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Putting Accelerated Carbonation of Bottom Ash into practice: Operation of a Continuous-Feed Pilot Scale Reactor

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Abstract
Bottom ash (BA) is the dominant residue from municipal solid waste or refuse-derived fuel incineration. Disposal costs chiefly depend on the leachability of trace metals and salts. The mobility of these constituents is classically minimized by ageing for several months. Ageing involves the oxidation of metals, dissolution and precipitation reactions, and most importantly, car-bonation of BA induced by the uptake of carbon dioxide. Enhanced exposure to carbon dioxide sources has been referred to as accelerated carbonation. Here we report on the successful implementation of the accelerated carbonation of BA in a continuous pilot-scale rotating drum reactor supplied with the exhaust gas of a cogeneration plant. The system was tested in 20 field trials that aimed at stabilizing the ash such as to comply with the regulatory standards for disposal on a lower landfill class or for its geotechnical re-use. Performance and process efficiency were addressed by maximizing the reactor loading and minimizing the BA residence time. While leachates of the fresh BA ash were indicative of a hazardous waste pertaining to a class III landfill, the carbonated material fulfilled the regulatory standards for a class I landfill and, in addition, complied with the standards for geotechnical re-use. In the field trials bottom ash residence times could be cut to 60 minutes thus allowing for an on-line integration of the process.
Keywords: bottom ash, enhanced carbonation, scale-up, contaminant leaching

1. Introduction

Bottom ash (BA) is the major residue of solid waste incineration. Leaching of pollutants from BA determines its disposal pathway (e.g. landfilling or geotechnical re-use) and the costs related therewith. Classically, BA is aged for several months. Ageing processes most prominently include the uptake of atmospheric CO_2 (carbonation) with a concomitant decline of pH and lower leachability of amphoteric trace metals (Chimenos et al. 2003). Accelerated carbonation aims at reducing the ageing timeframe by employing a reactant gas with elevated concentrations of CO_2. Fernández Bertos et al. (2004) first postulated that carbonation could be enhanced further under dynamic conditions where the solid phase is in motion. Lombardi et al. (2016) compared two reactor designs for CO_2 sequestration from flue gas by BA and confirmed this assumption. Similar results were obtained by Brück et al. (2018). Continuously operated rotating drums are used in a series of industrial applications to provide the solid's motion (Sherritt et al. 2003). When reactions are kinetically controlled, the mean residence time of the solid (MRT) determines the degree of mass and heat transfer, and therefore, the reaction turnover. The mass flow rate (MFR), in turn, determines the reactor throughput and, hence, its productivity (Chen et al. 2009).

The MRT depends on the rotational speed (N), reactor inclination (Θ), and the MFR. Liu und Specht (2006) and Chen et al. (2009) showed that the reactor hold-up (M, product of MFR and MRT) is proportional to MFR/N.

So far, the performance of rotating drums for the accelerated carbonation of BA was studied in laboratory experiments. However, putting BA carbonation into practice requires information on scaling effects and their consequences for process performance and stability. In this study the accelerated carbonation of BA was performed in a continuously fed pilot-scale rotating drum reactor operated with the flue gas of a gas-powered co-generation plant. The effects of mass flow, rotational speed, configuration of reactor outlet and mixing tools on the hold-up were investigated. Carbonation performance was evaluated by batch and column leaching tests conducted with carbonated BA samples collected after the experiments.

2. Materials and Methods

The BA used in this study was from a grate-type RDF incinerator with a wet deslagger located in central Germany. The BA was collected from a roofed storage pile, see Brück et al., 2018). It was screened with a 20 mm a mesh and the oversize grain (40 %) was discarded.

