LIFE CYCLE ANALYSIS AND SOLID WASTE MANAGEMENT: HOUSEHOLD BATTERIES

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SUMMARY: Life cycle inventory analysis is a phase of life cycle assessment involving the compilation and quantification of inputs and outputs for the system under study throughout its life cycle. Life cycle is considered as consecutive and linked stages, from raw materials acquisition or generation of natural resources to final disposal. For each stage, the relevant inputs and outputs, which may include the use of resources and releases to air, water and land are quantified. An overview of the life cycle inventory analysis as a part of a life cycle assessment to compare disposal options of spent household alkaline batteries: landfilling, incineration and recycling, is presented. It includes the presentation of the first stage in the study, definition of goal and scope, the systems definition and discusses the data requirements and information that will comprise the life cycle inventory analysis.

1. INTRODUCTION

Batteries comprise a convenient source of portable energy, being present in a wide range of electronic domestic products.

The disposal of spent household batteries became a subject of discussion mainly due to the presence of heavy metals and other substances known to be harmful to people and environment. Long-term releases of heavy metals even at low levels have the potential to magnify their amount in environment and human body. As the releases and the contributions to the environment of such substances depend on the disposal method, a care must be taken on selecting alternatives.

In Portugal, most household batteries are disposed of with municipal solid waste (MSW) and are sent to a landfill, however, due to some voluntary activities of environmental associations, some batteries are discharged separately and collected for recycling.

At this moment are in construction two municipal solid waste incinerators in the country, thus it is important to understand the suitability of the disposal options in order to clarify their relative benefits and potential environmental consequences concerning household spent batteries.

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The comparison between landfilling, incineration and recycling in terms of environmental burdens could be made by analysing an hypothetical case study comprising these options available for disposal of spent household batteries, using the life cycle assessment technique.

Due to the largest share of household battery market represented by alkaline batteries, the study is limited to this type of household batteries.

2. BATTERIES

A battery is an electrochemical device that converts chemical energy to electrical energy. The basic cell consists of an anode (negative electrode), a cathode (positive electrode) and an electrolyte (a liquid solution through which an electric current travels)

Household batteries are classified as primary and rechargeable or secondary. There are seven household battery types in the Portuguese market: alkaline, zinc/carbon, mercury oxide, silver/oxide, zinc/air, lithium and nickel/cadmium. Such denomination is related with the batteries chemical composition.

The knowledge of battery composition is essential on evaluating a disposal option. The potential contribution of these batteries to environment is calculated from the average percentage of each component and the number of batteries discarded, that is assumed to be equal to the batteries sold in the same period of time.

Batteries composition may vary significantly for the different sizes/formats. The most popular format in the Portuguese market is the AA standard whose dimensions are 50mm length, 14mm diameter and approximately 23g of weight.

Alkaline batteries have a cathode of manganese dioxide, a zinc anode and the electrolyte is an alkaline solution. The cathode is a high-density mixture of manganese dioxide and graphite compressed into a cylinder format to fit around the anode, which consists of a zinc powder paste with aqueous potassium or sodium hydroxide. A permeable membrane separates these two electrodes. The cell is in a steel can and buttons, at each end of the outer can, provide negative and positive terminals. This steel can is covered by a thin plastic sleeve, which is then covered by a lacquered metal outer cover. The products of the discharge reaction are zinc oxide and hydrated manganese (III) oxide. Zinc anodes often include other elements (as mercury and cadmium) added to avoid passivation during the electrochemical reaction. Alkaline batteries average composition is: steel - 37%, manganese dioxide – 22%, Zinc – 14%, Graphite – 3%, Plastic/paper – 4%, heavy metals (Hg, Cd, Pb in a variable amount) and alkaline solution of KOH or NaOH from the electrolyte.

Being a complex product in terms of structure and chemical composition, including several materials and components, some of them in a very low amount but highly pollutant and harmful to human and environment, batteries disposal is quite problematic. Batteries include metal components, metal compounds, paper and plastic. These materials are not immediately accessible and each disposal method acts in a different way so that, the behaviour of degradation or transformation is quite different and specific, resulting in different reactions and associated emissions or environmental burdens.

