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Workshop on "Technologies and data for material recovery from waste incineration residues in Europe"

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Czech Academy of Sciences
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PROGRAM, ABSTRACTS and PRESENATIONS

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IMPRESSUM

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Technologies and data for material recovery from waste incineration residues in Europe.

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Technologies and data for material recovery from waste incineration residues in Europe

Jakob Lederer, Technische Universität Wien, Austria

European governments as well as multilateral bodies (EU) in Europe are increasingly interested in the strategic utilization of secondary raw materials, i.e. from wastes. What we have learned from past and present ambitions towards producing secondary raw materials from different waste streams, is that there are many more or less isolated activities going on by different research groups all over Europe. Furthermore, when it comes to secondary raw materials inventories, there is a trend that selected institutions are doing research or consulting projects where the result are reports or databases with selected features, e.g. quantity of secondary raw materials. However, these databases/reports do often neither have a clear structure, nor they are frequently updated.

We thought that, in order to structure and group these activities, we have to 1) design a framework where the activities on producing secondary raw materials from wastes can be integrated in, and 2) to built-up a network of competent institutions (rather than just a database) that can provide and update the information required within a secondary raw materials inventory. To do so, we would like to carry out a first case study on a particular waste stream, namely solid residues from municipal solid waste incineration (MSWI), mainly bottom and fly ashes.

Thus, the general objective of Working Group A3 in the MINEA Cost Action is to built-up a network of competent institutions from different European countries which can provide the information required for a secondary raw material inventory by using the case study of waste incineration residues as a role model for such a network. The objective of this workshop is to provide an overview i) on existing data and data management regarding secondary raw materials in waste incineration residues in Europe, and ii) on different technologies to recover secondary raw materials from waste incineration residues in Europe. The intended result is a proposal on i) which data on waste incineration residues should be collected to enhance the extraction of secondary raw materials, ii) how this data should be managed and updated, and iii) case studies for its practical implementation on European level. Thereby, available secondary raw material extraction technologies, legal and economic aspects are considered.

Waste incineration in Europe and its residues

Jan Peter Born, Confederation of European Waste-to-Energy Plants, Netherlands

The Waste-to-Energy sector (incineration of municipal waste with recovery of energy) has been increasing steadily in Europe for the last decades. More than 480 plants are now in operation all around the continent, treating 88.6 million tonnes of municipal waste in 2014. This increase in capacity happened end-in-end with an increase of recycling.

But what about the residues of Waste-to-Energy plants? Incinerating 88.6 million tonnes of waste means that, yearly, around 14 million tonnes of incinerator bottom ash (IBA) are produced. Around 8-10% of these bottom ash are ferrous and non-ferrous metals, which are possible to recover either on-site or in specific treatment plants. In the Circular Economy package, the European Commission proposes that this metal recycling would be accounted for in national waste management statistics. This would be an opportunity to improve even more the recovery of metals, and hence to save greenhouse gas emissions as one tonne of recovered metals saves two tonnes of $CO_{2\text{-equiv.}}$ emissions.

The mineral part that composes the rest of the IBA also has various applications for instance as an aggregate in construction. Legislation varies throughout the EU as to the conditions for the use of IBA. A few local initiatives are paving the way forward such as the Green Deal in the Netherlands, which aims to upgrade IBA and find new applications for it. That is why CEWEP is working with other European associations in order to raise awareness of metal extraction and further uses from IBA. Recent policy proposals at the EU level might however pose a threat to IBA recycling, as they would tend to overestimate the hazardousness of the material based on its composition rather than on a risk assessment

Mineralogy of Waste Incineration Residues and its Impact on Recycling

Daniel Höllen, Montanuniversität Leoben, Austria

Data on qualities of waste incineration residues in Europe are often restricted to chemical parameters and do not include mineralogical information. However, for the recovery of secondary raw materials from these residues their mineralogical composition plays an important role.

This presentation contains an overview of the mineralogical composition of waste incineration residues which was obtained in the "Research Studio Austria CarboResources" by Montanuniversität Leoben. The focus of this project was indirect aqueous mineral carbonation as innovative recycling technology to recover Si-rich dissolution residues, metal hydroxide concentrates and finally Ca- and Mg-carbonates for industrial applications. However, the fundamental insights which were gained regarding the distribution of valuable and environmentally critically chemical elements among the crystalline and amorphous mineral phases in waste incineration residues are highly relevant also for other recycling routes.

During the project dissolution and carbonation experiments were conducted which yielded new information about the mobility of valuable and environmentally critically elements throughout the recycling process. Tracing back these observations to the mineralogy of the input materials and investigating the incomplete and incongruent dissolution of primary phases and the precipitation of secondary phases during this specific recycling process yields generally applicable knowledge about the stability of individual minerals and the mobilisation and fixation of metals from/in waste incineration residues in other technological and environmental settings as well.

Finally, open research questions regarding the mineralogy of waste incineration residues are asked in order to influence the research agenda of the European Commission, and possible approaches how to answer these questions within future joint research projects originating from COST are suggested to initiate the formation of appropriate consortia.

