

Management of residues from waste-to-energy processes

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1 Introduction

Incineration of municipal solid waste (MSW) started in the 1870s in England as disposal route for residential waste which guaranteed complete disinfection and allowed safe disposal of the inertised residues, the so-called grate or bottom ashes. Already in early times energy released from the combustion process was utilised and in some instances even the bottom ashes were compacted to form bricks for the building sector [de Fodor 1911].

The quality of solid residues, bottom ashes as well as air pollution control (APC) residues came into focus again during the last two decades, after the environmental impact of air emissions had drastically been reduced. Today the main objectives are

- production of highly inert bottom ashes by adequate combustion control,
- achievement of excellent gas phase and fly ash burnout,
- inertisation and safe disposal – if not utilisation – of boiler and filter ashes, and
- management and safe disposal of the residues from the chemical gas cleaning.

In the following the amount and quality of the various solid residues, their disposal or utilisation options, and the actual practice in this area in selected countries will briefly be discussed. The paper will describe only residues from grate systems and focus mainly on metal recovery.

2 EU regulatory framework

All waste management has to comply with legislative regulations which are inside the EU based on directives issued by the European Council and the European Parliament. The fundamental directive setting the standards for all EU waste policy is the 'Directive 2008/98/EC of the European Parliament and Council of 19. November 2008 on waste and repealing certain directives', the so-called Waste Framework Directive.

For residue management the most important directive is the EU Landfill Directive 1999/31/EC (LFD) issued in 1999. Its primary goal is the prohibition or at least reduction of disposal of untreated and reactive organic waste on landfills. Measures to achieve the LFD targets should include in particular recycling, composting, biogas production, or materials and energy recovery. Especially the latter option promotes waste incineration as the easiest efficient method combining total destruction of organic matter with energy recovery.

In 2003 the LFD was amended by the Council Decision 2003/33/EC which sets landfill acceptance standards, together with protocols for sampling and testing. The main standards are organic inventory measured as TOC (total organic carbon) or LOI (loss on ignition), pH value, leaching of metals and other species as well as the inventory of some organic parameters.

The Council Decision 2003/33/EC specifies also the respective methods to be applied for sampling and measuring the various regulated parameters.

Another directive in the area of residue management is to a limited extent the Waste Incineration Directive 2000/76/EC (WID) of 2000 which addresses waste incineration and co-incineration of waste or waste derived fuels like SRF in industrial furnaces and utility boilers. Aside from its main topic, the regulation of emissions to air, it contains general instructions for residue treatment and plant operation.

3 Mass flows in grate operated MSW incineration plants

Grate furnaces are preferred for waste incineration with high throughput, especially in Europe. A grate system accepts untreated MSW and has almost no limitation concerning particle size of the fuel. The flow of solid masses in a grate type incinerator burning MSW is shown in Fig. 1. The graph compiles averaged ranges as found in modern mass burning systems [IAWG 1997, European Commission 2005]. Although different grates and boilers are in use, the amount as well as the quality of the respective residues is more dependent on fuel quality and operation mode than type of grate.

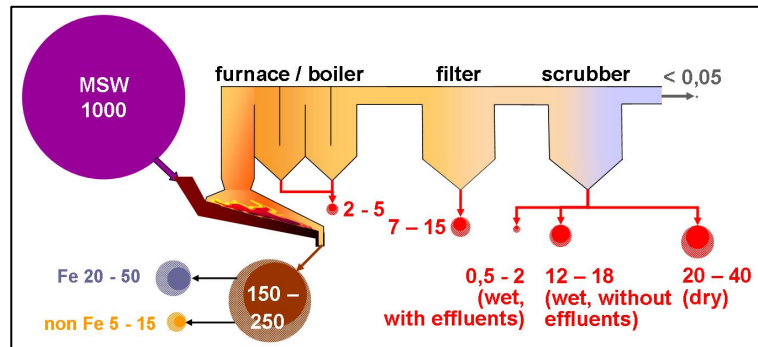


Fig. 1 Flow of solid mass in a modern waste incinerator equipped with a grate furnace

State-of-the-art plants produce approximately 200 kg grate or bottom ashes per 1000 kg of burnt waste. Grate siftings, not shown in the graph, account for 1 – 3 kg/Mg and have to be kept separately in most countries.

