary and secondary facilities and waste battery recycling plants have been associated with high levels of Pb and Mn in the tissue samples of the employees and persons residing near such facilities (Bader *et al*., 1999; Wohl *et al*., 1996; Ritcher *et al*., 1979; Lai *et al*., 1997). Ingestion through hand and mouth contamination has been a major source of lead absorption in such facilities (Far *et al*., 1993; Hwang *et al*., 2000; Chia *et al*., 1996). The high levels of especially Pb observed in the tissue samples of the employees family members

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reveals a problem arising from employees' transferring lead dust home, probably in their working cloths (Fergusson *et al.*, 1981).

The management of primary and secondary battery waste materials is a recognized environmental problem even in the developed countries. Household batteries contribute 52% of Cd and 88% of all Hg found in the municipal solid waste, yet they comprise less than 1% by weight of municipal solid waste (Shapek, 1996). Most developing countries do not have special facilities for handling wastes. They have neither well-established systems for separation, storage, collection and transportation, nor the effective enforcement of regulations relating to hazardous wastes management generated from industrialized and nonindustrialized sectors (Ozaki *et al.*, 2003).

The main concern about batteries on the waste stream is that the heavy metals in them could leach from landfills into ground water, or volatilize into the atmosphere during combustion at open dumpsites or at waste-to-energy plants (Malloy, 1994). Solid wastes dumped on roadsides usually find their way into streams and rivers, which may leach out the heavy metals. The highly acidic pH of as low as 3.4 observed in some water bodies of the industrialized areas of Lagos may accelerate the dissolution of heavy metals (Sridhar and Bammeke, 1986).

In the present study, we report the result of the determination of the Pb and Cd content of dry cells imported into Nigeria and estimate the levels of Pb and Cd emissions from such consumptions.

MATERIALS AND METHODS

Thirty-eight dry cell batteries imported into Nigeria were purchased in October-November 2001, from retail outlets in Okigwe and Umuahia in Southeastern Nigeria. The dry cells were carefully opened and dried to constant weight at 110°C. The carbon rod and cathode mix (MnO_2 + carbon + electrolyte) was ground into a fine particle 'black mix' using a porcelain mortar. A representative sample of the dry cells as is discarded (the black mix and the metal cover) was digested with 2:1 mixture of $HNO_3/HClO_4$, evaporated to near dryness on a hot plate and then cooled. More of the acid mixture was added and the digestion process continued till the evolution of white fumes marking the end of the digestion process. The digest was then heated to near dryness and taken up in 1 M HNO_3. This was filtered through a pre-acid washed Whatman No. 4 filter paper into a 10 mL volumetric flask and made up to mark with the 1 M HNO_3. The digest was subsequently analyzed for Pb and Cd with flame atomic absorption spectrometry (BUCK Scientific, Model 210) using the standard calibration technique. Internal quality control procedure with re-tests of Pb and Cd standards prepared in 1 M HNO_3 was undertaken. Reagents used were of analytical grade. Reagent blanks were also included and results reported are average of duplicates. Calibration standards were made by dilution of the high purity commercial BDH metal standards for atomic absorption analyses. A recovery test of the total analytical procedure was carried out for Pb and Cd in two dry cell brands by spiking analysed samples with aliquots of Pb and Cd standards and reanalyzing the samples. Average recoveries obtained were 81 and 91% for Pb and Cd, respectively. These recovery results are acceptable considering the high carbon content of the digested samples and the high adsorption power of carbon.

RESULTS AND DISCUSSION

The battery industry represents one important and growing sector where the use of non-toxic and non-hazardous substitute materials is not rapidly developed. As regulations increase and concern for the environment and human health becomes more prevalent, the fate of toxic and hazardous materials in the environment should be more carefully considered (Lankey and McMicheal, 1999). Worldwide, more than 300,000 tons of zinc batteries or 7.5 billion cells are sold yearly. The typical composition of the zinc-carbon and alkaline manganese batteries are shown in Table 1. The production of this number of zinc batteries requires an average of 75,000 tons of zinc, 60,000 tons of manganese and 70,000 tons of iron (Gega and Walkowiak, 2001). This tonnage corresponds with the amount of metals, which can be recovered from the spent batteries.