Data on quantities, qualities, treatment and disposal practices of MSW incineration residues in the Czech Republic

Michal Syc, Aneta Krausová, Petra Kameníková, Oleg Samusevich
Institute of Chemical Process Fundamentals of CAS, Czech Republic

Bottom ash (BA) from waste-to-energy (WtE) plants contains valuable components, especially Fe and NFe metals. Metal-free mineral fraction can be used in construction industry. There are three WtE plants in the Czech Republic that produce in total 160 000 tons of BA per year. One plant is nowadays equipped with conventional NFe metals recovery system whereas in other two plants only Fe scrap is separated. BA is in the Czech Republic usually landfilled or used as a protective and building material at landfill sites.

To assess the resource recovery potential of BA in the Czech Republic, it was necessary to obtain the information about its material composition. We analysed in total 6 samples from all three WtE plants in the Czech Republic. It was found that raw BA contains 10–23 % of glass, 2–5 % of ceramics, 10–16 % of magnetic fraction, 6–11 % of ferrous scrap, and around 1.3–2.8 % of non-ferrous metals. Lower glass or NFe content was found in WtE plant co-incinerating commercial waste.

The contents of individual components were also studied with respect to the granulometry. Most of the glass was found in size fractions between 6 and 20 mm. Ceramics and porcelain were mainly found in particles over 15 mm. The content of ferrous scrap increased with increasing particle size. Nonferrous metals were nearly equally spread into all size fractions.

Particles below 2 mm were analysed in cooperation with TESCAN company by SEM. The most abundant metals in fine fractions of BA were Fe (including Fe oxides) and Al (pure Al or Al_2O_3). Other metals like Cu, Zn, Pb, Sn, and different alloys were usually below 0.2 wt. %. Iron particles had usually elongated shape and had more than 80 % of the surface free. On the contrary, Al particles were substantially less liberated. Pure aluminium was often covered in Al_2O_3, caused by oxidation during the incineration process.

Incineration of Municipal Waste in Estonia

Kaja Orupold, Mait Kriipsalu, Estonian University of Life Sciences, Estonia

There is one waste incineration plant in Estonia, close to the capital Tallinn, Iru. It is operated by state-owned energy corporation Eesti Energia AS, and it is running at full power since July 2013. The plant had an annual designed capacity of 220,000 tons. The installed electrical capacity of the plant amounts to about 17 MW and the installed thermal capacity to 50 MW. Manufacturer of the furnace is CNIM/Martin and manufacturer of flue gas cleaning is CNIM/LAB. Incineration mode is reverse-acting grate, and flue gas cleaning is semi-wet. Actual calorific value of waste is smaller than expected, therefore the annual load has been increased beyond 250,000 t.

The demand for waste incineration plants in the country is fully satisfied. Because of overcapacity in waste processing, waste has been transported for incineration from all over Estonia, and also imported from Finland and Great Britain.

In 2013, a daily load of 500 t was transported from excavated landfill to Iru facility for test-incineration. Analyses of fly and bottom ash were made along with flue gas composition.
Some municipal waste is processed in three major mechanical biological waste treatment facilities to produce solid recovered fuel for cement mill of Heidelberg Cement in Kunda. About 30 % of fossil fuels has been replaced by SRF in Estonian cement industry. SRF is both imported to and exported from Estonia.

There is one smaller hazardous waste incinerator in Tartu, South-Estonia, operated by EplerLorenz Ltd. Up to 3000 tons of contaminated materials and hazardous waste is thermally destructed annually.

Chemistry, mineralogy, and material flows of MSWI residues in Italy

Roberto Braga, University of Bologna, Italy

According to the last available data, nearly 6 Mt of unsorted municipal waste were treated in 46 MSWI plants in Italy, most of them adopting the grate furnace technology. Bottom ashes (BA) account for about the 20% of the input waste (ca. 1 Mt) whereas fly ashes (FA) represent only a minor fraction (0.2 Mt).

The chemical composition of BA is within the CaO-Al2O3-SiO2 chemical system whereas alkalis, chlorine and sulfur are important components of FA. The mineralogical composition is ill defined due to the large number of phases that complicates the interpretation of X-ray diffractograms. Consequently, available data refer to the mineral identities and are lacking of quantitative estimates. BA is mainly composed of quartz, calcite-vaterite, melilite group minerals and plagioclase. FA contains Ca-aluminosilicates and more sulphates and chlorides with respect to the BA. Iron (hydro)oxides occur both in BA and FA.

When BA and FA are considered for their content of precious (gold, silver, platinum group elements) and other critical elements (e.g. Cr, REE), the absolute values of these elements (up to hundreds mg/kg) coupled with the huge material flow turn into significant metal streams, representing an interesting target for further upgrading and metal extraction. However, the potential of extractable metals form BA and FA is hampered by lack of cost-effective technology. Current technologies (e.g., thermal treatments, electrochemical processes, and hydrometallurgy) are often costly and highly energy demanding. Bio-hydrometallurgy is an interesting prospect but its implementation at the plant scale is still far from being real.