The production of boiler ash depends on the type of boiler and on the amount of dust originally released from the grate. Typical numbers in modern plants amount to 2 – 5 kg/Mg. Boiler ashes must not be combined with bottom ash.

The fine particulate fly ashes are removed from the flue gas by an ESP or a fabric filter. Modern waste incinerators prefer 'gentle' combustion in order to limit the PCDD/F formation in the boiler. Their filter ash figures are at the lower end of the given range.

The mass flow of APC residues shows the highest variation of all residues. Wet scrubbers are operated close to stoichiometry; the respective residues are 10 - 15 kg/Mg. The number comprises 2 - 3 kg/Mg of dry neutral sludge and 8 - 12 kg/Mg of soluble salts. If the plant is allowed to discharge liquid effluents into a sewer the only residue for disposal is the neutralisation sludge, a hazardous material requiring special surveillance.

In semi-dry or dry systems the amount of residues is significantly increased because of not reacted additives. The 20 – 40 kg/Mg is a typical value found in modern waste incineration plants.

4 Bottom ashes

4.1 Ash discharge and quality

In grate systems bottom ash falls typically from the backend of the grate directly into a water bath where it is quenched. The bottom ash is then discharged by a hydraulic ram or a drag chain system. The system is often operated with a surplus of water for not only to replenish the evaporation losses but also to remove highly soluble salts, first of all chlorides, from the ashes. If wet gas cleaning is applied, the chloride-rich brine can be fed into the first acid scrubber of the plant. In case of dry scrubbing it may be injected into the spray drier.

For more efficient metal recovery already in the 1990s dry bottom ash discharge was tested in a Swiss MSW incinerator [Simon 1995]. Increasing prizes of metals in the 2000s caused a revival of this technology and in 2009 two waste incineration plants in Switzerland – KEZO in Hinwil and SATOM in Monthey – have been equipped with respective systems. The installed technology is slightly different, the principles, however, are almost the same. As an example Fig. 2 shows the KEZO system where the hot ash falls onto a vibrating conveyor and is transported to a sieving machine to separate the fine

fraction. So-called tertiary air is introduced into the system which replaces approximately 10 % of the secondary air and promotes the burnout.

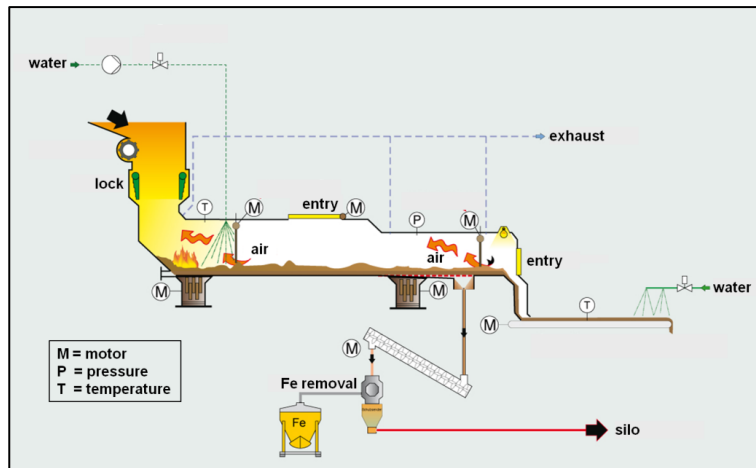


Fig. 2 Scheme of the dry bottom ash discharge at the KEZO Hinwil plant ([KEZO 2012], modified)

Bottom ash is a rather heterogeneous material comprising widely varying fractions of ash, stones, metallic phases and unburnt matter. The burnout is a key parameter for disposal as well as for utilisation of bottom ashes. In modern well operated MSW incineration plants it stays typically below 1 wt.-%.

The TOC of bottom ashes comprises mainly elementary carbon, but to a certain extent also organic compounds are found which cover the spectrum from short-chain compounds up to low volatile species such as PAH or PCDD/F.

