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LCA of management strategies for RDF incineration and gasification bottom ash based on experimental leaching data

Martina Di Gianfilippo [a], Giulia Costa [a,*], Sara Pantini [a], Elisa Allegrini [b], Francesco Lombardi [a], Thomas Fruergaard Astrup [b]

[a] Laboratory of Environmental Engineering, Department of Civil Engineering and Computer Science Engineering, University of Rome "Tor Vergata", Via del Politecnico 1, 00133 Rome, Italy

[b] Department of Environmental Engineering, Technical University of Denmark, Building 113, DK-2008 Kgs. Lyngby, Denmark

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ABSTRACT

The main characteristics and environmental properties of the bottom ash (BA) generated from thermal treatment of waste may vary significantly depending on the type of waste and thermal technology employed. Thus, to ensure that the strategies selected for the management of these residues do not cause adverse environmental impacts, the specific properties of BA, in particular its leaching behavior, should be taken into account. This study focuses on the evaluation of potential environmental impacts associated with two different management options for BA from thermal treatment of Refuse Derived Fuel (RDF): landfilling and recycling as a filler for road sub bases. Two types of thermal treatment were considered: incineration and gasification. Potential environmental impacts were evaluated by life-cycle assessment (LCA) using the EASETECH model. Both non-toxicity related impact categories (i.e. global warming and mineral abiotic resource depletion) and toxic impact categories (i.e. human toxicity and ecotoxicity) were assessed. The system boundaries included BA transport from the incineration/gasification plants to the landfills and road construction sites, leaching of potentially toxic metals from the BA, the avoided extraction, crushing, transport and leaching of virgin raw materials for the road scenarios, and material and energy consumption for the construction of the landfills. To provide a quantitative assessment of the leaching properties of the two types of BA, experimental leaching data were used to estimate the potential release from each of the two types of residues. Specific attention was placed on the sensitivity of leaching properties and the determination of emissions by leaching, including: leaching data selection, material properties and assumptions related to emission modeling. The LCA results showed that for both types of BA, landfilling was associated with the highest environmental impacts in the non-toxicity related categories. For the toxicity related categories, the two types of residues behaved differently. For incineration BA the contribution of metal leaching to the total impacts had a dominant role, with the highest environmental loads resulting for the road scenario. For the gasification BA, the opposite result was obtained, due to the lower release of contaminants observed for this material compared to incineration BA. Based on the results of this study, it may be concluded that, depending on the type of BA considered, its leaching behavior may significantly affect the results of a LCA regarding its management strategies.

1. Introduction

Bottom ash (BA) is the most abundant solid residue generated by waste thermal treatment, accounting for 10–30% of the input waste mass, depending on the specific type of technology and operating conditions applied (Hjelmar et al., 2010). As BA exhibits similar technical properties to those of natural aggregates, in recent years, several efforts have been made in order to encourage the recycling of BA as secondary material in construction applications. This may result in two main beneficial effects: (1) a decrease in waste landfilling, which presents significant environmental impacts including land use, (2) a reduction in the consumption of

Abbreviations: AD Fossil, abiotic depletion of fossil resources; AD Mineral, abiotic depletion of mineral resources; ANC, acid neutralization capacity; BA, bottom ash; CD, contaminants distribution; CF, characterization factor; EF, eutrophication in freshwater environments; EM, eutrophication in marine environments; EP, eutrophication in terrestrial environments; ET, freshwater ecotoxicity; FU, functional unit; HTc, human toxicity, carcinogenic effects; HTnc, human toxicity, non-carcinogenic effects; GW, global warming; L, landfill; LCA, life cycle assessment; LCIA, life cycle impact assessment; *L/S*, liquid to solid ratio; LWB, landfill water balance model; MSW, municipal solid waste; OD, stratospheric ozone depletion; POF, photochemical oxidant formation; R, road; RDF-G, refuse derived fuel gasification; RDF-I, refuse derived fuel incineration; TA, terrestrial acidification; TD, transport distance; WWTP, wastewater treatment plant.

* Corresponding author. Tel.: +39 0672597039; fax: +39 0672597021.
E-mail address: costa@ing.uniroma2.it (G. Costa).

