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Best Available Techniques in Municipal Solid Waste Incineration: State of the Art in Spain and Portugal

María Margallo[*a], Rubén Aldaco[a], Alba Bala[b], Pere Fullana[b], Ángel Irabien [a]

[a]Departamento de Ingeniería Química y Química Inorgánica, Universidad de Cantabria, Avda. de Los Castros, s.n., 39005, Santander, Spain;
[b]Escola Superior de Comerç Internacional (ESCI-UPF), Pg. Pujades 1., 08003 Barcelona, Spain
margallom@unican.es

In the year 2010 more than 24 Mt and 5 Mt of Municipal Solid Waste (MSW) were generated in Spain and Portugal. Landfilling, incineration and recycling are the most common treatments. In 2010, in the Iberian Peninsula between 58-6 2 % of the MSW generated was sent to the landfill, 9-19 % was incinerated and the rest was recycled and composting (EUROSTAT, 2010). Despite landfilling is still the most common practice, waste treatment by means of an incineration process has increased. The main advantages of this type of waste treatment are the reduction of mass and volume of residues and the energy recovery. Nevertheless, incineration had gained a bad reputation owing to the environmental impact, in particular, due to the emissions of acid gases, dioxins and furans (PCDD/F) and greenhouse gases. To assess the environmental advantages and disadvantages as well as the potential environmental impacts of waste incineration a life cycle perspective is required. Within this framework is the development of FENIX-Giving Packaging a New Life, a 3-year European LIFE+ funded project. This work is just the first step within this project where a database and a model based on Life Cycle Assessment (LCA) to assess the environmental impacts of waste incineration in Spain and Portugal will be developed. Particularly, the aim of this paper is to review the different technologies applied to MSW solid waste incineration and to carry out both the diagnosis of the current situation at the incineration plants in Spain and Portugal and to collect data to develop the Life Cycle Inventory (LCI).

1. Introduction

Municipal Solid Waste (MSW) generation in Europe has increased regularly in recent years, amounting in 2010 to more than 2 billion tons of waste, that is to say a waste generation rate of 502 kg MSW/person. The same growth trend can be seen in Spain and Portugal, where in 2010 a waste generation of 535 and 514 kg of MSW/per capita was reached respectively. In 2010 in Spain more than 24 Mt of MSW were generated, 58 % being sent to the landfill, 9 % incinerated and the rest being recycling and used produce compost. For the same year, in Portugal more than 5 Mt of municipal solid waste were generated. 62 % of this waste was sent to the landfill, 19% was incinerated and the rest was recycled and composting (EUROSTAT, 2008). According to the available data, from 1998 to 2010 an increase in the incineration share of 68 % in Spain and 100 % in Portugal has come about. This rapid development of the sector has taken place over the last 10 to 15 years driven by the legislation specific to industry that has reached reducing emissions to air (European Commission, 2006). The main advantages of this type of waste treatment are the reduction of mass and volume of residues and the recovery of energy content in that waste with a significant heating value. However, incineration had

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gained a bad reputation owing to the environmental impact specifically due to the emissions of acid gases, dioxins and furans (PCCD/F) and greenhouse gases (Chevalier et al., 2003, Morselli et al., 2007). To assess the advantages and disadvantages and the environmental impacts of the incineration process a life cycle perspective is required. Life Cycle Assessment (LCA) is a powerful tool for assessing the environmental performance of a product, process or activity from "cradle to grave" (ISO 2006a and 2006b). Within this framework is the development of FENIX-Giving Packaging a New Life, a 3-year European LIFE+ funded project that started in January 2010. The aim of this project is to develop a flexible and user-friendly software tool to be used by Spanish and Portuguese municipalities and other territorial organizations, to obtain LCA results for packaging waste management, integrating environmental, economic and social aspects.

This work is just the first step in the development of a database and a model based on LCA to assess the environmental impacts of waste incineration in Spain and Portugal. Specifically, the aim of this paper is to review the different technologies applied to MSW solid waste incineration and to carry out both the diagnosis of the current situation at the incineration plants in Spain and Portugal and to collect data to develop the Life Cycle Inventory (LCI).

2. The incineration process

The main objective of Municipal Solid Waste (MSW) incineration 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. Incineration is used as a treatment for a very wide range of waste types such as MSW, Hazardous Waste (HW) or sewage sludge (European Commission, 2006).

2.1 Thermal treatment

Different types of thermal treatments are applied to the different types of waste, however not all treatments are suited to all waste. The most common technologies applied are grate incinerators, rotary kilns, fluidised beds (FB) and pyrolysis and gasification systems. For MSW and Refuse Derived Fuel (RDF) incineration grates are widely applied, FB and rotary kilns are also applied but to a lesser extent. On the other hand, pyrolisis and gasification are rarely applied because they are still considered as emerging technologiesthis. In poarticular it is a less proven technology and the unclear economic benefits hamper a larger market penetration (Van Caneghem et al., 2012). In particular, in Spain and Portugal only grate incinerators and fluidised beds are applied at MSW incineration plants. In Spain 80 % of thermal treatment systems are grates while in Portugal this goes up to 100 %.