In Nigeria, an average of 11,000 metric ton of primary batteries and parts are imported yearly (Federal Office of Statistics, Abuja). This gives an average battery importation of 275 million batteries/year or 2 batteries/person/year. This does not include the quantities smuggled in or imported packed with items such as cameras, torchlight and transistor radios. Household batteries consumption in the United States, Germany and France in 1994 is 83,000, 26,000 and 25,000 tons, respectively (Gega and Walkowiak, 2001).

The mean Pb and Cd contents of the dry cells studied are 1051 mg kg^{-1} (range 42-3170 mg kg^{-1}) and 107.2 mg kg^{-1} (range 4.6- 410 mg kg^{-1}), respectively, (Table 2). About 5% of the dry cells contained >0.025% Cd, the level recommended by the EU for special disposal or recycling while about 24% contain ~0.02% Cd by weight. All the cells studied contain Pb levels below the 0.4% Pb by weight.

Table 1: Typical composition of zinc batteries (%)

Dry cell type	Mn	Fe	Zn	C	Cu	Pb	Cd	Hg	H_2O	Other*
Zinc-carbon	18	21	35	9	-	0.15	-	<0.0005	11.0	5.8
Alkaline-Mn	23	25	16	4	0.5	0.04	<0.01	<0.0005	7.0	24.0

*Oxygen in compounds, paper, plastics, electrolyte. Source: Gega and Walkowiak (2001)

Table 2: Lead and Cadmium content of dry cell batteries imported into Nigeria from various countries

		Lead (mg kg^{-1})		Cadmium (mg kg^{-1})	
Country	N	Mean	Range	Mean	Range
China	14	1368.4	42-3170	151.5	30-410
Indonesia	2	1032.0	806-1258	84.4	71.2-97.6
Japan	5	715.2	168-1295	131.5	104.9-160
Korea	2	1137.5	493-1782	81.5	9.5-153.4
Malaysia	1	709.0	-	12.5	-
Spain	1	702.0	-	65.8	-
USA	1	303.0	-	11.1	-
Source not indicated	12	1070.3	100-2135	82.5	4.6-182.5
Entire study	38	1051.0	42-3170	107.2	46-410

The use of the dry cells' 'black mix' (electrolyte+ carbon black+graphite rod) for darkening classroom blackboards can expose school children to low doses of heavy metals. Studies of prevalence of elevated blood lead (PbB) levels in children 1-6 years old in Nigeria observed high average PbB levels in children 5 years old and attributed this to the tendency for this age group to play longer in contaminated outdoor environment (Nriagu *et al*., 1997). Such contaminations can result from leaded particle depositions resulting from the use of leaded gasoline, the degradation of dry cells within such areas or from depositions from storm run-off which may have leached such heavy metals from waste collection/minimization or landfill sites. Studies of the effect of blood lead on children's mental development have shown intelligence quotient deficits of an estimated 0.25 points for every microgram per deciliter (μg dL^{-1}) increment in blood lead level (USCDC, 1991; Wang *et al*., 2002). It has been suggested that lead may have this effect by interfering with the role of calcium in brain cell development and because the developing nervous system is thought to be far more vulnerable to toxic effect of lead than the mature brain (Koller *et al*., 2004). Cadmium can adversely affect the renal and respiratory systems, depending upon exposure, time and concentration.