The improvement in burnout of solid residues during the 20 years between 1985 and 2005 is shown in the compilation of literature data shown in Fig. 3 [Vehlow 2006].

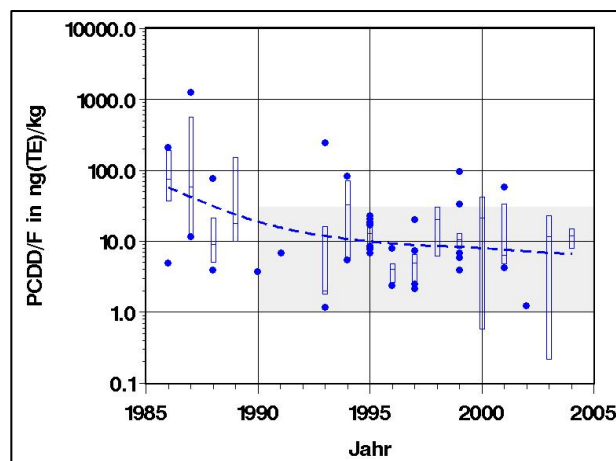


Fig. 3 PCDD/F inventory in bottom ashes between 1986 and 2005 [Vehlow 2006]

The actual figures from modern plants are meanwhile similar to PCDD/F concentrations in uncontaminated soils in Central Europe which range between <1 and 3 ng(TE)/kg. Hence PCDD/F are no critical constituent of bottom ashes any longer.

From chemical perspective the main inorganic components of bottom ashes are oxidic and silicatic compounds. Considering disposal or utilisation options, other ingredients come into focus: heavy metals and salts. Typical concentration ranges of Cl, S, and some heavy metals in bottom ashes are depicted in Fig. 4 [IAWG 1997, Belewi 2000, Zwahr 2006]. For comparison the respective concentration ranges in MSW [IAWG 1997] and in the lithosphere are included [Lide 1994].

Due to the mass and volume reduction by combustion almost all metals are highly enriched in bottom ashes compared to their natural occurrence in the lithosphere which necessitates that their behaviour,

e.g. their leaching properties on disposal sites or in utilisation scenarios, has seriously to be looked upon.

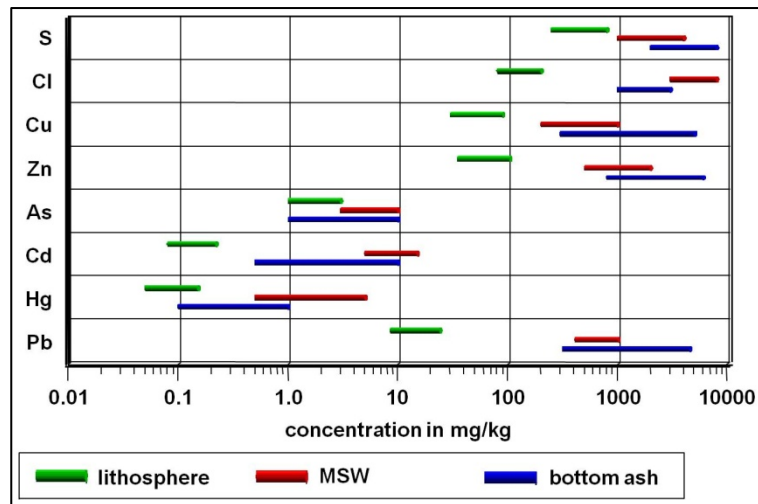


Fig. 4 Concentration ranges of selected elements and PCDD/F in bottom ashes and the earth's crust

Apart from chemical analysis, geochemical and mineralogical characterisation provides useful information in view of the long term behaviour of a material. Most publications on mineralogical composition of bottom ashes distinguish between main phases (>20 %), secondary phases (<20 %), accessories (<10 %), and traces (<5 %). Main phases are typically quartz and glass, secondary phases are melilites (e.g. gehlenites and akermanites) [Pfrang-Stotz 1992, Eighmy 1994, Lichtensteiger 1996].

Oxidic and silicatic phases account for roughly 80 % of the coarse ash fraction. These phases are mainly responsible for the mechanical properties of the ashes. In the fine fraction such phases account for approximately 50 % and the carbonates (e.g. calcite) and sulphates (e.g. anhydrite) are prevailing. These phases are more soluble and control to a certain extent the leaching stability of the ashes.