Grate incinerators (GI): in Europe approximately 90% of the installations treating MSW use grates. Grate incinerators usually comprise the waste feeder, incineration grate, bottom ash discharge, the incineration air duct system to ensure complete combustion, incineration chamber and auxiliary burners to heat up the furnace to a specified temperature. The optimum incineration conditions in which to achieve a good burn out of the gases are a minimum gas phase combustion temperature of 850 ºC (1,100 ºC in some hazardous wastes) and a minimum residence time of the flue-gases, above this temperature, of 2 seconds after the last incineration air supply (European Commission, 2000).The main types of grates are rocking, reciprocating, travelling and cooled grates (European Commission, 2006).

Fluidised beds (FB): they are widely applied to the incineration of finely divided waste such as RDF and sewage sludge. The FB incinerator is a lined combustion chamber in the form of a vertical cylinder. In the lower section a bed of sand, combustion ash, or other sand-like material is suspended in an upward flowing airstream. Normally this type of incineration requires a preparatory process step which makes raise the process costs. The main types of FB are stationary or bubbling fluidised bed, spreader-stoker furnace and rotating FB (European Commission, 2006; Van Caneghem et al., 2012).

2.2 Energy recovery

The majority of the energy produced during combustion is transferred to the flue-gases. Cooling of these gases allows energy recovery and the cleaning of flue-gases before they are released into the atmosphere. Conventional recovery involves passing the flue gases through a boiler, thereby obtaining steam, which can be turned into energy by means of an engine (White et al., 1995). The principal uses of the energy transferred to the boiler are the production and supply of heat and the production and supply of electricity. Specifically, in Spain and Portugal is carried out but the energy recovered is used for the self consumption at the plant and sold to the public grid.

2.3 Flue-gas treatment (FGT) systems
Before the emission to air, flue gases must be cleaned by a combination of individual process units that together provide an overall treatment. The number of different treatment processes used varies widely from plant to plant, reflecting the emission standard required (Chevalier et al., 2003). Different techniques are applied to clean different pollutants such as acid gases, organic compounds or NOx.

Particulates: the main types of techniques are electrostatic precipitator (EP), ionisation wet scrubbers (IWS), fabric filters or bag filters and cyclones and multi-cyclones.

Acid gases (HCl,HF and SO_x): these gases are cleaned using alkaline reagents (CaO and $Ca(OH)_2$) by means of dry, semidry or wet processes. The main different between them is that in the wet process the reaction product is aqueous requiring a treatment prior to discharge (White et al., 1995).

Nitrogen oxides (NO_x): NO_X are reduced to N_2 and water vapour by the reduction agent (NH_3 or urea) applying Selective Non-Catalytic Reduction (SNCR) process or Selective Catalytic Reduction (SCR) process where the flue-gas pass over a catalyst (European Commission, 2006).

Dioxins and furans (PCCD/F): most usual treatment is adsorption on activated carbon but also bag filters and SCR could be applied.

2.4 **Solid residue treatment**
The main waste types arising from the combustion stage are bottom ash and boiler and fly ashes that are usually treated together. They are generally disposed of, often after a solidification process with water and cement, but could be used as a filling material in civil construction. Slag is usually subjected to magnetic separation, from which a metallic fraction is obtained made up of metallic waste contained in MSW and non-metallic fraction comprising ceramic and vitreous materials and particles not burned in the combustion process. The metallic fraction, ferrous scrap, is used to produce steel in an electric arc furnace (Lopez-Delgado et al., 2003). The inert material is sent to landfill.

3. The incineration of MSW in Spain and Portugal

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), dated September 2010, 10 Spanish facilities and 3 Portuguese plants are included in group 5.b; installations for the incineration of non-hazardous waste with a capacity of 3 tonnes per hour (European Parliament and Council, 2006). Figure 1 shows a map of the plants location.

