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Life Cycle Assessment of Bottom Ash Management from a Municipal Solid Waste Incinerator (MSWI)

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Thermal treatment of Municipal Solid Waste (MSW) results in various types of solid wastes, distinguishing mainly bottom, boiler and fly ashes and slag. To minimise waste generation it necessary to carry out primary measures for controlling residue outputs that involve optimising control of the combustion process. Obviously, after primary measures a secondary treatment is required. The conventional bottom ash management is to carry out a solidification process. This solidification or stabilization process produces a material with physical and mechanical properties that promote a reduction in contaminant release from the residue matrix. Solidification methods commonly make use of inorganic binder reagents such as cement, lime and other pozzolanic materials. Once waste is stabilized, it is usually sent to the landfill. However, despite the heavy metal content, it is getting more and more common the use of this waste as a natural aggregate. In particular, it could be used as a raw material for clinker production, cement mortar or frit production. Other possible management options included its utilization as a drainage layer on a landfill and as a sub-base material in a road construction. In this work it was assessed different bottom ash management options. In this work the Life Cycle Assessment (LCA) methodology was applied to assess the environmental impact of different bottom ash management options. Specifically, the conventional ash solidification was compared with the ash recycling in Portland cement production.

1. Introduction

The main objective of Municipal Solid Waste Incineration (MSWI) is to treat waste so as to reduce its volume and hazard, while capturing or destroying potentially harmful substances. Incineration processes can also provide a means to enable recovery of the energy, mineral and/or chemical content from waste (European Commission, 2006). But also thermal treatment of Municipal Solid Waste (MSW) results in various types of solid wastes, distinguishing mainly bottom, boiler and fly ashes and slag. MSWI fly ashes are fine and are normally characterized by a high content of chlorides (even higher than 10 %) and significant amounts of dangerous substances (such as heavy metals or organic compounds). MSWI bottom ashes have coarser dimensions (particles can reach several tens of millimeters in size), and the amount of chlorides and hazardous chemical is usually much lower than of MSWI fly ashes (Bertolini et al., 2004).

To minimise waste generation it is necessary to carry out primary measures for controlling residue outputs that involve optimising control of the combustion process. These measures are carried out in order to guarantee an excellent burn-out of carbon compounds, to promote the volatilisation of heavy metals such as, Mercury (Hg) and Cadmium (Cd) out of the fuel bed, and to fix lithophilic elements in the bottom ash, thus reducing their leachability. Obviously, after these primary measures a secondary treatment is required. In particular, bottom ashes are commonly subjected to a stabilization process that produces a material with physical and mechanical properties that promote a reduction in contaminant release from the residue matrix (European Commission, 2006). This technique was originally applied in view of landfilling in order to decrease heavy metal leaching and to limit transport of components into the environment (Saika et al., 2008). Solidification methods commonly make use of inorganic binder reagents such as cement, lime and other pozzolanic materials. However, despite the heavy metal content, it is getting more and more common the use of this waste as a natural aggregate. In particular, the cement industry presents the

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opportunity to recover the energy from several waste materials under optimal technical and environmental conditions (temperature, residence time or pH environment in the kiln) (Aranda Usón et al., 2012). It could be used as a raw material for clinker production (Huntzinger and Eatmon, 2009), cement mortar (Saika et al., 2008). Other possible management options due to the high mineral content include the frit production (Barbeiro et al., 2010), its utilization as a drainage layer on a landfill (Toller et al., 2009) and as a sub-base material in a road construction (Birgisdottir et al., 2006).
In this work Life Cycle Assessment (LCA) methodology was applied to assess and compare the environmental impacts of different MSWI bottom ash management options: the conventional ash solidification and the ash recycling in Portland cement production.

2. Life Cycle Assessment methodology

2.1 Goal and Scope

The goal of the work is to assess the environmental impacts of different management options of MSWI bottom ash. In particular, the ash solidification process and the ash recycling in Portland cement production. As functional unit 1 ton of MSW was selected, so all the input and output data were referred to this reference unit. As case study an incineration plant or waste to energy plant sited in Spain was selected. According to the European Pollutant Release and Transfer Register E-PRTR and Directive 2008/1/EC, the so-called IPPC Directive (that replaced Directive 96/61/EC), 10 Spanish plants are included in group 5.b; installations for the incineration of non-hazardous waste with a capacity of 3 t/h (Margallo et al., 2012). The plant treats MSW with a Low Heating Value of approximately 2,100 kcal/kg. For thermal treatment it applies a travelling grate generating in 2009 86,105 MWh of electric energy from which 85 % was sold to the public grid. For flue gases treatment a Selective Non Catalytic Reduction (SNCR), a semidry and dry scrubber and a bag filter are the main techniques applied (Margallo et al., 2012). This plant applied a solidification process to treat the ashes however this work proposes the use of this ash in Portland cement production. Figure 1a) shows the conventional treatment while in Figure 1b) the recycling of ashes in Portland cement is proposed.