4.2 Metal recovery

Analytical data on bottom ash composition are published in great numbers, but data on the inventory of metallic components are rare. Table 1 compiles values taken from literature which seem to indicate that dry discharged bottom ashes enable better metal extraction than those from wet systems. Investigations showed that up to 40 % of the metals, in particular the non-ferrous ones, are found in the fine bottom ash fraction [Ammann 2011].

Table 1 Metal content in bottom ashes in wt. % (NF: non-ferrous metals)

	country	dis-charge	Fe	NF	Al	ref.
1995	Switzerland	dry	15-20	2		[Simon 1995]
2005	Germany	wet	10	0.9		[Zwahr 2005]
2010	Switzerland	wet	9		2.2-3.3	[Bunge 2010]
2010	Germany	wet	7.3	0.7		[Alwast 2010]
2011	Netherlands	wet	7	1.3		[AEB Amsterdam 2011]
2011	Switzerland	dry	11	3.2		[Ammann 2011]

Heavy non-ferrous metals like Cu, Zn and Pb, but also Ag, Au or even Pt came into focus during the last years. The latter ones will mainly be originated from small electronic equipment in household waste. If these metals are present they will always be in the metallic state, their concentrations will be extremely low and they will be found in the very fine particle fraction. Data published for heavy non-ferrous metals in bottom ashes of the Amsterdam incinerator are compiled in Table 2 [Muchova 2009].

The comparably low Zn concentration is due to its low redox potential which causes a rather high oxidation inside the combustion chamber.

Table 2 Concentrations of selected metals separated from the <2 mm fraction of bottom ash from the Amsterdam incinerator (data in mg/kg [Muchova 2009])

	<i>Cu</i>	<i>Pb</i>	<i>Zn</i>	<i>Sn</i>	<i>Ag</i>	<i>Au</i>
<i>content</i>	920	480	10	80	2	0.11

Metal separation from bottom ashes starts in most plants with ferrous scrap removal directly at the bottom ash discharge by an over-band magnet installed on top of the bottom ash conveyer.

More efficient ferrous separation is done after storage of the raw bottom ashes for few days to reduce their water content. The most common technology is a drum separation system as shown in the left graph in Fig. 5. Non-ferrous scrap is typically removed by eddy current systems. A scheme of such system is shown in **Error! Reference source not found.**right graph of the same figure.

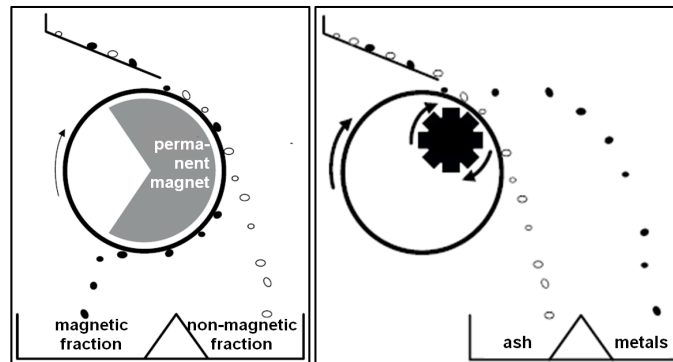


Fig. 5 Drum system for separation of ferrous scrap (left) and eddy current system for separation of non-ferrous metals (right)

Eddy current induces a propellant force in non-ferrous metals and pushes such particles out of the ash. In fine-tuned systems even heavier metals like Cu can be separated from lighter ones like Al. A problem arises with stainless steel which is not magnetic and also only little receptive for eddy current.