3. LIFE CYCLE ANALYSIS

Life cycle assessment (LCA) is a technique for assessing the environmental aspects and potential impacts associated with a system by: (i) compiling an inventory of relevant inputs and outputs of the system; (ii) evaluating the potential environmental impacts associated with those inputs and outputs; (iii) interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study (ISO 14040, 1997).

The environment surrounds the system (product or service), being the source of inputs and the sink of outputs. The interface is the system boundary. The system should be modelled in such a way that inputs and outputs at its boundaries are elementary flows, i.e., material or energy streams drawn from or discarded to the environment without human transformation.

Life cycle assessment should include (ISO 14040, 1997):

- goal and scope definition,
- inventory analysis,
- impact assessment,
- interpretation of results.

Life cycle inventory studies (also called life cycle analysis) include goal and scope definition, inventory analysis and interpretation of results.

Life cycle assessment is widely used in comparative studies. In that case, the equivalence of the systems under comparison plays an important role, therefore, system boundaries and data quality should be evaluated with caution.

The goal of an LCA study shall present the intended application, the reasons for carrying out the study and the intended audience. Scope should include the basic statement of the system as the function of the system, the functional unit, the system boundaries, allocation procedures, data requirements, assumptions and limitations. Among these functional unit definition is an important matter since it is the reference to which inputs and outputs are related, necessary to ensure comparability of LCA results. Comparability of results is particularly critical when different systems are being assessed to ensure that such comparisons are made on a common basis.

The system boundaries determine which unit processes will be included in the study as the depth and breath of the study, i.e., which are the limits of the study.

Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a system. These inputs may include the use of resources and releases to air, water and land, associated with the system. These data then constitute the input to the life cycle impact assessment.

4. DEFINITION OF GOAL AND SCOPE

4.1. Goal of the study

The goal of this study is to compare the environmental burdens associated with three different disposal options for spent alkaline household batteries: landfilling with MSW, incineration with MSW and recycling with zinc recovery.

The comparison of these options should help decision-makers on predicting environmental performance, demonstrate environmental sustainability and define benefits and handicaps of each option concerning environmental issues.

4.2. Function, and functional unit

The function of the service systems under comparison, i.e. the purpose for which the system exists, is the disposal of spent alkaline household batteries.
The systems considered are:

- System 1: landfilling with MSW
- System 2: incineration with MSW
- System 3: recycling with zinc recovery

The reference flows for each system are presented below in the respective system modelling.

The functional unit is defined as the amount of the batteries disposed of inside the geographical area under study during 1 year. This value is calculated assuming that the disposal of that type of batteries is equal to the average annual consumption per capita for the overall country, multiplied by the number of people living in the area covered by the study.

4.3. Initial system boundaries

The system boundaries define what is included in the system under study. Everything external to the system belongs to the system environment which is the source of inputs and the sink for outputs.

The initial system boundaries include the transport of spent batteries to the disposal unit: landfill, incinerator or recycling unit. The collection and transport to these units are included and are considered with MSW on landfilling and incineration. On recycling the collection is voluntary to a specific location and then batteries are transported to the recycling unit.

Concerning inputs and outputs the boundaries include (Figure 1):

- auxiliary materials,
- recovery products,
- energy (consumption and recovery),
- air emissions,
- water emissions,
- solid waste.

5. MODEL OF THE SYSTEMS, DATA REQUIREMENTS AND COLLECTION

The life cycle inventory stage involves collection of data that describes each system to manage spent batteries. For each system a process flow should be provided, defining the relevant inputs and outputs, the beginning of the study and the end.

For each system, batteries behaviour is predicted and emissions and resources consumption are estimated or experimentally determined.

In landfilling and incineration, specific emissions derived from the product are estimated on the base of each component behaviour, which is related to its occurrence and thermodynamic properties. Process emissions are estimated based on materials distribution on batteries and possible reactions occurring on each system. The allocations of the emissions from the landfill and incinerator to the incoming products will be based on chemical and physical causation as far as possible.