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virgin raw materials. The main recycling option adopted for BA is as unbound material in road sub-base construction (e.g.: Åberg et al., 2006; Hjelmar et al., 2007; Lidelöw and Lagerkvist, 2007). In addition, the use of this type of waste material to produce aggregates or as additive in concrete has also been tested at lab scale (Ferraris et al., 2009; Cioffi et al., 2011; van der Wegen et al., 2013). However, the limiting factor for utilizing this type of residue is related to its potential release of contaminants upon contact with water (i.e. its leaching behavior). In fact, compared to natural aggregates, waste thermal treatment BA generally presents a higher content of contaminants (metals, metalloids and salts) that, depending on the environmental conditions and the characteristics of the waste itself, may be more or less mobile. In the last decades several studies have analyzed the mechanisms controlling the leaching behavior of municipal solid waste (MSW) incineration BA (e.g. Meima and Comans, 1999; Polettini and Pomi, 2004; Dijkstra et al., 2006; Hyks et al., 2009). Various leaching testing procedures have been developed (e.g. Kosson et al., 2002) and different parameters related to the intrinsic characteristics of BA (i.e. particle size distribution, chemical composition and the solubility of the mineral phases making up the solid matrix of the waste material) and specific field conditions, i.e.: pH, the amount of water percolating through the waste solid matrix (*L*/*S* ratio) and temperature, were found to significantly influence the release of pollutants from BA (van der Sloot, 1996; Sabbas et al., 2003). However, BA characteristics are also influenced by the type of thermal treatment applied and the composition of the input waste. In some EU regions, such as Central Italy, thermal treatment is being increasingly applied for energy recovery from the dry light fractions of residual MSW produced in mechanical biological treatment plants (Rotter, 2010). This material, formerly defined as Refuse Derived Fuel (RDF) and currently comprised in the wider definition of Solid Recovered Fuel (SRF), presents a higher calorific value and homogeneity compared to commingled residual MSW. Typically, thermal treatment of RDF is carried out in grate-fired incineration plants; however, owing to its characteristics, this type of waste, differently from residual MSW, is also suitable to be treated in gasification plants. The potential advantages of this process versus incineration are associated with the higher electrical conversion efficiencies that may be attained (Giugliano et al., 2008) and to the lower emissions of contaminants associated to both gaseous emissions and solid residues (Bosmans and Helsen, 2010). Previous studies have shown in fact that RDF gasification yields BA with significantly different physico-chemical characteristics and leaching behavior compared to BA produced from direct incineration of commingled MSW (Gori et al., 2011; Rocca et al., 2012; Di Gianfilippo et al., 2015). However, concerning the management options currently applicable to BA in Italy, no distinction is made on the basis of its origin, in particular regarding the type of thermal treatment process applied, and the only recycling option authorized, besides landfill disposal, is as secondary raw material in cement production (M.D. 186/2006). Nevertheless, on the basis of the results obtained from experimental analysis conducted on RDF incineration and gasification BA (Rocca et al., 2012; Di Gianfilippo et al., 2015) it appears that alternative management options to landfilling may be viable depending on the specific characteristics and origin of the BA. In fact, for example, leaching data obtained for RDF gasification BA showed to comply with the limit values established for recycling by the Italian M.D. 186 (2006) (Rocca et al., 2012), while natural weathering was found to be necessary and effective for improving the leaching behavior of RDF incineration BA (Rocca, 2011). However, in order to establish the viability of a specific management option for a particular type of BA, a wider evaluation accounting for the technical performance of the material, as well as of the various potential environmental impacts deriving from the specific management strategy considered is required. By far the most applied methodology for assessing the potential environmental impacts associated to a waste management system is life cycle assessment (LCA) (Astrup et al., 2015; Laurent et al., 2014a, 2014b). Many studies addressed the importance of considering the release of toxic substances resulting from the landfilling of different types of waste including bottom ash focusing either on long-term emissions (e.g. Hellweg, 2000; Doka and Hischier, 2005; Doka, 2009), or on short-term ones (within 100 years) estimated mainly on the basis of field or literature data (e.g. Obersteiner et al., 2007; Manfredi, 2009; Damgaard et al., 2011). It should be considered that the specific properties of the waste and field conditions may significantly affect the leaching behavior of the material. In addition, field data regarding the emissions originating from the landfilling of specific types of waste (such as bottom ash from RDF thermal treatment) may not be available. Hence, in order to improve the description of the environmental behavior of a specific waste material in a disposal/recycling scenario, it is important to make reference to data representative of both the properties of the material and real site conditions. This may be achieved by employing the results of laboratory leaching tests. A few studies have focused in particular on the environmental aspects associated to the recycling of MSW incineration residues in a LCA perspective using the results of laboratory and/or field leaching tests (Olsson et al., 2006; Birgisdóttir et al., 2007; Allegrini et al., 2015). Specifically, while Olsson et al. (2006) evaluated the potential environmental impacts of the use of bottom ash in road construction making reference to field tests, Birgisdóttir et al. (2007) compared landfilling and recycling in road by employing laboratory leaching tests. Allegrini et al. (2015) assessed the importance of including impacts related to leaching and data quality in LCA when evaluating management strategies for solid residues. In particular, in the above mentioned study the results of several laboratory leaching tests as well as their analysis by geochemical modeling were employed for the assessment of MSWI BA recycling in road sub bases (Allegrini et al., 2015). Nevertheless, no specific studies regarding the analysis of management options for RDF thermal treatment BA were found.

This study focuses on RDF gasification and incineration bottom ash and aims at identifying and comparing by LCA the potential environmental impacts associated with two different management options for these specific types of BA, i.e. landfilling and recycling as filling material in road sub-bases. The study was performed employing the EASETECH LCA model (Clavreul et al., 2014) and results of standardized leaching tests applied to each type of BA were used to estimate the potential release of contaminants under environmental conditions relevant to the disposal/utilization scenario considered. Moreover, in order to evaluate the robustness of the conclusions of the LCA, a sensitivity analysis was performed to evaluate the influence of the type of leaching test employed to estimate the potential release of contaminants, the pH value of the leachant and important scenario modeling assumptions.

2. Materials and methods

2.1. Bottom ash sampling, characterization and leaching data

The data regarding the types of bottom ash analyzed in this work refers to samples generated by two thermal treatment plants (an incinerator and a gasifier) located in central Italy (Lazio region). Both plants are fed by the dry light weight fraction (i.e. the flow formerly termed as RDF) obtained from mechanical biological treatment (MBT) of the residual MSW generated in the province of Rome. Hence, the RDF treated in the two types of thermal