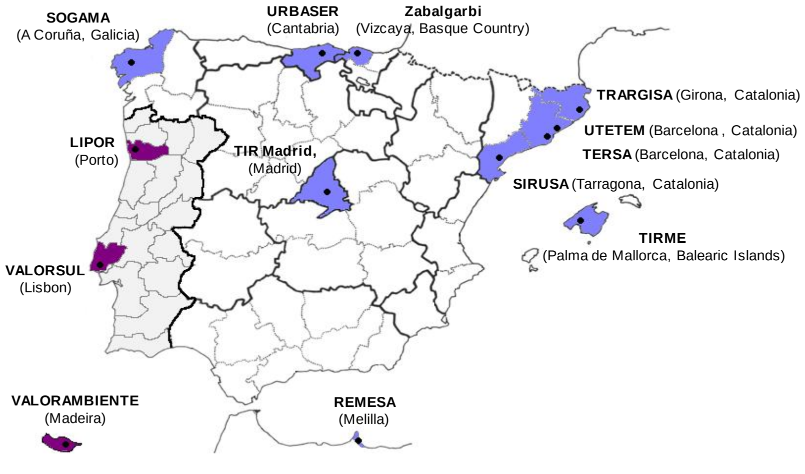

Figure 1. Location of the Spanish and Portuguese incinerators (Source: own elaboration based on E-PRTR information).

In relation to the Spanish incineration plants, there are four plants in Catalonia (Spain). Two of them are located in Barcelona -Planta de Valortització Energética Sant Adrià de Besòs (TERSA) and Tractament i Revaloritzaió de Residus del Maresme, S.A. (UTETEM)- one in Girona -TRARGISA area de residus- and the last one in Tarragona -Incineradora de Tarragona (SIRUSA)-. Table 1 shows technical and operational data for the four incineration plants sited in Catalonia (AEVERSU, 2010).

Table 1: Technical and operational data of TERSA, UTETEM, TRARGISA, SIRUSA.

	Tersa	**Utetem**	**Trargisa**	**Sirusa**
Type furnace	Von Roll grate	Martin travelling grate	Martin reverse-acting grate	Reciprocating grate
Tons MSW incinerated	321,728	170,274	35,053.46	151,849
LHV (kcal/kg)	1,900-2,200	2,100	1,800	2,000
Energy production (MWh)	167,504	86,105		44,552
Energy sales (MWh)	144,761	72,809		N.A
Slag (t)	55,642	41,973	6,338	30,921
Ashes (t)	12,039	7,237	650	3,508
Flue gases treatment	SNCR, bag filters, scrubbers, electro filters, activated carbon	SNCR, semidry and dry scrubber, bag filter	Bag filter, activated carbon	Semidry system, bag filter, activated carbon

Three incinerators are sites in the North of Spain. In particular in Cantabria -Planta de Tratamiento Integral de RSU de Cantabria (URBASER)-, Vicaya (Basque Country) -Zabalgarbi, S.A.- and in A Coruña (Galicia) -Complejo medioambiental de Cerceda (SOGAMA)-. The rest of incineators are located in Madrid -TIR Madrid-, Melilla –PIR Melilla, REMESA- and in Mallorca (Balearic Islands)- TIRME S.A.-. In Table 2 and 3 are given the data of these plants and in Table 4 the emissions to air of all the Spanish incinerators are shown (AEVERSU, 2010) .

Table 2: Technical and operational data of Zabalgarbi, SOGAMA and URBASER.

	Zabalgarbi	**SOGAMA**	**URBASER**
Type furnace	Reciprocating grate	Circulating FB	Roller grate
Tons MSW incinerated	223,933	550,000	113,338
Energy production (MWh)	661,160	335,078	82,800
Energy sales (MWh)	632.000	332,761	N.A
Slag (t)	42,547	69,038	14,972
Ashes (t)	8,375	33,240	4,536
Flue gases treatment	SNCR, semidry system, bag filter, activated carbon	Semidry system, bag filters, activated carbon	Scrubber, bag filter, activated carbon

Table 3: Technical and operational data of Zabalgarbi, SOGAMA and URBASER.

	TIR Madrid	**PIR Melilla**	**TIRME**
Type furnace	bubbling FB	serrated grate	roller and cooled grates
Tons MSW incinerated	418,905	40,986.7	294,185
LHV (kcal/kg)	3,500	1,400-3,000	1,800
Energy production (MWh)	234,841	N.A	152,389
Energy sales (MWh)	170,014	11,298	119,759
Slag (t)	N.A	9,397	69,133
Ashes (t)	N.A	1,043	28,242
Flue gases treatment	Cyclones, bag filters, SCR, scrubber, activated carbon	Semidry system, bag filter, activated carbon	Semidry scrubber, SCR, bag filter, activated carbon

Table 4: Emissions to air of the Spanish incinerators in 2009.