Bottom Ash Management in Italy – an overview

C. Santella, M. Grosso, S. Cernuschi, G. Dolci, L. Biganzoli, LEAP - Laboratorio Energia e Ambiente Piacenza, Italy

In 2014 in Italy more than 1 million tonnes of incineration bottom ash (IBA) were generated by Waste-to-Energy (WTE) plants treating municipal solid waste. Such IBA are delivered to dedicated plants where they are subjected to a number of processes including ageing, metal separation and treatment of the inert fraction. The resulting mineral fraction can be recovered as secondary material or sent to landfill. Currently only 18% of IBA is directly landfilled in Italy, while 82% is recovered as granulate in road construction mainly in the building sector and in the cement production.

An overview of the state of the art of IBA treatment technologies and utilization in Italy will be presented.

The description of processes applied in four of the largest facilities will be given, together with a comparison based on the different destination and characteristics of the secondary materials produced.

The presentation will also include the results of the elaboration of data regarding analysis of about 20 samples of bottom ash produced by 9 different WTE facilities in 2015. Data will give information about the chemical composition of IBA, the physical parameters and, above all, on their hazardousness and classification according to the European Waste Catalogue. For some of the samples results of leaching and ecotoxicity tests will also be presented.

Municipal solid waste incineration in Lithuania

Saulius Vasarevicius, Raimondas Grubliauskas, Ausra Zigmontiene, Jurgita Seniunaite
Vilnius Gediminas Technical University, Lithuania

Currently, Lithuania has the only (planned to build two more) non-hazardous waste incineration plant, which combustion chamber projected capacity - 255 ths. tons per year. As fuel in incineration plant used non-hazardous municipal solid waste after secondary sorting, non-hazardous industrial waste and biofuel. Municipal solid waste incineration (MSWI) produces two main types of combustion ash: bottom ash (BA) – 75 ths. tons per year and fly ash (FA) – 9.9 ths. tons per year. Using electromagnet partially separated ferrous metals from the bottom ash.

Vilnius Gediminas Technical University investigated the bottom ash composition. Chemical composition determination research showed that silicon, a part of a silicon dioxide (SiO_2) is the main element of the composition of bottom ash, this oxide constitutes more than half (57 ± 2%) of the total weight of BA. In BA also is 16±2.5 % CaO, 8±3.2 % Fe_2O_3, 5±1 % Na_2O and 5±0.5 % Al_2O_3. Heavy metals (Cr, Mn, Ni, Cu, Zn, Sr, Pb) concentration in BA was relatively low (<1 %).
According to Lithuanian waste management rules MSWI bottom ash is classified as waste (code 19 01 12), so the hazard properties and further management options are identified using a leaching test according to LST EN 12457-2:2003 standard. The obtained results are compared with the values of the European Commission's requirements (2003/33/EC) of waste deposited inert and non-hazardous waste landfills.

Three metals (zinc, molybdenum and lead) and soluble salts (chlorides, sulfates) concentrations exceed leaching limits for waste, which are removal in inert waste landfills. Therefore, the bottom ash cannot be attributed to inert waste, but BA meets requirements for the waste removal in non-hazardous waste landfills.

Currently, in Lithuania bottom ash is removal in non-hazardous waste landfills. No additional bottom ash processing (full metal separation, aging) is not applicable. Also on the legislative shortcomings waste incineration bottom ash are not re-used for road construction or building structural elements.

Acknowledgement: this work was supported by Fortum Heat Lietuva [grant number 13770].

Re-use and recycling of municipal solid waste incineration residues in the Netherlands

Andre Van Zomeren, Energy research Centre of the Netherlands, Netherlands

Municipal solid waste (MSW) and commercial waste is largely incinerated in MSW incineration plants in the Netherlands (6.0 Mton in 2014 and 1.6 Mton imported waste). Technological and policy developments have led to both better prevention of waste generation as well as to increased source separation of waste to recover resources for new applications. These developments aim to produce more secondary resources for production and less residual waste that is available for waste incineration.

The residues of waste incineration are mainly bottom ash (±85%), ferrous and non-ferrous metals (±7%), fly ash (±4%) and air pollution control residues (±2%). Mainly the MSWI bottom ash is re-used as a mineral construction material in road construction works and embankments. Alternatively, bottom ash aggregates can also be produced to replace gravel in concrete applications. However, the environmental quality of MSWI bottom ash does not yet meet the desired criteria for a so-called open application under the Dutch regulation for (re-)use of construction materials. The material is currently applied in isolated constructions using HDPE liner systems to ensure emissions are acceptable for the environment. However, this re-use practice is not preferred since these applications require monitoring of groundwater and of the isolation construction (“aftercare”).

The Dutch ministry of Infrastructure and the Environment and the incineration industry have signed a so-called Green deal to work on quality improvement of bottom ash. The aim is to apply 50% of the bottom ash freely in 2017 and 100% in 2020. This agreement asked for substantial technological developments to improve the quality of bottom ash and to improve metal recovery. Generally, the leaching of Cl, Cu, Mo, Sb and SO4 does not meet the stricter limit values for open application. An overview of the main quality improvement technologies and the effects will be given in the presentation.

