Petrology, geochemistry and leaching behaviour of a high temperature municipal solid waste incinerator residue

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Today's municipal solid waste incinerators (MSWI) produce a heterogeneous and reactive residue at 850°C. The residue is mostly contained in landfills (some use in road construction) and is difficult to characterize with respect to its long-term leaching behaviour. Treatment at higher temperature produces a more uniform residue and an improved separation of heavy metals by evaporation. These residues have a potential to be used as secondary raw materials. Environmental impact is judged today by measuring bulk contents of heavy metals and the behaviour during short term (e.g. 48 h) leaching tests.

The aim of this study is to predict long-term behaviour on the basis of phase chemistry and long-term column tests. A detailed knowledge of the phases can also lead to an improved understanding of the thermal process. The project is part of Swiss Priority Programme "Environment", supported by the National Science Foundation.

Incineration process

The residues were produced in the VS Kombi Reactor (Küpat AG) that combines a grate firing with a rotary kiln [1]. The process temperatures of 1200-1400 °C cause almost complete melting of the waste. The advantage of the process is that the energy for melting is derived from the heat content of the waste itself. The biggest disadvantage is that no separation of metals takes place.

Sample material

The sample material consists of porous slag with metallic and refractory inclusions. Polished thin sections coated with carbon have been used for examination with the scanning electron microscope (SEM) and for quantitative analysis with the electron microprobe (EMP).

The slags may be subdivided into two groups: one having a crystalline the other a glassy matrix. The
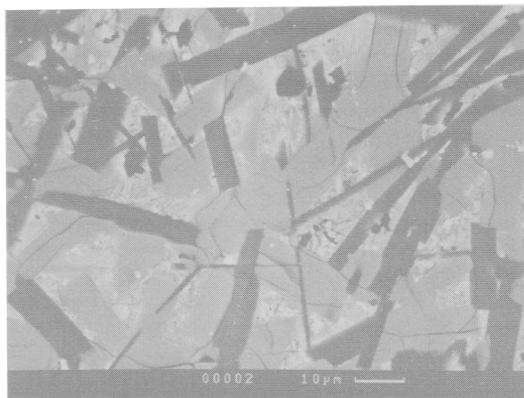

FIG. 1. BSE-Image of the matrix of a crystalline sample. Plagioclase: dark; melilite: grey; interstitial phase: bright.
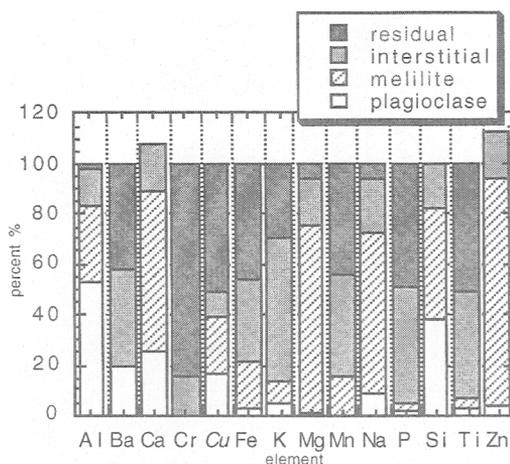

FIG. 2. Distribution of the elements among the different phases of a sample with crystalline matrix.
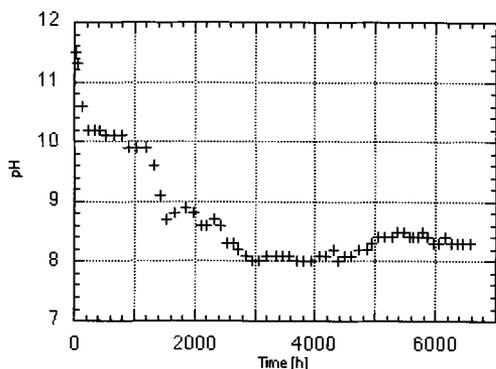
FIG. 3. Evolution of pH during the first 9 months.

matrix of the crystalline samples consists of Ca-rich plagioclase, melilite and an interstitial glassy to microcrystalline phase (Fig. 1). The analysis of backscatter electron images yields about 30 volume % plagioclase, 45% melilite and 25% interstitial phase.

The matrix of glassy samples consists of newly formed glass with incipient crystallisation of plagioclase or of regions of SiO_2-rich molten scrap glass. Refractory inclusions consist of ceramic fragments, quartz and lime from carbonate decomposition.

The amount of metallic inclusions (apart from large pieces of scrap iron) is generally smaller than 1 %. Metallic inclusions comprise pure metals, alloys, multi-phase compounds and phosphorous compounds. Lead occurs as minute inclusions in metallic form, Cu is found pure or in alloys, and Zn occurs in Al- and Si-rich alloys as well as in silicate glass and melilite.

Bulk chemistry and liquidus relationships

According to rock classification, the samples are basic to ultrabasic. The CaO content varies between 15 and 25 wt.%, Al_2O_3 between 17 and 22 wt.%, and SiO_2 between 38 and 49 wt.%. Projections of the composition into the system CaO-Al_2O_3-SiO_2 fall into the liquidus field of anorthite. Trace element contents show large variations (e.g. Zn by a factor 15). Table 1 gives an example of a bulk chemical analysis after elimination of large metal pieces.

Samples with a crystalline matrix have a CaO/SiO_2 [wt.%] ratio higher than 0.54, the ones with a glassy matrix smaller than 0.5. High CaO/SiO_2 ratios direct crystallisation towards and along the cotectic with melilite. Theoretical computations (Shaw Model) show 1 to 1.5 log units lower melt-viscosities for the now crystalline samples. The lower viscosities

seem to have enhanced crystallisation since a decrease in the number of crystals has been observed with a decrease of the CaO/SiO_2 ratio.

Phase chemistry

Plagioclase. The EMP analysis of plagioclase reveal uniform compositions of around 95 mole% anorthite content and 5% albit content (Table 1).

Melilite. The average melilite consists of 30% gehlenite-, 37% åkermanite-, 24% sodium-melilite-component (Table 1). The contents of Fe-åkermanite and the Zn-endmember hardystonite are about 5%. Zn concentration in the melilites is about 1.5 times higher than the bulk concentration. The variation of melilite composition within a sample is significant: 19 to 34% for gehlenite, 33 to 43% for åkermanite and from 20 to 27% for Na-melilite. Comparison to experimental work in a simplified system suggest liquidus temperatures between 1350 and 1400°C. Melting experiments on the sample material indicate a liquidus temperature of about 1190°C.

Interstitial phase. The interstitial phase is relative to melilite and plagioclase enriched in the elements K, Fe, Cl, S, Ba, P, Cr, Ti and Mn (Table 1).

Distribution of the elements

With the knowledge of phase chemistry and relative amount of each phase one can compute the relative distribution of the elements among the different phases. It can be shown that Zn is almost completely bound to oxide or silicate phases: up to 80% are incorporated into melilite. Copper could not be detected in the silicate or glass phases: the assumption of a concentration equal to the detection limit leads to the statement that at least 60% of Cu is bound to metallic inclusions. Due to the high detection limits of the microprobe relative to the bulk content no quantitative statement about Cd and Pb can be made, although Pb is frequently observed in minute metallic inclusions. Figure 2 shows the distribution of the elements in a crystalline sample. The phase named 'residual' is the difference between bulk composition and the contents accounted for by plagioclase, melilite and interstitial phase.

Leaching behaviour

Crushed slag material has been leached in flow-through columns, running for about 1 year. The input solution is pure water adjusted to pH = 4 using hydrochloric acid at conditions of CO2-saturation with respect to atmosphere.