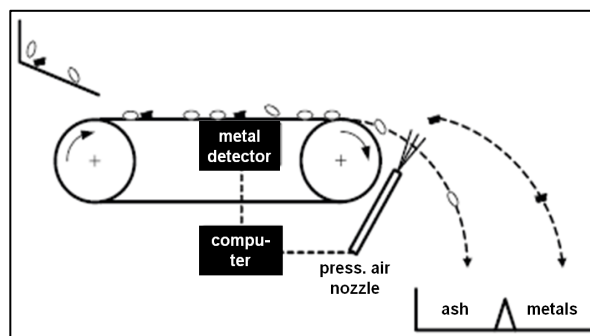


Fig. 6 Sensor operated metal separation system

New systems have been developed using a matrix sensor system which detects pieces of metals in a thin layer on a conveyor belt. The signal triggers a computer operated nozzle which blows the metal piece out of the ash falling down at the end of the conveyer [Eggenberger 2010]. A scheme of such system is shown in Fig. 6. For optimisation some plants implemented meanwhile complex systems to recover metals specifically from even small particle fractions as is shown in Fig. 7.

To get a feeling about the potential of metal recovery from MSW incineration bottom ashes, the annual consumption of selected metals in Germany will be brought into perspective to the amount which could be recovered. A rough estimate is shown in Table 3.

The data base on a bottom ash production of 4.76 mill. Mg in 2008 [Alwast 2010]. The concentrations of non-ferrous metals are estimated to be the same in Dutch and German ashes. Data on total metal consumption and metal scrap prices were collected from a report for the German Umweltbundesamt [Alwast 2010] and from several statistics and dealer offers found in the internet.

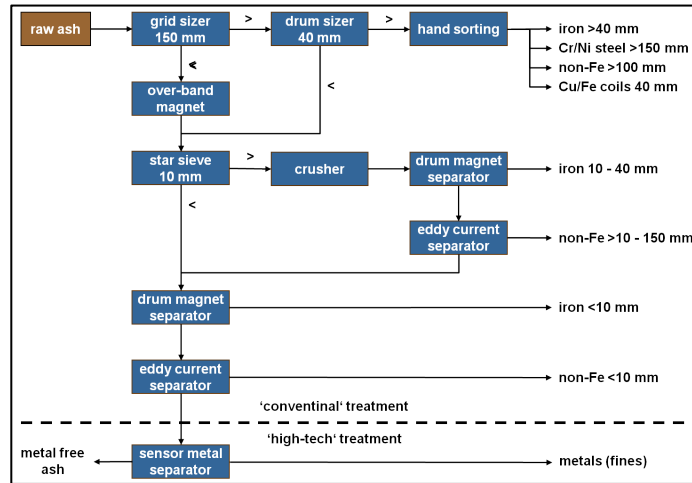


Fig. 7 Optimised metal separation system ([Bunge 2010], modified)

Table 3 Recovery potential of selected metals and their value on the scrap market in Germany

	<i>Fe</i>	<i>Al</i>	<i>Cu</i>	<i>Pb</i>	<i>Zn</i>	<i>Sn</i>	<i>Ag</i>
<i>content in ash (kg/Mg)</i>	100	10	0.9	0.5	0.01	0.08	0.002
<i>total recovery (Mg)</i>	474,100	47,410	4,267	2,370	47	380	9.5
<i>total consumption (Mg)</i>	20,000,000	3,300,000	1,700,000	320,000	350,000	300,000	1,230
<i>potential (%)</i>	2.4	1.45	0.25	0.74	0.013	0.13	0.77
<i>value (1,000 €)</i>	71,115	15,200	12,800	2,500	40	3,200	7,600

The table points out that the amount of recoverable metals reaches only for iron slightly more than 2 % of the annual consumption. For Al almost 1.5 %, for Pb and Ag about 1 % of the consumed metals may be recovered from bottom ash, the share of Zn is negligible.

The reported value does not take the processing costs into account. The achievable revenues by selling the non-ferrous heavy and precious metals could reach 3 – 5 € per ton of bottom ash. This would mean an annual extra profit in the order of 200,000 € for a medium size German waste incinerator with an annual throughput of 200,000 Mg and a production of 40,000 – 50,000 Mg of bottom ash.

4.3 Treatment for utilisation

Whereas metal separation is often the only pre-treatment of bottom ashes prior to final disposal, in case of utilisation more efforts have to be spent to reach not only the environmental requirements but also to comply with the physical and mechanical properties needed for the intended utilisation scenario. The scheme of a technical bottom ash treatment plant, operated at the Hamburg MSW incinerator MVR, is shown in Fig. 8 [Zwahr 2005].