Municipal solid waste incineration residues: data on quantities, qualities, treatment and disposal practices in Portugal

Margarida Quina, University of Coimbra, Portugal.

In European countries and in Portugal as well, municipal solid waste (MSW) management has evolved significantly over the last two decades, driven by the “waste hierarchy”, which demands a minor focus on landfilling. Indeed, in the last years there is a clear shift from landfilling up to incineration, recycling and composting [1,2]. Table 1 shows the amount (in Mt) of MSW treated in EU-27 from 1995 to 2014 by treatment method [2]. In that period, municipal solid waste incineration (MSWI) has grown gradually, and the amount incinerated has risen about 100%, corresponding to 28% of the total MSW generated in 2014. In Portugal, incineration started in 2000 and since then about 20% of the global MSW has been incinerated into three waste-to-energy plants (mass-burning technology).

Table 1- Municipal waste landfilled, incinerated, recycled and composted in the EU-27 (in Mt) from 1995 to 2014.

Method	1995	2000	2005	2010	2014	Change (%) *
incineration (MSWI)	32	39	48	57	64	100
landfill	144	139	109	92	66	-54
recycling	25	40	52	62	66	164
composting	14	24	29	34	38	171
other	10	11	16	7	5	-50
TOTAL	225	253	254	252	239	6
APCr (~3% MSWI)	0.96	1.17	1.44	1.71	1.92	
BA (~30% MSWI)	9.6	11.7	14.4	17.1	19.2	

*- Change of variation from 1995 to 2014; APCr- air pollution control residues; BA- bottom ash.

MSWI produces bottom ash (BA) and air pollution control residues - APCr) with or without fly ash. Typically, BA represents around 20%-30% of the original MSW by weight, and contains ferrous and non-ferrous metals that can be recovered. In 2014, about 19 Mt of BA was generated (considering 30% of the original MSW). In addition, APCr are formed during the clean-up of the flue gases and comprising fly-ash and additives (lime, activated carbon, etc.). APCr are classified as hazardous waste, and their disposal must be accomplished in accordance with regulations. Considering that in average the weight of APCr formed is about 3% of the MSW incinerated, in 2014 around 1.92 Mt was generated (Table 1). From 1995 to 2014 the amount of APCr produced could reach 28 Mt in the EU-27. In Portugal the rate of production has been around 30 kt/year. The composition of this fine particulate material may vary widely, but in general the major elements are Si, Al, Fe, Ca, Mg, K, Na and Cl, and the most frequent heavy metals are Cd, Cr, Cu, Hg, Ni, Pb and Zn, with Zn and Pb generally found in the largest amounts [3]. Trace quantities of very toxic organic compounds (PAH, PCB, PCDD/F) are usually present in APCr. The appropriate treatments for APCr can be grouped into three classes (i) separation processes; (ii) solidification/stabilization (S/S); (iii) thermal methods. Although it would be better to find a practical application than merely dump the material in a landfill site, to find good solutions for this hazardous waste has been a great challenge. In Portugal, APCr have been treated with hydraulic binders (Portland cement) followed by landfilling in specific sites (monofills). Considering all difficulties, it is clear that this topic requires a thorough discussion.

References

[1] – EEA report nº2/2013, Managing municipal solid waste - a review of achievements in 32 European countries, European Environmental Agency, Copenhagen, 2013.
[2]- http://ec.europa.eu/eurostat/statistics-explained/index.php/Municipal_waste_statistics
[3]- M.J. Quina, J.C.M. Bordado, R.M. Quinta Ferreira, Treatment and use of air pollution control residues from msw incineration: an overview, Waste Manage. 28, 2097-2121, 2008.

Treatment and disposal practice of MSW incineration in Spain: the case study of Catalonia.

Josep Maria Chimenos, University of Barcelona, Spain

As the other 28 EU Member States, waste generation in Spain gradually has decreased over the past decade, amounting to more than 20,217 thousand tons of waste in 2014 with an annual per capita generation rate of 435 kg of municipal solid waste (MSW). In 2014, 55% of MSW was landfilled, while only 9% was incinerated. However, despite landfilling remaining the most common practice, MSW incineration has increased in recent years; currently, Spain has 10 incinerators, or waste-to-energy (WtE) plants, with a capacity higher than 3 t h^{-1}. The most common technologies applied in these plants are grate (8 WtE), and the fluidized beds (2 WtE) in a less extend. Four of these WtE plants are located in Catalonia (northeastern Spain), which incinerate more than 17% of MSW collected in this autonomous region and generate 349 GWh of electric energy. The four WtE plants produce 134 thousand tons of fresh bottom ash (FBA), around 20% of MSW managed, and 24 thousand tons of air pollution control fly ashes (3.5 % of MSW). Unlike fly ash, FBA is classified as non-hazardous waste (European Waste Catalogue) that can be revalorized as a secondary building material. However, for its proper reutilization, FBA must be stabilised through weathering process (2-3 months) in order to obtain a weathered bottom ash (WBA). In what environmental behaviour concerns, the concentration of heavy metals and metalloids in the leachates was below the concentration limits established by the Catalan legislation for the revalorization of residues. Concerning to material distribution, ceramics play a major role in current WBA composition and the content of glass (primary and secondary) is estimated to be around 60%. This high glass content restricts WBA reutilization as secondary road material due to their elevated fragility and low resistance to fragmentation.