The Pb and Cd emissions into the environment from imported dry cells can be estimated using

$$C * I * E$$

where C is the mean Pb or Cd content of the dry cells, I is the net quantity of dry cell imported and E is the emission factor. Emission factor is defined as the part of the product that is mobilized in the environment within a decade (Bergback *et al*., 1992). An emission factor of 0.01 has been used to estimate consumption emissions of Pb from the use of batteries in Sweden (Bergback *et al*., 1992). Applying this emission factor, it can be predicted that an estimated consumption emission of 1.16 metric ton of Pb per decade (115.6 kg Pb/year) is witnessed in Nigeria. This is in addition to the emission of 15,000 kg of Pb (Agbo, 1997) from the daily consumption of 20 million liters of petrol containing an average Pb level of 0.7 g/L (0.6-0.8 g/L) (Osibanjo and Ajayi, 1998). Automobile exhaust accounts for more than 80% of the air pollution in Nigeria (Osibanjo and Ajayi, 1998; Awofolu, 2004). Automobile leaded emissions was proposed by a recent study as the source of high levels of lead observed in human scalp hair sample in Nigeria (Nnorom *et al*., 2005). If the same emission factor is assumed for Cd, then the estimated emissions of Cd is 0.12 metric ton per decade (11.8 kg Cd/year). The highest importation of dry cells for the period 1980-1998 was 56000 metric tonnes in 1987. Thus in 1987 an estimated 607 kg Pb and 62 kg Cd were emitted into the air, water and soil from consumption of dry cell batteries (Table 3).

These emissions are of concern considering that most of the emissions are witnessed in inhabited areas. These emissions results from the open burning of wastes

Table 3: Estimated consumption emissions of Pb and Cd in Nigeria from imported dry cell batteries

		Estimated consumption emissions (kg)	
Year	Quantity imported (tonnes)	Pb	Cd
1980	1898.03	19.93	2.03
1983	714.80	7.51	0.77
1984	2062.76	21.68	2.21
1986	495.56	4.26	0.43
1987	57742.57	606.87	61.90
1988	4155.69	43.68	6.99
1989	6515.83	68.48	6.99
1990	16795.71	176.52	18.01
1992	2836.55	29.81	3.04
1993	1837.22	19.31	1.97
1996	26918.64	282.91	28.87
1997	10521.01	110.58	11.28
1998	6805.26	71.52	7.30

Table 4: Estimated Pb and Cd emissions into the atmosphere, soil and underground water from consumption of dry cell batteries (g t^{-1})

	Fly ash		Soil		Underground water	
Year	Pb	Cd	Pb	Cd	Pb	Cd
1980	269.2	84.2	601.4	7.3	6.00	0.07
1983	111.6	31.7	226.5	2.8	2.30	0.03
1984	321.9	91.6	653.6	8.0	6.50	0.08
1986	63.3	18.0	128.5	1.6	1.30	0.02
1987	9012.1	2562.7	18297.3	222.8	183.00	2.23
1988	648.6	184.4	1316.8	16.0	13.20	0.16
1989	1017.0	289.2	2064.7	25.2	20.70	0.25
1990	2921.4	745.4	5322.2	64.8	53.20	0.65
1992	442.7	125.9	898.8	11.0	9.00	0.11
1993	286.7	81.5	582.2	7.1	5.80	0.07
1996	4201.3	1194.7	8529.9	103.9	85.30	1.04
1997	1642.1	466.9	3333.9	40.6	33.34	0.41
1998	1062.1	302.0	2156.4	26.3	21.60	0.26

to reduce the waste mass before transport to landfills. Metal pollution from waste incineration in Nigeria has been studied (Onianwa, 1994). This form of pollution is classified as an environmental transfer of metal and not a true source of metallic pollution. This is because the metals emitted have been originally embodied in items of consumption discharged as wastes (Ayres and Ayres, 1994).

The major origin of Pb and Cd in household waste are small sealed batteries, Ni-Cd batteries and flame-proofed products. These metals have been reported to shift to fly ash on incineration, the transfer ratio of Pb and Cd being about 33 and 92% respectively (Nakamura *et al*., 1996). If it is assumed that about 45% of the discarded dry cells are completely combusted in a system similar to the incinerator, then an estimated average of 1671 g/t of Pb and 475.3 g/t of Cd are emitted into the atmosphere with fly ash particulates yearly in Nigeria. Also an estimated 3393.3 g/t Pb and 41.3 g/t Cd are released into the soil through ash and cinder from the waste minimization/combustion sites and the landfills (Table 4). These estimated consumption emissions does not consider neither the locally produced dry cells nor the quantities smuggled into the country.