In recycling system, as the basic function is batteries disposal, and a secondary material is recovered (zinc), the flows derived from zinc extraction as raw material are subtracted from that in order to become systems function equivalent.

5.1. Incineration with MSW

The incineration system comprises a combustion chamber where the wastes enter and the combustible and thermally reactive components of the waste stream are burned in a short time period. The energy produced is then recovered and two products result from this chamber: the bottom ash and the flue gas. The gas passes on an electrofilter where particles (fly ash) are retained and follows to a special cleaning where is treated. Bottom ashes are landfilled in a monocell landfill or used as an inert product. Fly ashes and solid waste from gas cleaning are stabilised with cement and disposed of on a landfill cell for stabilised wastes. The leachate treatment of these cells is not considered.

The incineration process includes combustion on furnace, flue gas cleaning, energy recovery, fly ash stabilisation, bottom ash use and stabilised fly ashes landfilling.

The incineration process considered on this study is a mass-burn incinerator with semi-dry gas cleaning process. The system boundary and elementary flows, inputs and outputs should be clearly defined and schematically represented (Xará et al, 1999).

Concerning the emissions, a distinction can be made between product-derived emissions and process-derived emissions (Lindfors et al, 1995). Product-derived emissions are derived from the products being incinerated and examples of them are heavy metals. Process derived emissions depend basically on the combustion process. In this study, both process and product-derived emissions are considered. Each duality component-physical occurrence is specified and its behaviour predicted, and associated emissions and consumption estimated. For each component the matrix defines the availability of the component and the way how it could be transformed and/or emitted. For example, on incineration, metals will be mainly on solid residues obtained, except Hg. The chemical nature of heavy metals may be modified by heat, but they are not destroyed, therefore they will leave the incinerator either in the air emission, bottom ash, filters dust or sludge from gas cleaning (White, 1995). Obviously the emissions factors for metals depend on their matrix by consequence on the duality compound-occurrence.

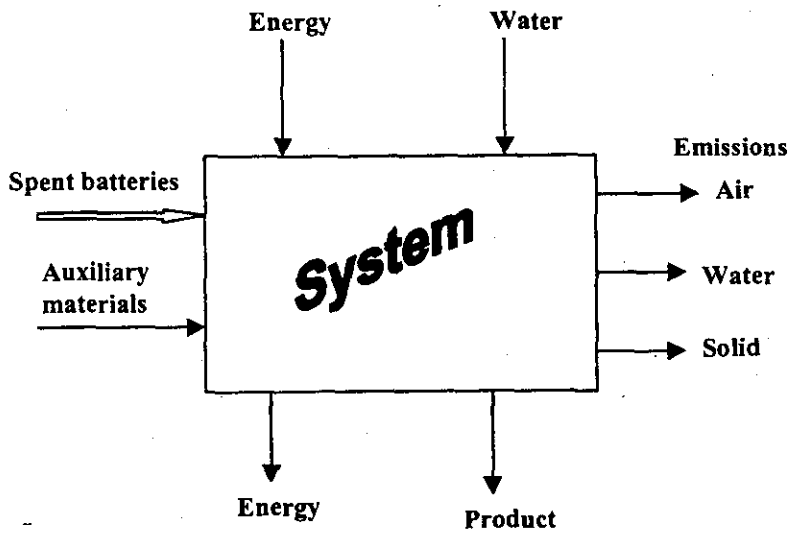

Figure 1. Template for disposal spent batteries system.

Some mass balances for metals are already published, however an attempt to consider this duality is needed. Examples of metal emissions some of them appearing also on batteries are described on literature (White, 1995, Lindfords et al, 1995).

Examples of emission parameters that can be described as both process and product derived are NOx, dust and chlorinated organic compounds ("dioxins") (Finnveden et al, 1995). Process-derived emissions will be defined based on the amount and also the occurrence of each batteries compound. The transfer coefficient on the different unit processes of incinerator, thermodynamic properties and its amount on each unit allow the prediction of auxiliary materials and energy needed. Also emissions are estimated from such analysis. Always when possible, laboratory analysis will be used to confirm predictions.