Experiments were performed in a rotary drum reactor (length 5.8 m, diameter 0.5 m, inclination 1 °). The reactant gas (T=50-60 °C; ~7 %-vol. CO_2, ~3,200 m³/h) originated from a gas-powered cogeneration plant and passed the reactor in co-flow with the solid. The BA feed and outlet were equipped with pneumatically

operated double flaps. An annular exit dam (36 cm open diameter) and 3 cylindrical mixing tools were used as built-ins. A calibrated screw conveyor served to set the MRF at the feed side. The output MRF was measured by weight and M was obtained at the end of each experiment by weighing the output of emptied reactor. Under steady-state conditions (MRF_{in} = MRF_{out}), the MRT was obtained as the ratio of M/MRF.

Before starting the input of BA, the reactor was heated by feeding the reactant gas until reaching temperature equilibrium. The carbonation tests were performed at varied rotational speeds (2 to 8 1/min) and mass flow rates (3 to 10 kg/min). Three reactor configurations were used: a) plain drum without built-ins, b) drum with exit dam, and c) drum with exit dam and mixing tools.

Carbonation performance was evaluated by batch leaching tests according to EN 12457-4 and the leachates were analyzed for pH and electric conductivity (EC), Pb, Zn, Cu, Mo, Cr and V as well as for the bulk anions sulphate and chloride.

3. Results and Discussion

The MRF was adjusted by varying M at a given MFR and N keeping the reactor inclination constant. Figure 1 shows the influence of MFR/N on M for three different built-in configurations. For the plain drum a maximum hold-up of 185 kg was reached. A higher hold-up was achieved with the exit dam. This means that for a given MRF the MRT can be increased by use of the exit dam. This is important since BA carbonation has been shown to depend on specific CO_2-supply (Brück et al. 2018).

Figure 2 exemplarily shows the leachate concentration of Pb as a function of the established MRT. An MRT of 60 min was sufficient to safely meet the waste acceptance criteria for non-hazardous waste landfills. This holds true for further amphoteric trace metals. However, oxyanion-forming elements (especially Cr and V but not so Mo) showed an increasing mobility with extended MRT. This agrees with previous findings and is presumably due to the pH-dependent stability of host minerals.

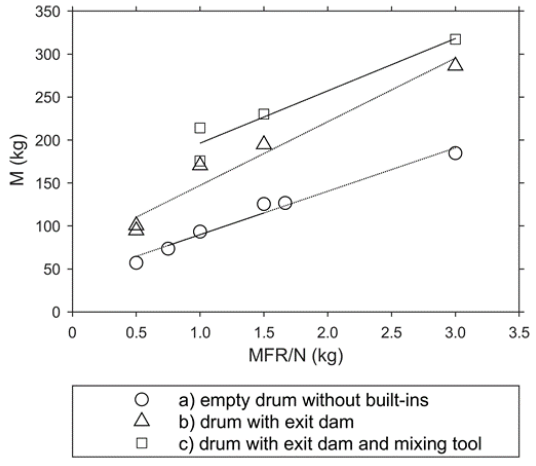

Figure 1. Influence of mass flow rate (MFR) and rotational speed (N) on the reactor hold-up (M).

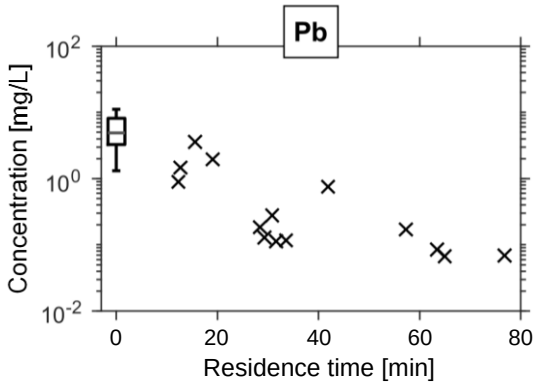

Figure 2. Leachate concentration of Pb as a function of the BA residence time adjusted in independent experiments; box: leachate of the untreated BA.

4. Conclusions

The results indicate that both the reactor hold-up and the mean residence time of bottom ash can be controlled under pilot-scale conditions. This is deemed a step forward for the implementation of the process into the management of bottom ash at incinerator sites.

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