Preliminary inventory of alkaline batteries incineration

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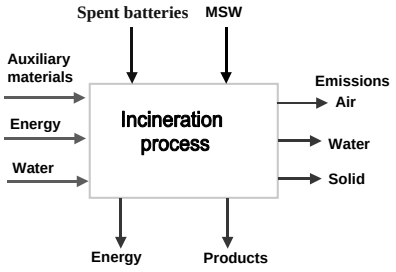
Why this inventory?

- To compare the environmental impact of incineration, landfilling and recycling domestic spent alkaline batteries using **Life Cycle Assessment** technique
- Part of a project to develop a model for evaluating the environmental impact of Municipal Solid Waste (MSW) management strategies

Life Cycle Assessment (ISO 14040)

- Technique for assessing the environmental aspects and potential impacts of a system from cradle to grave by:
  - **Compiling an inventory of relevant inputs and outputs of the system**
  - Evaluating the potential environmental impacts associated with those inputs and outputs
  - Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study

System definition

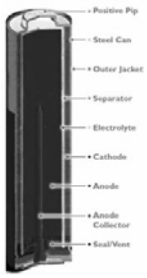


Methodology

- **Batteries characterization**
  - Structural components
  - Chemical composition
- **Incineration process description**
  - Data collection from a Portuguese incineration plant
  - Laboratory batteries incineration
- **Incineration process modelling and calculations**
  - Assumptions definition
  - Input/Output modelling and estimate

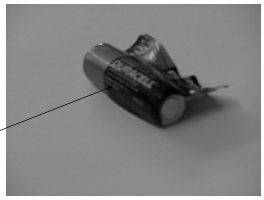
Batteries characterization

- Structural components
- Proximate analysis
  - Moisture
  - Ash content
- Chemical composition (ultimate analysis)
  - Laboratory determinations
    - Zn, ZnO (cathode)
    - C, Mn (anode)
  - Empirical formulae
    - C, S, Cl, N (plastics, paper/cardboard)
- Heating value



Structural components

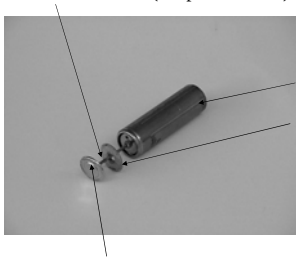
AA alkaline batteries



Outer plastic sleeve (PVC)

Structural components

Anode collector (tin-plated brass)

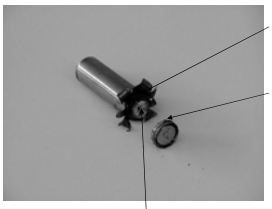


Cathode collector/can (steel)

Insulator (cardboard)

Anode cap (steel)

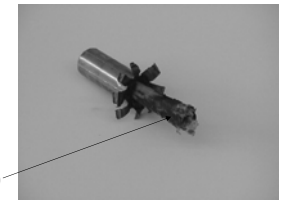
Structural components



Cathode (MnO2, C, KOH)

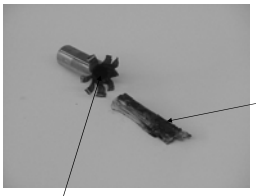
Plastic grommet (PA)

Anode
(Zn, ZnO, KOH)



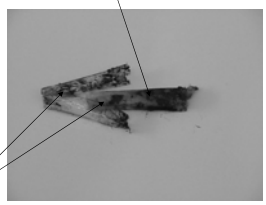
Separators (paper)

Structural components



Anode
(Zn, ZnO, KOH)

Cathode (MnO2, C, KOH)



Separators (paper)

Structural components

- **Active components**
  - Outer sleeve (PVC)
  - Insulator (cardboard)
  - Plastic grommet (PA)
  - Separators (paper)
  - Anode (Zn)
  - Cathode (C)
- **Inert components**
  - Anode cap (steel)
  - Metal separator (steel)
  - Anode collector (brass)
  - Cathode collector (steel)
  - KOH
  - Anode (ZnO)
  - Cathode (MnO_2)

Batteries characterization

- Average weight: 23.5 g
- Moisture:1.1-2.1 g
- Lower heating value: 125 kJ

- Steel: 4.7 g
- Brass: 0.44 g
- Zn: 2.4 g
- ZnO: 0.95 g
- Mn: 5.4 g
- C (graphite): 0.71 g
- Paper/cardboard: 0.22 g
- Plastics: 0.45 g