Waste incineration residues data in Switzerland: Situation regarding reliable data

Leo Morf, ZAR, Stiftung für nachhaltige Abfall- und Ressourcennutzung, Switzerland

Roughly 15 years ago, there has been very limited reliable and comprehensive data about waste streams in general and about waste incineration residues in detail available. The situation in Switzerland was similar to other European countries.

Only data about mass flows and about the content of matrix elements (Si, Ca...) and bulk and most relevant heavy metals such as Fe, Cd, Pb etc. have been available. Almost no substance flow analysis data has been available at that time. And no data was available on contents and flows of precious metals and rare earth metals at all. Information about the uncertainty of data usually was not available. Unfortunately, available data generally had been based on very poor sampling concepts, too.

During the last years more and more effort was put into more reliable sampling concepts and the data base has been enlarged. In the Canton Zurich substance flow related goals and Urban Mining activities related to the new waste and resource management plan asked for more reliable and comprehensive data.
Such data about incineration residues is essential in order to evaluate:
- reliable resource potentials in the residues
- future risk reduction potentials in landfills
- heterogeneous waste incinerator input composition (for waste management quality control)

Therefore, the Canton Zurich has established a substance flow analysis based monitoring of the most relevant parameters (TOC, Metals) in the residues. And it has supported the development of more adequate sampling methodologies for incineration residues.

The presentation gives an overview about the situation of incineration residue data and sampling methodology developed in Switzerland during the last years.

Municipal solid waste incineration residues in the UK

Julia A. Stegemann, Anna Bogush, Centre for Resource Efficiency & the Environment (CREE), Department of Civil, Environmental & Geomatic Engineering (CEGE), University College London (UCL), UK
Amitava Roy, J Bennett Johnston Sr Center for Advanced Microstructures & Devices, Louisiana State University, USA, UK

More than 15% of the 200 Mt of waste generated in the UK in 2014, i.e., 31.1 Mt, was municipal solid waste (MSW), corresponding to 482 kg/person (Eurostat 2016)). 27% of MSW, about 8.3 Mtpa, was incinerated (more than twice the proportion in 2010) (Defra 2016). While there were 87 permitted waste incinerators in the UK in 2014 (2016), many of these are small-scale, with only 28 practicing energy recovery (but without R1 accreditation), ranging in capacity from 30 to 700 Mtpa (WRAP 2013); the latter are among the largest facilities in Europe. Most are permitted to accept commercial and industrial (C&I) waste together with MSW, but the proportion of C&I waste must be small, as the total capacity is only about 6.3 Mtpa (and 2.4 Mtpa of MSW were exported to Europe as RDF in 2014) (Defra 2016). It is estimated that these incinerators produce about 0.3 Mtpa of air pollution control (APC) residue (Lets Recycle 2016), and 2 Mtpa of incinerator bottom ash (IBA).

The chemical composition and mineralogy of eight APC residues from six UK EfW facilities were determined as part of a UCL CREE project commissioned by the English Environment Agency (Bogush et al, 2014). The samples were digested by EPA 3050B with determination of 66 elements by inductively coupled plasma-optical emission/mass spectroscopy. Potential pollutants, especially Zn (0.26–0.73 wt.%), Pb (0.05–0.2 wt.%), As, Cd, Cu, Mo, Sb, Sn and Se were found to be enriched in all APC residues. Ag (6–15 mg/kg) and In (1–13 mg/kg), elements of strategic importance for advanced electronics, were also enriched, but not to exploitable concentrations.
Results from a combination of powder X-ray diffraction, thermal analysis, Fourier transform infrared spectroscopy and scanning electron microscopy with energy dispersive X-ray spectroscopy indicated that the bulk of the crystalline phases present in the UK APC residues were similar to those also identified in the international literature: CaCO3, CaSO4, CaClxOH2-x, NaCl, KCl, Ca(OH)2 and CaO. Sulphur appears to have a mixed oxidation state, presenting as both anhydrite and hannebachite in some UK EfW APC residues. Hazardous elements were widely dispersed in different phases, often associated with soluble Ca- and Cl-bearing phases. Specific metal-bearing minerals were also detected in some samples, e.g., cerussite; gahnite, zincowoodwardite, copper nickel zinc oxide, tenorite and fedotovite. Aluminium foil pieces were present and abundantly covered by fine phases, particularly in any cracks, probably in the form of Friedel’s salt. The pH of the UK APC residues ranged from 11.8 to 12.4.