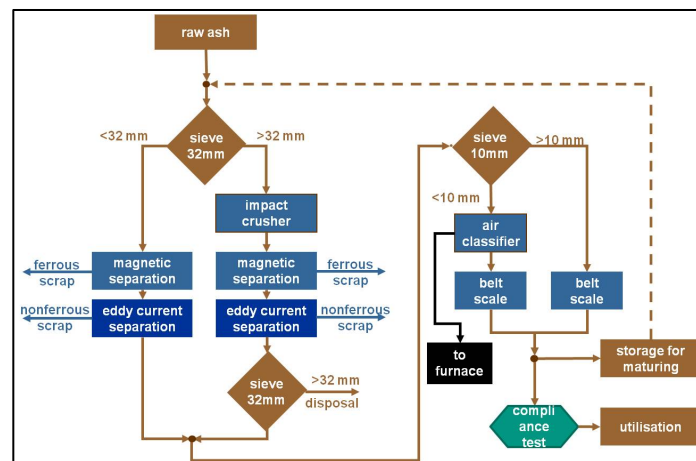


Fig. 8 Bottom ash treatment for utilisation at MVR Hamburg ([Zwahr 2005], modified)

After maturation the ashes meet typically easily the standards for utilisation as shown in Fig. 9 for German bottom ashes. The bar plot compiles data of 26 samples tested during one year [Pfrang-Stotz 1995]. The only value exceeding the limit few times was that of sulphate. The good performance of bottom ashes was ten years later confirmed by tests of Hamburg bottom ashes [Zwahr 2005]. These ashes did meet the sulphate limit all the time.

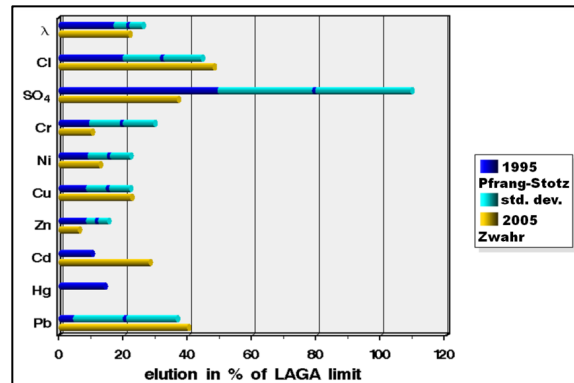


Fig. 9 Leaching test results of 26 bottom ash samples [Pfrang-Stotz 1995a] and respective results of samples from a Hamburg MSW incinerator [Zwahr 2005] standardised to the limits of the German LAGA memorandum for utilisation

However, meeting legal standards does not necessarily tell about the acceptability of the environmental impact. Fig. 10 visualises DEV S4 leaching tests on bottom ashes, recycled concrete, and gravel which document, that the leaching stability of matured high quality bottom ashes can be kept in the same order of magnitude as that of conventional building materials [Sauter 2000].

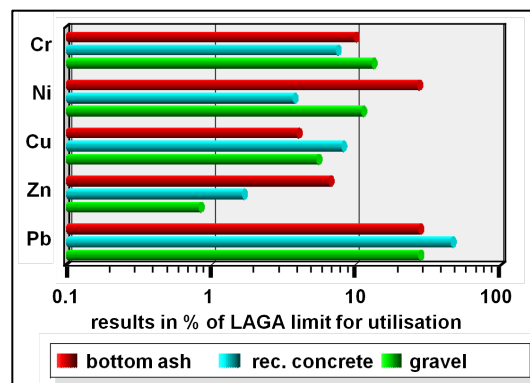


Fig. 10 Results of leaching tests on treated bottom ash, recycled concrete, and gravel [Sauter 2000]

4.4 Disposal and utilisation practice in Europe

With the exception of Switzerland which acknowledges bottom ashes as reactive materials due to their significant inventory of heavy metals and other critical constituents and landfills them, many other European countries practice utilisation of treated ashes in the building sector. Main applications are road construction (where the ash is used as basic layer under water-tight capping), noise protection walls, inner filling of dykes, or aggregates in cement production.