Pollutants mg/Nm^3	Incineration plants									
	Tersa	**Utetem**	**Trargisa**	**TIR Madrid**	**Zabal-Garbi**	**Sirusa**	**Tirme**	**Sogama**	**PIR Melilla**	**Urbaser**
HCl	5.9	2.11	3.8	4.2	3.2	7.0	0.0	<2.5	8.7	5.3
Particles	3.24	2.73	3.0	9E-1	8.7	7.0	<1.1	<6	22.6	3.68
CO	35.9	24.9	4.1	14.1	4.47	8.35	<4.0	<27	<4.6	11.6
HF	6E-2	1.9E-1	0.0	6E-2	2.8E-2	1.0	<4E-2	<1.5	<3.2E-2	3.3E-1
SO_2	14.4	20.15	0.0	3.2E-1	11.37	33	<7.5	<14	<13.6	1.36
Metals [(1)]	3.9E-2	3.8E-2	5E-3	5.3E-2	6.1E-2	6E-3	<2.9E-2	7E-2	<9.8E-2	1.4E-1
Cd+Tl	7.2E-3	5.4E-3	2.5E-3	<5E-4	2E-3	4.4E-3	<2E-3	<3E-2	<7.2E-3	1.4E-2
NH_3	6.1E-3	2.3E-3	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A
TOC	1.59	3.63	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A
Hg	N.A[(3)]	N.A	3E-3	6E-4	2E-3	5E-2	<2.5E-3	<1E-2	<1.6E-4	2.5E-3
VOC	N.A	N.A	3.4	1.4	1.4	8E-1	<5	<7	<1.4	2.8
PCDD/F[(2)]	1.4E-2	4.6E-3	6E-3	9E-3	7E-3	3E-3	5.6E-3	1.4E-2	2.5E-2	1.7E-2
NO_x	135 ppm	155	225	123	157	161	51.3	116	195	158

[1)] Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V; [2)] ng ITEQ/Nm^3; [3)] N.A: Data Not Available.

In Portugal the 3 incinerators are located in Lisboa -VALORSUL, Valorização e Tratamento de Resíduos da Área Metropolitana de Lisboa (Norte), S.A S.-, Madeira -Valor Ambiente Gestão e Administração de Resíduos da Madeira- and Porto –LIPOR, Serviço Intermunicipalizado de Gestão de Resíduos do Grande Porto-. In Table 5 the main data and emissions of the Portuguese incinerators are given (VALORSUL, 2010, Valor Ambiente, 2010, LIPOR, 2010).

Table 5: Technical and operational data and emissions to air of the Portuguese incinerators in 2009.

	VALORSUL	**Valor Ambiente**	**LIPOR**
Incineration capacity (ton/year)	662,000	126,000	400,000
Type furnace	Reverse-Acting grate	Roller grates	Grate
Energy production (MWh)	N.A	N.A	200,000
Slag (kg/ton MSW)	200	160	N.A
Ashes kg/ton MSW)	30	N.A	N.A
Emissions to air (mg/Nm^3)			
CH_4	N.A	515,000	N.A
PCDD/F	N.A	1E-4	N.A
CO_2	502,000,000	N.A	357,000,000
Hg	N.A	N.A	N.A
HCl	17,600	N.A	N.A
NO_x	502,000	N.A	265,000
N_2O	59,500	N.A	N.A
NH_3	N.A	N.A	11,700

4. Conclusions

In this work the most relevant technologies applied in MSW incineration in Spain and Portugal have been determined and will be included in the future database and model based on LCA. The main data are collected from the European Pollutant and Transfer Register (E-PRTR), the Business Association of MSW valorisation (AEVERSU) and websites of different incineration plants.Regarding the thermal stage, grate incinerators, rotary kilns and FB could be applied to a range of waste types. In the case of MSW treatment, only grate incinerators and FB are used. Fluidised bed are applied to a smaller extent than grate incinerators because a preparatory stage is required when heterogeneous waste is treated. Specifically, in Spain the application of grate incinerators makes up 80% of incinerators, rising to 100% in Portugal. The majority of the energy produced during combustion is used for the self consumption at the plant and sold to the public grid.The amount of energy produced differs from one plant to another and depends on the amount of waste incinerated and the heating value. Before being emitted the flue gases need treatment. Different systems are applied depending on the pollutants contained in the gases. For reducing particulate emissions in Spain and Portugal, electrofilters and bag filter are the technologies that are most often applied, and to a less extent cyclones and multicyclones. Acid gases such are treated through dry and semi-dry processes using an alkaline reagent such as CaO and $Ca(OH)_2$. To remove NOx Selective Non Catalytic Reduction (SNCR) and the Selective Catalytic Reduction (SCR) are applied. In both cases NH_3 or urea is the reagent used to reduce the NOx to N_2. Other important pollutants generated during the combustion are organic compounds like PCDDD/F. These substances are usually treated by absorption on activated However, SCR systems, catalytic bag filters, and static bed filters are also available. With regard to waste, slag and ashes (bottom, fly and boiler ash) are generated during the combustion process. Ashes are usually disposed of at a landfill, sometimes following a stabilization process with cement and water. Slag is usually subjected to magnetic separation, with the metallic fraction, ferrous scrap used to produce steel in an electric arc furnace and the inert material sent to landfill.

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