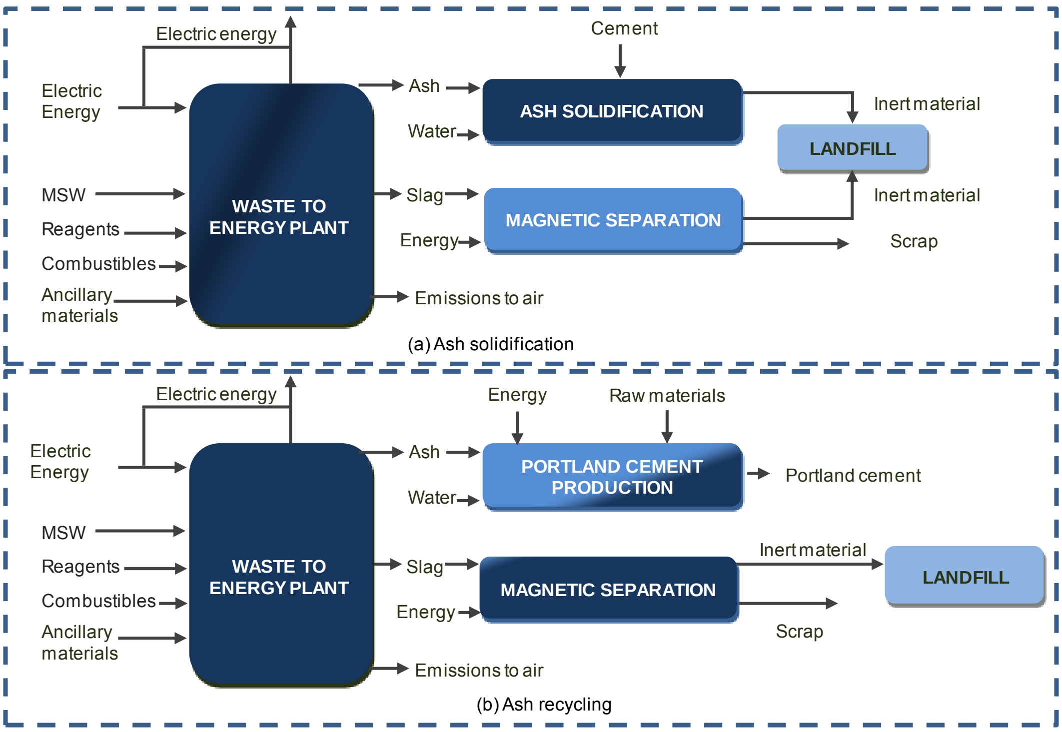

Figure 1: System description a) ash solidification and b) ash recycling in Portland cement production.

According to Figure 1 two scenarios were proposed:

- Scenario 1: ash solidification. In this process it is employed a mixture of water (30 %), cement (20 %) and ashes (50 %). This means that per each 100 kg of ashes, 40 kg of cement and 60 kg of water are required (Doka, 2003). The inert material is sent to a landfill.

- Scenario 2: ash recycling in Portland cement production. Traditional Portland cement is composed primary of calcium silicate materials such as limestone and sand. Raw materials are quarried, crushed and milled into a fine powder that feed a rotary kiln. The clinker or kiln product is cooled and gypsum is added to regulate the setting time. Usually a 20 % of gypsum is added, but in the recent years this amount has changed, replacing the gypsum by natural or industrial pozzolans. The amount of gypsum substituted range from 25 – 60 % (Huntzinger and Eatmon, 2009).

On one hand, ash recycling has a material and energy consumption associated to the Portland cement production and consequently a high environmental impact. On the other hand waste recycling avoids their disposal and the associated impacts and replaces non-renewable resources (Chen, 2010). The Portland cement production using bottom ash avoids the extraction of virgin materials such as gypsum. These recycling problems are usually solved through system expansion in most LCAs applied for waste. The system expansion applied is given in Figure 2.

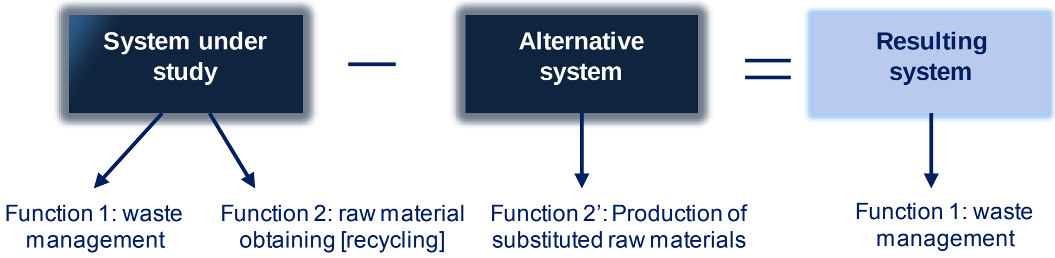

Figure 2: Scheme of the system expansion.

