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Life-cycle assessment of selected management options for air pollution control residues from waste incineration

Thilde Fruergaard, Jiri Hyks, Thomas Astrup *

Department of Environmental Engineering, Miljoevej, Building 113, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark

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ABSTRACT

Based on available technology and emission data seven selected management options for air-pollution-control (APC) residues from waste incineration were evaluated by life-cycle assessment (LCA) using the EASEWASTE model. Scenarios were evaluated with respect to both non-toxicity impact categories (e.g. global warming) and toxicity related impact categories (e.g. ecotoxicity and human toxicity). The assessment addressed treatment and final placement of 1 tonne of APC residue in seven scenarios: 1) direct landfilling without treatment (baseline), 2) backfilling in salt mines, 3) neutralization of waste acid, 4) filler material in asphalt, 5) Ferrox stabilization, 6) vitrification, and 7) melting with automobile shredder residues (ASR). The management scenarios were selected as examples of the wide range of different technologies available worldwide while at the same time using realistic technology data. Results from the LCA were discussed with respect to importance of: energy consumption/substitution, material substitution, leaching, air emissions, time horizon aspects for the assessment, and transportation distances. The LCA modeling showed that thermal processes were associated with the highest loads in the non-toxicity categories (energy consumption), while differences between the remaining alternatives were small and generally considered insignificant. In the toxicity categories, all treatment/utilization options were significantly better than direct landfilling without treatment (lower leaching), although the thermal processes had somewhat higher impacts than the others options (air emissions). Transportation distances did not affect the overall ranking of the management alternatives.

1. Introduction

Residues from municipal solid waste (MSW) incinerators have received considerable attention within recent decades and numerous studies have been carried out focusing on treatment, utilization, and leaching mechanisms (e.g. Kirby and Rimstidt, 1994; Kosson et al., 2002; Dijkstra et al., 2008). While bottom ashes can serve as excellent construction materials after simple treatment (Van Gerven et al., 2005; Astrup, 2007), air pollution control (APC) residues are categorized as hazardous waste and are generally not suited for utilization due to their poor technical properties and high contents of salts and heavy metals (Hjelmar, 1996; Hyks et al., 2009a). Over the years significant efforts have been placed on developing stabilization processes focusing on immobilizing heavy metals in APC residues (Kinto, 1996; Iretskaya et al., 1999; Ecke et al., 2000; Lundtorp et al., 2002; Cai et al., 2003; Aguiar del Toro et al., 2009) and while numerous processes have been implemented worldwide, no specific trend has emerged with respect to the stabilization approach (Astrup, 2008). Apparently, management strategies and selection of processes primarily rely on local traditions and conditions rather than on a systematic evaluation of environmental benefits and drawbacks.

Today APC residue management strategies can be categorized by the following process types (Chandler et al., 1997; Sabbas et al., 2003; Astrup, 2008): i) extraction and separation, ii) chemical immobilization, iii) solidification, and iv) thermal treatment. While the simpler processes, such as extraction, solidification and to some extent chemical immobilization, only require limited use of resources (energy and materials) they may also provide less-than-perfect stabilization. Thermal treatment on the other hand may potentially provide excellent stabilization but also use substantial energy in the process. Ideally, when selecting a specific treatment process stakeholders should balance such aspects accounting for relevant indirect consequences too. This is, however, a complicated task and is done only in very rare occasions.

With numerous processes available worldwide (Astrup, 2008) selecting the best treatment and disposal options for APC residues from an environmental point of view may not be an easy task. To provide an improved basis for waste incinerators and approving authorities, coherent evaluations of benefits and drawbacks related to the wide range of treatment and disposal options available are necessary. Life-cycle assessment (LCA) is a suitable method for such an evaluation as it provides a holistic approach by aiming at including

* Corresponding author. Tel.: +45 4525 1558; fax: +45 4593 2850.
E-mail address: tha@env.dtu.dk (T. Astrup).

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and quantifying all direct and indirect emissions and resource consumptions throughout the life-cycle of the considered system. During the past 15–20 years life-cycle assessment has been a widely applied tool for assessment of waste management solutions, but only a few studies have focused on the environmental aspects of ash management. Olsson et al. (2006), Birgisdóttir et al. (2007) and Carpenter et al. (2007) focused on utilization of bottom ashes from waste incineration, whereas Mroueh et al. (2001) and Babbitt and Lindner (2008a,b) evaluated the environmental impacts of utilization of fly ashes from coal combustion. Toller et al. (2009) focused on two ash types: MSW bottom ash and wood fly ash. No studies on environmental assessments of APC residues were found.

