**ETHZ Master Thesis**  21.12.2021

**CO2-Absorption by Incinerator Bottom Ash**

**Background**

The incineration of waste releases considerable amounts of CO2. However, bottom ash from municipal solid waste incinerators (IBA) is also able to bind CO2 by carbonation processes, especially by the carbonation of calcium hydroxide (CaOH2)) to limestone (CaCO3). While the thermodynamics of the CO2-uptake of IBA is well understood, the kinetics is not. It is quite unclear just how much CO2 is being absorbed by the IBA along its "life cycle" from the discharge of the municipal waste incinerator to its final destination in a landfill.

Carbonation along the "life cycle" of the incinerator bottom ash IBA includes the following steps:

1. Discharge from the incineration plant: Carbonation begins with the discharge from the incineration plant. Usually this is a wet discharge with the bottom ash being conveyed out of the incinerator through a water-filled siphon. The moist bottom ash will absorb ambient CO2.
2. Storage: Before processing for metal recovery, the IBA is deposited for "internal drying" in piles several meters high. Presumably, carbonation by air-CO2 occurs during piling up and subsequently in the outer layers of these stockpiles.
3. Metal recovery: During the metal recovery process, the IBA is crushed, which creates new surfaces that can absorb CO2. This is significant considering the current trend towards increasingly aggressive comminution of bottom ash. For example, at the Elbisgraben landfill, the entire bottom ash is crushed to <5 mm. This leads to a much larger specific surface area for possible carbonation.
4. Landfilling: During and after landfilling the following carbonation processes occur.
   * Carbonation by air CO2 during installation of the material and by exposure of the landfill surface. For the kinetics of carbonation, the "open exposure time", i.e. the time until the next layer of material is covering a layer of landfilled IBA, will be critical. Presumably, the moisture content of the landfilled material has an influence on carbonation kinetics.
   * Carbonation by percolating rainwater. Rainwater is in equilibrium with ambient CO2 and it is a carrier for CO2 into the landfill body by infiltration. What exactly happens to the CO2 there, is unclear. About one meter below the surface, the temperature of bottom ash landfills rises to about 65°C. Likely some of the dissolved CO2 will be released from the infiltrating rainwater at this temperature and thus cannot penetrate into the deeper layers of the landfill.
   * Another variable is the leaching of alkaline components from the landfill body. If the landfill leachate is exposed to air, carbonation can also occur ex situ, i.e. outside the landfill body.
   * Regarding total CO2 uptake, it is irrelevant whether carbonation occurs "in si-tu" or "ex situ". Carbonation before landfilling or in the landfill body would, however, be advantageous, as the alkalinity potential (Ca(OH)2) will not leach out but remain in the landfill body as CaCO3. This increases the buffering capacity of the landfill body, which in turn favors the long-term stability of heavy metals. This mechanism can have a positive effect on landfill aftercare.
   * Furthermore, it is unclear whether CO2 releasing processes take place under landfill conditions, e.g. by (chemical/microbial) oxidation of unburned organics present in deposited bottom ash.

The vast majority of studies conducted to date on CO2 uptake by MSWI bottom ash have been based on laboratory experiments. They focused mainly on thermodynamics, i.e. on the CO2 uptake capacity under different conditions. Only very few studies dealt with the kinetics of carbonation under semi-realistic conditions.

**Goal of the thesis**

To date, it is unclear how much CO2 is absorbed by IBA along its life cycle from the wet discharge from the incinerator to the landfill.

**The objective of this thesis is to investigate the kinetics of bottom ash carbonation and to estimate its magnitude:**

1. **How much CO2 per m3 and day is being absorbed by IBA ash in each step along the life cycle presented above?**
2. **How much of the carbonation potential of IBA is still present in Swiss bottom ash landfills?**
3. **Which technical measures can be employed for promoting the carbonation process?**
4. **Will "forced" carbonation of landfilled bottom ash result in benefits for landfill aftercare?**

Points 3 and 4 should also take into account aspects such as feasibility and economic viability.

**Thesis content**

The thesis includes the following tasks:

* Literature research and identification of research gaps
* Rough estimates of the progress of carbonation during the "life cycle" of the IBA.
* Experiments on CO2 absorption by IBA ash as a function of particle size. Tackling the question, whether the absorption potential is determined mainly by the "natural" fine fraction of the bottom ash, or whether further crushing the larger components can increase this potential.
* "Column tests" with 10...100 kg of material in the laboratory. The material will be filled into containers and flushed with an air stream (possibly enriched with CO2). By measuring the outflowing CO2 concentration and weight increase of the material, the degree of carbonation is determined. If necessary, deep sections of the landfill body are opened up by means of dredging slots, boreholes or pile-driven coring in order to determine the "natural" carbonation progress in the incorporated bottom ash.
* Laboratory investigation of the carbonation of heavy metal hydroxides, e.g. iron (hydr)oxides to Siderite using X-ray diffraction XRD (available at UMTEC in the Advanced Materials and Processes group).
* Interviews with landfill operators and experts in the field and review of leachate analyses.
* Modeling the CO2 balance of a landfilled bottom ash with special consideration of the input of CO2 with rainwater and the discharge of potentially CO2-absorbing alkaline components by the leachate.
* Evaluation of technical measures for CO2 sequestration in landfilled bottom ash bodies incl. feasibility assessment and cost/benefit analysis.
* Documentation of the results
* Writing of a scientific report in English
* Presentation of the results

The list of tasks above represents only a selection of interesting subtopics to be clarified within the framework of this thesis. Depending on the progress of the work and the results of the literature research, this list can be extended or shortened. **Various aspects of the thesis can be extracted and researched in the context of a Master Project.**

At UMTEC, the project DepoCarb, which is co-financed by the FOEN environmental technology funding, will start in January 2022. The aim of this large-scale project is the inertization of bottom ash landfills through forced carbonation. Project partners are a waste incineration plant, two landfilling sites, an environmental technology company and a cantonal environmental agency. This master thesis is embedded in the ongoing work of the DepoCarb project and therefore has a strong practical relevance. The task is particularly suitable for students with interest in aquatic chemistry.

Note: This thesis will be conducted at the Institute of Environmental Technology and Process Engineering UMTEC at Ostschweizer Fachhochschule OST in Rapperswil. It will be supervised by Prof. Rainer Bunge, head of the group "Raw Materials and Process Engineering".

**Supervision**

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