To expand the system and subtract the environmental impacts associated to the recovery of recycled materials it is necessary to determine a) to which type of material is replacing this recycled material and b) its equivalence to the virgin material. So it is necessary to calculate the process efficiency and the substitution factor. Bottom ash is replacing to gypsum in the Portland cement production. So the production or extraction of gypsum must be subtracted to the system under study in order to take into account the ash recycling. According to Huntzinger and Eatmon, 2009, the properties of the traditional Portland cement such as strength, durability and life are equivalent to those of the blended (with bottom ash). So a substitution factor of 1 could be applied.

2.2 Life cycle Inventory (LCI)

The Life Cycle Inventory (LCI) given in Table 1 was based on data provided by the Spanish non-profit company ECOEMBES which is responsible of the collection and recovery of packaging waste (ECOEMBES, 2010), the Spanish association of MSW valorisation AEVERSU (AEVERSU, 2011), the Spanish Pollutant Release Transfer Register PRTR (PRTR, 2010), the Environmental Integrated Authorization (EIA) of the plant, data provided by the incineration plants and bibliographic data.

Ash solidification data were collected from the Ecoinvent report on waste incineration (Doka 2003) and Portland cement production was based on the Reference Document on the Best Available Techniques on cement, lime and magnesium oxide manufacturing industries and the scientific papers (European Commission, 2010). In relation to the cement production, it was observed that different percentages of each raw material were used. This amount varies from country to country and type of cement. Table 2 shows these variations.

Table 1: Life Cycle Inventory of the incineration plant.

INPUT DATA	AMOUNT	UNITS	SOURCE	Timeframe
Combustibles				
MSW	1	t	ECOEMBES	2009
Natural gas	27.70	MJ/t MSW	EIA	2006
Reagents flue gases treatment				
$Ca(OH)_2$	12.80	kg/t MSW	EIA	2006
Activated carbon	7.77E-01	kg/t MSW	EIA	2006
Urea	11.00	kg/t MSW	EIA	2006
Ancillary materials				
Air	9,100	kg/t MSW	EIA	2006
Water	4.36E-01	m^3/t MSW	EIA	2006
OUTPUT DATA				
Main product				
Energy production	2,271	MJ/t MSW	AEVERSU	2009
Energy sales	1,921	MJ/t MSW	AEVERSU	2009
Emissions to air				
Antimony (Sb)	1.77E-05	kg/t MSW	PRTR	2009
Arsenic (As)	2.16E-05	kg/t MSW	PRTR	2009
Cadmium (Cd)	1.72E-05	kg/t MSW	PRTR	2009
Chromium (Cr)	1.29E-05	kg/t MSW	PRTR	2009
Cobalt (Co)	3.73E-06	kg/t MSW	PRTR	2009
Copper (Cu)	1.60E-05	kg/t MSW	PRTR	2009
Lead (Pb)	1.33E-04	kg/t MSW	PRTR	2009
Manganese (Mn)	1.50E-05	kg/t MSW	PRTR	2009
Mercury (Hg)	7.47E-06	kg/t MSW	PRTR	2009
Nickel (Ni)	1.20E-05	kg/t MSW	PRTR	2009
Thallium (Tl)	7.54E-06	kg/t MSW	PRTR	2009
Vanadium (V)	3.44E-06	kg/t MSW	PRTR	2009
Chloride (HCl)	1.44E-02	kg/t MSW	PRTR	2009
Fluoride (HF)	1.33E-03	kg/t MSW	PRTR	2009
Sulphur oxides (SOx/SO_2)	1.35E-01	kg/t MSW	PRTR	2009
Nitrogen oxides (NO_x)	1.10	kg/t MSW	PRTR	2009
Carbon dioxide (CO_2)	415	kg/t MSW	PRTR	2009
Carbon monoxide (CO)	1.05E-01	kg/t MSW	PRTR	2009
Total Suspended Particles (TSP)	1.84E-02	kg/t MSW	PRTR	2009
PCDD + PCDF (dioxins + furans)	3.44E-11	kg/t MSW	PRTR	2009
Incineration waste				
Slag	282	kg/t MSW	AEVERSU	2009
Ashes	47.5	kg/t MSW	AEVERSU	2009

Table 2: Raw materials for Portland cement production.