Plastics, cardboard, paper, C from graphite:

- C: 1.02 g
- H: 0.04 g
- O: 0.13 g
- N: 0.03 g
- Cl: 0.12 g
- S: 0.16 mg
- Ash content: 25 mg

Incineration operation conditions

Mass-burn incinerator

- 379 918 t/y
- 7 700 kJ/kg

Semi-dry flue gas cleaning system

- Ammonia solution (NO_x): 1 620 t/y
- $Ca(OH)_2$ (acid gases): 7 446 t/y
- Activated carbon (dioxins, Hg): 38 t/y
- Fabric filter (particles)

Fly ash stabilization

- Aditives: 26 060 t/y

Water: 106 507 m^3/y

Electricity: 2.5 MWh

Solid residues

- Bottom ash: 70 285 t/y
- Recovered ferrous: 13 860 t/y
- Fly ash: 23 175 t/y

Air emissions

- Flue gas:1 857 240 000 Nm^3
  - CO_2, SO_2, HCl, HF, Dust
  - Cd, Tl, Hg, Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V
  - CO, COV, Dioxins/furans, NO_x

Electricity: 24.7 MWh

Incineration process modelling - air emissions

- **CO_2**
  - C content batteries
  - 97% oxidation
- **SO_2, HCl**
  - S and Cl content batteries
  - 80% transferred to gas
  - 95% cleaning efficiency
- **Dust**
  - Ash content organic components
  - Zinc metal oxidation
  - 100% transferred to gas
  - 99.5% filter efficiency
- **Heavy metals**
  - Laboratory incineration tests
  - 90% removal efficiency Hg
  - 99% for other metals
- **CO, COV, Dioxins/furans**
  - C content batteries
  - Total C waste (0.3 kgC/kg waste)
  - Plant total emission
- **NO_x**
  - Fuel: 95%
    - N content batteries
    - Total N content waste (0.007 kgN/kg waste)
  - Prompt: 5%
    - Organic carbon (plastic/paper)
    - Total C waste
  - Plant total emission

Incineration process modelling

- **Bottom ash**
  - All inert components
- **Fly ash**
  - Ash content organic components
  - Zinc metal oxidation
  - 99.5% filter efficiency
  - + calcium hydroxide, activated carbon
- **Stabilized fly ashes**
  - Fly ash amount
  - Stabilization additives
- **Electricity production**
  - Heating value batteries
  - Total heating value of MSW
  - Plant production
- **Ammonia, calcium hydroxide, activated coke**
  - NOx, acid gases, dioxins from batteries
  - Total NOx, acid gases, dioxins from waste
  - Plant consumption
- **Stabilization additives**
  - Fly ash from batteries
  - Fly ash from waste
  - Plant consumption
- **Energy, water consumption**
  - Mass batteries
  - Total mass waste
  - Plant consumption

Results - 1 battery

Inputs

- Ammonia solution: 0.016 g
- Calcium hydroxide: 0.23 g
- Activated carbon: 0.34 mg
- Fly ash stabilization additives: 3.4 g
- Water: 6.6 ml
- Electricity: $1{,}5x10^{-7}$ kW

Outputs

- Bottom ash: 13.1 g
- Ferrous materials recovered: 4.7 g
- Fly ash: 3.0 g
- Electricity: 8.1 $x10^{-3}$ kW

Air emissions

- **CO_2** – 3.6 g
- **SO_2** – 0.013 mg
- **HCl** – 5.1 mg
- **Dust** – 15.1 mg
- **Cd** – 0.0001 mg **Hg** – 0.00008 mg
  Pb – 0.005 mg **Cu** – 0.0008 mg
  Mn – 0.028 mg **Zn** – 2.6 mg
- **CO** – 0.83 mg
- **COV** – 0.17 mg
- **Dioxins/furans** – 0.0017 ng
- **NO_x** – 4.5 mg

Conclusions

- Gaseous emissions versus regulatory limits:
  - **HCl** (from Cl of the outer PVC sleeve) 1st pollutant
  - **Mn** (cathode) is 2nd
  - **ZnO** from Zn oxidation is the major component of fly ash
  - **NO_x**, **VOC**, **dioxins/furans** and **CO** have the same low importance
- **Bottom ash** is the main output flow. Therefore, its disposal option may influence decisively LCA results
- **Auxiliary materials** extraction and **energy** production impact evaluation is needed