Lead is relatively immobile both in soil and water (Bergback *et al*., 1992). Only a minor part of the Pb and Cd may leach down into the lower parts of the soil profile and eventually reach the groundwater. If a leaching rate of 1% for Pb and Cd in the soil per decade is assumed (Tyer, 1978), then an average of 33.93 g/t Pb and 0.41 g/t Cd reaches the underground water per year in Nigeria from consumption of imported dry cells (Table 4). The metals in the ash and cinder can be leached into drinking surface water bodies.

Precise estimates of the metal emissions will consider not only the vapor pressure of the elements and the concentration of the elements in the waste but also the exact compounds used/present and the changes these would undergo during the open burning or incineration. The concentration of these metals in the waste ash and soil solution and hence its availability and potential toxicity is most likely to be controlled by sorption-desorption reaction at the surface of both inorganic and organic colloidal materials (Swift and McLaren, 1991).

About 25 billion household batteries are purchased each year in the United States. Of this, over 90% are single use batteries that find their way into landfills or incinerators. The United States Environmental Protection Agency (US-EPA) estimated that in 1989, 88% of the 1.4 million pounds of mercury in urban trash (MSW) in the US came from single use batteries (Schwartz *et al*., 1994). Environmental considerations have tended to push well-established battery technologies based on materials like silver, mercury and cadmium into the background. The reduction/removal of the Hg and Cd contents of the zinc-carbon and zinc chloride cells have resulted in the recommendation that these dry cell types be disposed with household wastes (EHSO, 2005).

One major source of worry to environmentalist in Nigeria is the inappropriate management of Ni-Cd rechargeable batteries. There is no policy of 'collection and recycle' of Ni-Cd batteries in Nigeria and this has resulted in the disposal of such highly toxic materials with municipal waste and into surface waters. The market for portable electronic products is expanding and the global production of portable rechargeable batteries grew at an annual rate of 14% within the past two decades. The total number of portable cells produced in 1999 was 2.9×10^9 cells (Rydh and Kalstrom, 2002).

The design, manufacture, recycle and disposal of batteries all necessitates some form of hazardous waste management (Lankey and McMicheal, 1999). Basically four disposal options are available for battery: composting, incineration, landfilling and recycling. The first two options were not practical; landfilling was the most frequently used; and recycling was the most preferred by industry and environmentalists (Palchy, 1998). With any battery disposal method, the potential exists to release heavy metals into the environment through landfill leachate or incineration stack gases. Dry cells battery waste disposal should be regulated through legislation with the establishment of a waste management hierarchy that encourages source reduction and recycling prior to landfilling or incineration. A viable option in spent primary battery management is the setting up of a body to coordinate and recycle spent batteries. The financing of the 'collection and recycling' project will be paid for by the battery producers and distributors. This would then be passed on to the consumers through a price increase (SEPA, 1997).

The improper disposal of dry cell batteries may contribute significantly to the levels of Pb and Hg observed in solid wastes from residential areas of Ibadan, Nigeria (Sridhar and Bammeke, 1986). This observed higher levels of Pb and Hg in the solid wastes from high-density areas compared to medium and low density areas could have resulted from the high use and improper disposal of dry cell batteries used in powering torchlight and transistor radios. This increase in use of dry cell could be attributed to the erratic supply of electricity to such low-income areas.

There is an urgent need to legislate and enforce the implementation of the national policy on environment, which recommends the use of environmentally safe and technologically sound techniques for the disposal of toxic and hazardous wastes (FEPA, 1991). The public is generally unaware of the potential health and environmental risks of unrestricted disposal of dry cells (Shapek, 1996). Due to increase in environmental awareness, attention is now on sustainable management of natural resources and waste minimization. This has resulted in devotion of efforts at collecting and recycling of batteries of all kinds. The cost implications of collecting the dry cells and the subsequent disposal/recycling costs are the possible reasons why most countries are reluctant at initiating the collection program. In 1998, the Swedish battery ordinance came into effect, which states that all kinds of household batteries must be collected to avoid the spread of Cd, Hg and Pb. Within the same year, approximately 1400 ton of mixed household batteries were collected in Sweden (Rydh and Kalstrom, 2002).