	Huntzinger and Eatmon 2009	Pan et al., 2007	BAT document on cement manufacturing in Spain (Spanish Environmental Ministry, 2004)	BREF document on lime, cement and MgO manufacturing industries (European Commission, 2010)
Limestone	60 – 67 %	75 – 77 %	88.2 %	66.3 – 68 %
Sand, sílica (SiO_2)	17 – 25 %	1 – 2 %	8.7 %	22.5 – 24 %
Alumina, Clay (Al_2O_3)	2 – 8 %	17 – 22 %	2.2 %	2.3 – 6.2 %
Iron or copper oxide	0 – 6%	0 – 2 %	0.9 %	0.2 – 2.1 %

3. Life cycle Impact Assessment

The environmental assessment of the proposed scenarios was carried out following the ISO 14040 (ISO, 2006a) and ISO 14044 requirements (ISO, 2006b) with the LCA software GaBi 4.4 (PE International, 2011) and the environmental impact method proposed by CML (CML, 2001). The selected impact categories were: Abiotic Depletion (ADP) [kg Sb-Equiv.], Acidification Potential (AP) [kg SO_2-Equiv.], Eutrophication Potential (EP) [kg Phosphate-Equiv.], Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB-Equiv.], Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB-Equiv.], Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.], Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.], Photochemical Ozone Creation Potential (POCP) [kg Ethene-Equiv.] and Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB-Equiv.].

Results given in Figure 3 show that ash treatment by means of a solidification process (Scenario 1) has the highest impact in the categories of GWP and HTP. This treatment includes the ash solidification and landfilling. Solidification with cement is the stage with the highest impact in all the categories, representing between the 84 - 99.9 % of the total impact in the ash treatment. This is due the high impact associated to the cement production, mainly due to the high energy consumption of the process and the emissions generated in the clinker production. Inert landfill contribute around 20 % to the total impact of ash treatment in AP, EP and PCOP (20%) due to the air emissions of ammonia, SO_2, NMVOC, hydrocarbons and other organic compounds.

The highest impacts in Scenario 2 are in the categories AP, HTP and PCOCP. The emissions of SOx, HF and HCl (AP), Hg and dioxins (HTP) and NMVOC (POCP) in the clinker production are the main contributors to these impacts.

When both scenarios are compared, Figure 3 shows that ash recycling has lower impact in all the categories except in AP and POCP. The main reasons are the benefit of ash recycling together with the high environmental impact of the cement production in the solidification process. This environmental benefit associated with the avoided gypsum consumption can be observed in the negative values of some categories such as ADP, FAETP or TETP.

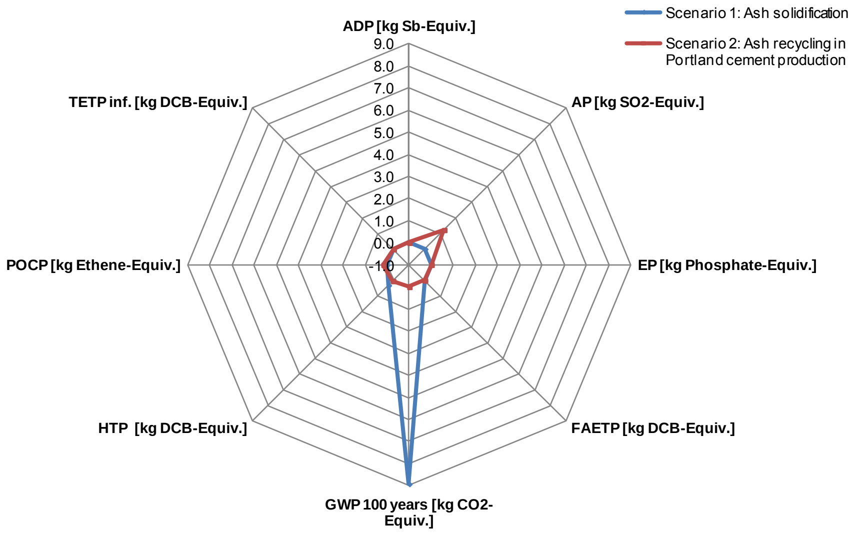

Figure 3: Environmental impacts of ash solidification and ash recycling in Portland cement production.

4. Conclusions

This work assesses the environmental impacts of some treatment alternatives of MSWI bottom ash: ash solidification with water and cement and ash recycling in Portland cement production. For this propose the LCA methodology was applied. Results show that ash recycling in Portland cement production has lower impact in all the categories selected except in Atmospheric Acidification Potential (AP) and Photochemical Ozone Creation Potential (POCP). This can be associated on one hand to the high impact of cement production in the ash solidification and on the other hand to the environmental benefit of ash recycling. In particular it avoids the extraction of virgin materials such as gypsum which can be observed in the negative values of some impacts categories.

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