No equivalent analysis of UK IBA has been published, but the available data suggest that UK IBA also resembles similar materials in other countries (Environment Agency 2002; Turrell et al 2012). An Environment Agency Report from 2002 showed that concentrations of toxic metals vary considerable and range from a fraction to several multiples of their concentrations in APC residues (e.g., up to 100 times in the case of Cu). Concentrations of chloride are about an order of magnitude lower. The pH of UK IBA ranges from 8.5 to 13, depending on its age. Zn leaching has been found to be controlled by zinc silicates (ZnSiO3 or ZnSiO4), whereas Cu and Ni leaching are dominated by their respective hydroxides in weathered IBA. Cu release from fresh ashes is dominated by copper complexed with iron hydroxide and particulate organic matter (Turrell et al 2012).

It has been common practice for UK APC residues to undergo simple partial neutralisation with waste acid and blending with other neutralised wastes before landfilling as hazardous waste under a

derogation of the limits for soluble salts. Changing regulation and policy is affecting management practices and regulatory end-of-waste approval has been achieved for processes that incorporate APC residues in concrete blocks (Lets Recycle 2016), despite the risk of eventual pollutant dispersal.

The majority of IBA is processed by removal of metals and fines and weathering to enable carbonation and stabilisation of the minerals, resulting in an aggregate (IBAA). Environment Agency Regulatory Position Statement 017 (2015) allows use of IBAA in unbound and bound (road materials, concrete) applications provided that it must conforms to civil engineering and highways agency standards. However, there are concerns about the metal concentrations found in some IBA and development of a Quality Protocol for end-of-waste appears to have stalled.
References

References

Bogush, A, Stegemann, JA, Wood, I, Roy, A (2015) Element composition and mineralogical characterisation of air pollution control residue from UK energy-from-waste facilities, Waste Management 36, 119–129.

Defra (2016) Digest of Waste and Resource Statistics – 2016 Edition (revised) March 2016, UK.

Environment Agency (2002) Solid Residues from Municipal Waste Incinerators in England and Wales, Bristol, UK.

Environment Agency (2015) The regulation of materials under consideration for an end of waste Quality Protocol, Regulatory position statement 017.

Eurostat (2016) http://ec.europa.eu/eurostat/statistics-explained/index.php/ Waste_statistics.

Lets Recycle (2016) Defra urged to set date for APC residue rule change, http://www.letsrecycle. com/news/latest-news/defra-urged-to-set-date-for-apc-residue-rule-change/.

Turrell, J, Lewin, K, van der Sloot HA (2012) An Assessment of the Mineralogy of UK Municipal Waste Incinerator Bottom Ash using Geochemical Modelling WRc Ref: UC8564.

WRAP (2013) List of Energy from Waste Sites. http://www.wrap.org.uk/node/15031.

Bibliography

Stegemann, JA (2014) The potential role of energy-from-waste air pollution control residues in the industrial ecology of cement. Journal of Sustainable Cement-Based Materials, 1-17.

Bogush, A, Stegemann, J (2013) Zinc Speciation in Air Pollution Control Residues from UK Energy-from-Waste Facilities. Bristol, UK: Environment Agency.

Lampris, C, Stegemann, JA, Pellizon-Birelli, M, Fowler, GD, Cheeseman, CR (2011) Metal leaching from monolithic stabilised/solidified air pollution control residues. J Hazard Mater, 185 (2-3), 1115-1123.

Lampris, C, Stegemann, JA, Cheeseman, CR (2009) Solidification/stabilisation of air pollution control residues using Portland cement: Physical properties and chloride leaching. Waste Manage, 29 (3), 1067-1075.

Lampris, C, Stegemann, JA, Cheeseman, CR (2008) Chloride leaching from air pollution control residues solidified using ground granulated blast furnace slag. Chemosphere, 73 (9), 1544-1549.

Stegemann, JA, Buenfeld, NR (2004) Mining of existing data for cement-solidified wastes using neural networks. J Environ Eng-ASCE, 130 (5), 508-515.

Stegemann, JA, Schneider, J, Baetz, BW, Murphy, KL (1995) Lysimeter Washing of MSW Incinerator Bottom Ash. Waste Manage Res, 13 (2), 149-165.

Stegemann, JA, Schneider, J (1991) Leaching potential of municipal waste incinerator bottom ash as a function of particle size distribution. In GOUMANS, J.J.J., Van der Sloot, H.A., Aalbers, T.G. (Eds.), Waste Materials in Construction. (pp. 135-143). Elsevier Science B.V..

Stegemann, JA, Schneider, J (1990) Leachability of Bottom Ash from a Municipal Waste Incinerator. 12th Canadian Waste Management Conference. (pp. 347-375). St Johns, Canada.