The overall aim of this paper was to compare seven selected treatment and disposal options for APC residues in a life-cycle perspective representing a wide range of process types used around the world. With these processes as examples and based on actual data collected for both full-scale and pilot-scale installations, the paper i) quantifies the potential environmental impacts and highlights significant emissions from the selected alternatives, ii) evaluates critical boundary conditions and uncertainties, and iii) provides important recommendations for future management of these residues.

2. Modeling approach

2.1. Life-cycle assessment framework

The functional unit was “treatment and final disposal of one tonne of APC residue, including secondary and avoided processes”. The time horizon of the LCA was 100 years, focusing on environmental impacts within a foreseeable future. The impacts of this choice were discussed in Section 4.4. To provide more generic conclusions, an average chemical composition of APC residues from a range of Danish incinerators with semi-dry and wet flue gas cleaning systems was used as a basis for the assessment. The importance of this choice was discussed in Section 4.3.

The assessment included consumption of energy and resources for managing residues, emissions to air/water/soil, secondary processes (i.e. processing of materials for utilization) and avoided processes (i.e. avoided production of primary materials substituted by the residues). Residue transport was assessed separately based on Danish conditions.

Construction and decommissioning of infrastructure, buildings, machinery, etc. and household-like waste generated in small amounts from the treatment plants were excluded from the assessment. Their impacts were assumed to be of similar size for each treatment option thereby counterbalancing each other out when comparing the different options. It was considered reasonable to exclude these impacts as the overall aim of the paper was to compare different treatment alternatives rather than quantifying the total environmental impacts of each option.

2.2. Impact assessment: scenarios

The LCA model EASEWASTE (Kirkeby et al., 2006) was used for the environmental assessment. EASEWASTE is specifically made for LCA of waste management systems and facilitates a comprehensive environmental impact assessment by calculating waste flows, resource consumption and environmental emissions from individual waste technologies within the system. The model allows flexible definition of individual scenarios and includes default background data needed for the assessments of waste systems. The environmental impacts assessed in this paper followed the EDIP97 methodology (Wenzel et al., 1997) using the latest version of the normalization references (Stranddorf et al., 2005). The impact categories included were: Global Warming (GW), Acidification (AC), Nutrient Enrichment (NE), Photochemical Ozone Formation (POF), Human Toxicity via Air (HTa), via water (HTw) and via soil (HTs), and Ecotoxicity in Water (chronic) (ETw) and in soil (ETs). For Global Warming the scale is global, for all other categories the results apply to Europe.

Seven overall scenarios were discussed, see Table 1. Each scenario is briefly outlined below. For technical details regarding the individual processes, please refer to Astrup (2008).

2.2.1. Scenario 1: landfilling without pretreatment

Scenario 1 involved direct landfilling of the residues without pretreatment and served as a reference for the discussions in this paper rather than being a realistic option for residue management in Denmark. The scenario included average energy consumption for low-organic landfills (Manfredi and Christensen, 2009), treatment of collected leachate, and leaching of heavy metals to water and soil during the 100 year time horizon. The leaching data were based on

Table 1
Management scenarios assessed in the LCA.

Scenario	Description	Process	Material utilization	Emissions from landfill
1	Landfilling without any pretreatment			Leaching from landfill
2a, 2b	Utilization as backfilling material in German salt mines	Solidification in cement	a: No substitution b: Substitution of natural aggregates	No
3a, 3b	Utilization for neutralization of waste acid in Norway	Water and acid extraction, solidification in gypsum	a: No substitution b: Substitution of limestone	No, but wastewater emissions
4a, 4b	Utilization as filler material in asphalt in the Netherlands	Solidification in asphalt	Substitution of limestone	a: Leaching from solidified material based on lowest data values in Scenario 5 and 6 b: Leaching from solidified material based on highest data values in Scenario 5 and 6
5	Ferrox stabilization followed by landfilling	Water extraction and chemical stabilization		Wastewater emissions and leaching from landfill
6	Vitrification followed by landfilling	Melting		Leaching from landfill
7a, 7b	Thermal co-treatment of APC residues with automobile shredder waste followed by reutilization and landfilling	Melting	Substitution of energy and natural aggregates a: Avoids landfilling of shredder waste b: Avoids incineration of shredder waste	Leaching from solidified material