5.2. Landfilling with MSW

Landfilling is the simplest, the oldest and the most used technique for municipal solid waste disposal. This process involves the decomposition of the material waste landfilled that is described as a sequence of different phases (Christensen et al, 1989).

The outputs from landfill unit are landfill gas and leachate derived from material decomposition and final inert solid waste. Landfill gas is partially used for energy recovery and leachate is collected and treated (Xará et al, 1999).

Emissions from landfills vary with time and are typical for each phase.

The time perspective considered on analysing landfilling is an important issue since emissions from landfills may prevail for a long time. Two different time frames are available: a short term and a long term period. The short time perspective or «surveyable time-period» is defined as the time it takes to reach a pseudo steady state, after which the changes are slower than during the initial phases (Finnveden, 1992, Sundqvist, 1994). This time period should correspond to approximately one century in order to be able to compare different waste management options (Finnveden et al, 1995). The longer time perspective, the «hypothetical infinite time period» is defined by a complete degradation and spreading of all landfilled materials (Finnveden, 1992, Sundqvist et al, 1994). Since available data for emission factors for metals on landfills for the surveyable time period shows quite small values compared to the emission factors for the hypothetical infinite time period, i.e. emissions of metals occur mainly after the surveyable time period, both time perspectives will be considered in order to compare environmental burdens associated.

When considering landfills, in connection with LCA, it is not the total emission from the landfill that is of interest, but those emissions caused by the product under study (Finnveden, 1992). A landfilled product or material can influence the emissions from the landfill both directly and indirectly. The direct influence is caused by the degradation of the product itself and the subsequent emissions resulted. Only these emissions are considered in this study.

Metals on batteries (both into metal materials and metal compounds) before being emitted, must be released to the percolating water. Once released and dissolved in the leachate, the following behaviour is independent of the origin of the metal. For metal materials on batteries, the releasing process is corrosion. For metal compounds on internal parts of batteries, the degradation of the outer case determines its availability to the environment. In that order is needed to define the degradation process of the batteries under study.

In general, metals will be emitted only by leachate, except for mercury. Estimated transfer coefficient indicates about equal transfer by gas and by leachate for mercury. In general, the total potential emissions for metals are equal to the input amount.

The potential emissions from the fly ashes from batteries incineration must be also considered. In this point of view an estimation of the fly ashes characteristics must be considered.

5.3. Recycling

The recycling of household batteries has been referred in a great number of publications. Batteries recycling leads to a metal recovery dependent on the technique used.

Household batteries recycling can be classified into hydrometallurgical and pyrometallurgical (Soares, P. et al, 1998) according to the main operation in which the process is based. Pyrometallurgical processes generate less solid and liquid residues than hydrometallurgical ones. On the other hand they are energy intensive routes and generate gaseous toxic emissions.

Imperial Smelting is a pyrometallurgical process for zinc recovery that has been referred as used for batteries recycling (Schenider, W.-D. et al, 1999). Therefore, it will be selected in this study. In this process, each unit operation must be defined and input and output flows characterised and quantified.

On recycling, besides the basic function of the service system is performed, i.e. the spent battery disposal, a secondary function is also involved: the production of recycled materials.
In that case, zinc recovery from spent alkaline batteries replaces the use of primary raw materials. Since the output is the recovered materials, when evaluating the environmental burdens associated to that process a credit must be considered, subtracting the elementary flows associated with the raw materials extraction (Xará et al, 1999). Also in this disposal option, environmental burdens will be allocated as possible to batteries themselves as an input material of this process. Emissions are considered also based on thermodynamic properties of batteries components and process conditions. The final disposal of residual wastes is also considered.

6. CONCLUSIONS

To compare the relative environmental burdens associated with the disposal options for spent household alkaline batteries, an overall methodological aspects that will be considered on the study undergoing on Portugal is present. The options considered are landfilling, incineration and recycling. Each system is composed by different steps connected by the flows studied. Energy, auxiliary materials and emissions are considered. The definitions of flows identified will compose the inventory. Further phases are data collection to complete the inventory, impact assessment and interpretation.

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