Phosphorus recovery from sewage sludge ash - data aquisition and recovery technologies

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Sewage sludge ash is a promising source for phosphorus (P) recovery due its high P content. However, the actual P content is crucial to know for an efficient recycling. Additionally, the content of other inorganic compounds determines whether the SSA meets the requirements of the respective fertilizer ordinances and has to be treated to reduce contaminant mass fractions. Thus we conducted a survey of all German SSA from 24 mono-incineration plants and determined their elemental composition and respective recovery potentials. Our survey covered more than 97 % of the 300,000 t SSA that accrue in Germany annually. We collected 252 samples from a period of one year. Thus we were also able to monitor seasonal changes in the elemental composition. The ashes contain about 19,000 t/a P that accounts for about 13 % of the P amount that is currently needed for mineral P fertilizer in Germany. The solubility of P in neutral ammonium citrate, an important parameter to estimate fertilizer efficiency, is about 30 % in the mean. Furthermore, about two thirds of the SSA shows contaminant values above the respective limit values and could not used as fertilizer directly. Some of these problems can be avoided by intelligent sludge management, but additional treatment of SSA is necessary in many cases. Several wet-chemical and thermo-chemical treatments have been developed for SSA. One of those is the AshDec process, where SSA is heated in a rotary kiln together with additives like Na2CO3 or Na2SO4. This leads to depletion of various toxic elements and enhancement of the P bioavailability.

Review of the Reference Document on Best Available Techniques for Waste Incineration (BREF WI)

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The adopted BREF on waste incineration is dated on August 2006. Kick-off meeting for the BREF review was in January 2015 in Sevilla. A draft version of the updated BREF was expected for December 2016, now delayed to the first quarter of 2017.

Plant-specific data for the review were collected by questionnaires to be filled in by plant operators. Information on handling and processing of bottom ash was retrieved with the Questionnaire for bottom ash treatment plants submitted to operators in January 2016. Meanwhile the results from bottom ash treatment plants in Germany are available. On the basis of 2.5 million ton bottom ash treated the actual metal yield was calculated. On average 6.6% of scrap iron have been separated, non-ferrous (NF) metals amounted to 2.0%. The results of the questionnaire enabled also an estimation of the specific energy consumption in the treatment plants. The applied technologies for bottom ash treatment exhibit common characteristics such as metal separation using magnets (scrap iron) and eddy current separators (NF metals), but also principle differences (wet treatment with and without prior ageing, dry treatment). Data were further collected on final bottom ash quality, type of air emission control systems and, if applicable, waste water treatment and quality. The response rate of the BREF survey was quite satisfying for Germany, but worse for other EU member states.

Recovery of waste incineration residues as building materials

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Municipal solid waste incineration (MSWI) generates residues normally referred as bottom ashes (BA) and fly ashes and/or air pollution control residues (APCr). Although BA are produced in larger quantities (~30% of MSW), APCr (~3% of MSW) are of greater concern due to their pollution potential and thus considered an anthropogenic hazardous waste. In fact, APCr is a complex material containing a huge amount of elements, nowadays well characterized [1]. Although APCr contain high concentrations of metals (zinc and lead) and soluble salts (chlorides and sulphates), about 66 elements were detected. Table 1 summarizes elements in major, minor and traces categories. Metal pollutants are significantly associated with fine deposits of $CaCl_xOH_{2-x}$.

Table 1- Major, minor and traces elements detected in APCr [1].

Group	Elements
Major (>0.1%)	Al, Ca, Fe, K, Mg, Na, P, Pb, Si, Ti, Zn, Cl and S
Minor (2-1000 mg/kg)	Ag, As, Ba, Bi, Cd, Ce, Cr, Cs, Cu, Ga, In, La, Mn, Mo, Nd, Ni, Rb, Sb, Sc, Se, Sn, Sr, V, W, Y, Zr
Trace (<2 mg/kg)	Au, Be, Dy, Er, Eu, Gd, Ge, Hf, Ho, Ir, Lu, Nb, Pd, Pr, Pt, Rh, Ru, Sm, Ta, Tb, Te, Th, Tm, U, Yb

Several studies of R&D over the last decades have proposed diverse treatment and disposal solutions for APCr, most of them only tested in the lab scale. Therefore, it is extremely important to discuss challenges and barriers as well as provide suggestions for evaluating the most relevant management solutions. Indeed, the solution found in most countries of treating and landfilling APCr to minimizing the release of contaminants must be called into question.

Recovery and utilization of APCr may be interconnected with treatment methods, since they can facilitate practical applications or improve properties of APCr [2-3]. The recovery is related to specific components present in APCr, mainly salts and metals. Indeed, salt recovery from APC is possible through washing processes. Although APCr represent low-grade ores to recover metals by traditional upgrading methods, they can be theoretically recovered using extraction processes (e.g. acid leaching) or thermal methods (e.g. melting). Some examples are discussed in the literature [4]. Other interesting routes are potential application as aggregates [5] or even using APCr for biogas upgrading [6].

In a previous work the assessment of technological properties (compressive strength, bloating index, water adsorption and porosity) and leaching behaviour of lightweight aggregates (LWA) produced by incorporating different quantities of APCr was considered [7]. Although the recycling of APCr into LWA does not reveal any technical advantages, after a washing pre-treatment and if the percentage of incorporation is low, these residues may be recovered as building material.