A secondary (rechargeable) battery is considered to be more environmentally friendly than a primary (non-rechargeable) battery because the primary battery is thrown away after one use. This results in significant waste of materials and energy used to manufacture the number of dry cells that would be equivalent to one rechargeable battery over the course of its useful life. In addition dry cells are not usually collected and recycled and this results in the use of more virgin materials.

Discarded electronic equipments or e-waste is one of the fastest growing waste streams in the industrialized world due to growing sales and rapid obsolesce of these products (Mundada *et al.*, 2004). These items are exported to developing countries as 'used wares'. The dumping of e-waste particularly computer and associated materials in poor countries has further aggravated the problem associated with waste management in developing countries.

Technologies are now available in Europe which reprocesses zinc-carbon and alkaline-manganese batteries using a number of different methods, which include smelting and other thermal-metallurgical processes to remove the metal contents, particularly zinc. Several hydrometallurgical processes have been developed for the treatment of spent primary and secondary batteries. The BATENUS process provides a global solution for the treatment of mixed battery waste, using sulfuric acid leaching and a combination of ion exchange and solvent extraction for metal purification (Gega and Walkowiak, 2001). Pyrometallurgical methods, or fusion-reduction methods can also be used to chemically reduce all metallic compounds to their metallic, or reduced forms by means of heating and providing adequate trapping and reducing substances (Asante-Duah *et al.*, 1992). A zinc-carbon/alkaline manganese battery recycling plant in Switzerland uses pyrometallic methods to recycle spent dry cells to recover ferromanganese, zinc nuggets, zinc oxides and mercury for re-use. The only disposed material is the salt from the battery electrolyte (DRAFT, 2001). Even with an effective recycling of batteries, lead has reached the environment from such processes and facilities (Bergback *et al.*, 1992). Improved material management can lead to better utilization of refined materials, decreased use of primary materials and energy resources and a reduced need for landfill areas. The benefits of recycling materials from an economic, environmental and technical point of view depend on many parameters, such as transport distance, recycling process and type of material (Rydh and Karlstrom, 2002). Consumption emissions in general are diffuse and widespread. In urban areas they contribute to increased lead and cadmium concentrations in storm-drain waters, soil and in household dust.

Heavy metals are highly toxic and are among the wastes exported to cash-poor developing countries due to increasing stringent environmental laws, limited disposal options and rising waste disposal costs (Envirogreen, 2005). One wonders if the export of dry cells containing more than 0.4% Pb and 0.025% Cd by weight would amount to hazardous waste trade. This will appear plausible when there is confirmation that some of the common brands of dry cells exported to Nigeria and other developing countries are not locally consumed in the home (exporting) countries.

The inadequate management of municipal and industrial wastes has resulted in the pollution of major streams in Nigeria (Ajayi and Osibanjo, 1981; Nwankwoala and Osibanjo, 1992). The technological advances though desirable for socio-economic reasons are taking place at the expense of environmental quality (Osibanjo, 1982). Nigeria does not have any integrated framework regarding the monitoring and management of toxic and hazardous materials and wastes. Limited funding has also caused significant impediments to the effective management of toxic and hazardous wastes. Apart from scarcity of financial resources, there has not been any development of appropriate technology following the principles of waste minimization and sustainable development.

Any credible interim effort to halt this form of metal pollution must include proper funding and management of wastes and the provision of basic infrastructure to halt the open burning of wastes in inhabited areas. Long term control measures will include appropriate legislation and enforcing the removal of dry cells and similar toxic items from wastes to be incinerated for proper management. This demands an urgent attention from the relevant authorities in Nigeria. This may also interest the Global Environmental Monitoring Systems (GEMS).

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