References

[1]- A. Bogush, J.A. Stegemann, I. Wood, A. Roy, Waste Management 36 (2015) 119–129.
[2]- T. Astrup, Management of APC residues from W-t-E Plants - An overview of management options and treatment methods, 2nd ed, ISWA- WG thermal treatment of waste, 2008.
[3]- M.J. Quina, J.C.M. Bordado, R.M. Quinta Ferreira, Waste Manage. 28, 2097-2121, 2008.
[4]- J. Fellner et al., Waste Manage., 37, 2015, 95–103
[5]- R. Del Valle-Zermeño et al., J. Hazard. Mater., 266, 132–140, 2014.
[6]- Baciocchi et al. , Waste Management 33 (2013) 2694–2705
[7]- M.J. Quina, J.C.M. Bordado, R.M. Quinta-Ferreira, Waste Manage. 34, 430-438, 2014.

Danish experience with utilization of bottom ash in road constructions: composition, pre-treatment (metal separation + ageing), leaching, monitoring

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In Denmark, the preferred management option for municipal solid waste incinerator bottom ash (IBA) has been utilization rather than landfilling. Today, 96-100% of IBA is utilized for road construction purposes after both ferrous and non-ferrous metals have been sorted out and the IBA has weathered in order to pass the legislation leaching limit values for utilization. In the presentation an overview of the full chain will be given starting at the incineration plant and following to the metal recovery facility, ageing facility and finally to the utilization scenario. Data from a field testing site will be presented and finally, the link between the leaching limit values for utilization and the results of commonly used compliance leaching tests e.g. EN 12457-1,2,3,4 batch tests will be discussed.

Thermo-Recycling - Newest trends in metal recovery from the waste incineration residues bottom and fly ash in Switzerland

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Solid waste incineration residues contain valuable metals and are potentially sources of secondary materials. At the beginning of the year 2010 the Centre for Sustainable Management of Recyclable Waste and Resources (ZAR) was founded by the Canton of Zurich, the Swiss association of waste the association of operators of Swiss waste recovery plants and the consortium waste recovery for region Zürcher Oberland, KEZO Hinwil. ZAR's main task is the challenge to maximize metal recovery from incineration residues by applying Thermo-Recycling.

The main focus of work at ZAR lies in the optimisation of metal recovery out of dry discharged bottom ash. The industrial size application of new, highly efficient metal separation processes over the entire range of grain sizes down to 0.1 mm has been developed and successfully put into full scale operation. This is instrumental for efficient recovery of metals, even precious metals.

The second focus is on the optimizing recovery of Zn and other heavy metals out of air pollution control (APC) residues, e.g. fly ash. With the wet extraction FLUWA-process of BSH AG the metals are transferred in a zinc-containing hydroxide sludge, which currently has to be exported abroad for subsequent metal recovery. The further developed FLUREC-process allows direct recovery of high purity zinc from APC residues by solvent-extraction and electolywinning. In addition, a mixture of cadmium, lead, and copper is recovered as a secondary resource, too.

Hence, compared to the extraction of virgin resources, Thermo-Recycling can contribute significantly to resource conservation and environmental protection in addition to direct recycling. Energy is saved, and emissions of e.g. CO_2 are reduced. The recovery of metals out of incineration residues allows at the same time to minimize long term heavy metals landfill-emissions.

The presentation gives an overview about newest metal recovery concepts and technology developed and applied in full scale size for incinerator residues in Switzerland.

Metal recovery from MSWI bottom ash and residual metal content of the fine fractions - examples from Austria.

Peter Mostbauer, University of Natural Resources and Life Sciences, Austria

Currently, metal recovery from MSWI bottom ash is performed often with magnetic separation and with application of the eddy current technique for the non-ferrous metals. Due to physical restrictions, some of the metals remain in the fine fractions. International data about aluminum, copper, platinum and gold content of the treated bottom ash/fine fractions are controversial. These data and the laboratory methods to determine Al, Cu, Pt and Au content will be discussed in our presentation. Examples from Austria (own data) and Italy (literature data) will document the influence of grain size on the composition of treated bottom ash. In our final slides, we will draw conclusions about further technological development/future options for improvement of metal recovery.

Metals recovery from waste incineration bottom ash by electrodynmic fragementation

Martin Streicher-Porte, University of Applied Sciences and Arts Northwestern, Switzerland

Between 10-20 % of metals are contained in bottom ash of incineration plants - despite separate collection of ferrous and aluminium metal cans. In Switzerland, a coarse ferrous metal extraction after incineration is carried out at most of the incineration plants; -either on site of the plant or more frequently before deposition on the landfill site.

The quality is low as lumps of ash and slag is aggregated to the metal components. Both, from sintering processes during incineration as well as bottom ash cooling, a complex mix is created. The wet bottom ash is chemically active and solidifies days, weeks or even month. Oxides, sulphates and incrustations are formed on the surface of metals.

Electrodynamic fragmentation (EDF) of wet-extracted bottom offers a unique technique to liber-ate metal components from such incrustations. Combined with state of the art sieving and sorting steps such as magnetic separation, eddy-current separation and optical sorting, ferrous and non-ferrous metals can be separated and recovered in larger volume and at a higher quality. A glass and ceramic fraction can also be separated and used as inert material for different pur-poses. Hence, EDF allows to recover metals at a high quality, metal free-inert material and to reduce the deposition volume for wet extracted bottom ash. Studies have shown that the earlier a wet extracted bottom ash is treated, the better metals are liberated from incrustations.