The situation in terms of disposal and utilisation in Europe is compiled in Fig. 11. The data are taken from country reports published by CEWEP, the Confederation of European Waste-to-Energy Plants.

In The Netherlands, Denmark, Belgium, Germany, and France close to 100 % of bottom ash is utilised. In these countries there are national standards regulating the properties and quality of materials for specific utilisation scenarios. There are other countries like Sweden where no national strategy for bottom ash utilisation exists and each intended use of bottom ash for road construction needs a special permit which is decided upon site specific conditions. In Austria and Spain 90% and more of the bottom ash is landfilled, the remaining amount is utilised as 'slag concrete for landfills' (Austria) and for road construction on landfill sites.

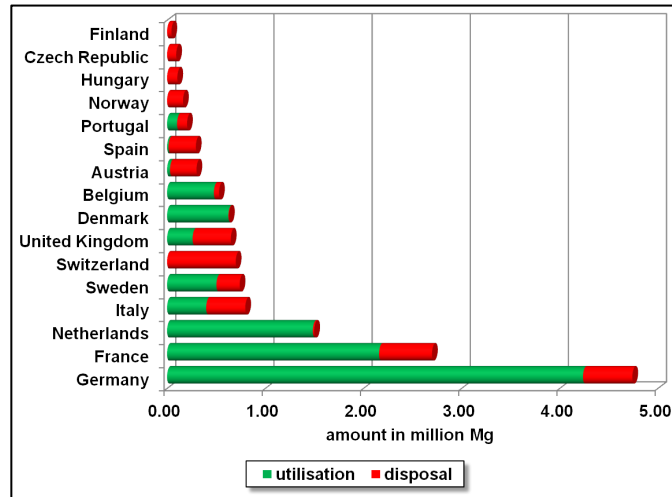


Fig. 11 Bottom ash disposal and utilisation in Europe in 2008/09

4.5 Future Development

For the time being there seems to be a tendency to extend utilisation of treated bottom ashes as secondary building material. The share in this market is rather low, in Germany it accounts for roughly 5 %.

Since conventional building materials carry typically lower loads of heavy metals it can be doubted whether bottom ashes will find a market in future. Some countries might decide to follow Swiss philosophy and give up utilisation for safe disposal. Such decision will not leave a big gap in the building material market behind, but may end debates about environmental impacts.

5 Filter Ashes

5.1.1 Characterisation

Boiler ashes are deposited inside the boiler at temperatures between approx. 800 and 200 °C, filter ashes typically at temperatures slightly below 200 °C in an electrostatic precipitator or a fabric filter. Due to their high inventory of volatilised heavy metals and dioxins these ashes are classified as hazardous materials. In many instances they are treated together. The main problem for aftercare free disposal is their high inventory of water soluble salts, first of all chlorides, rather than that of the other pollutants.

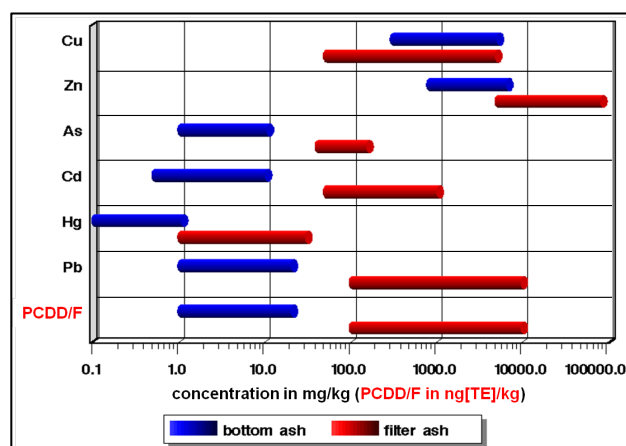


Fig. 12 Concentration ranges of selected metals and PCDD/F in bottom and filter ashes from grate systems

An overview of the partly enormous enrichment of selected metals and dioxins in filter ashes compared to their concentration in bottom ashes is shown in Fig. 12.

The concentrations of Zn (up to 10 wt. %) or Pb (up to 1 wt. %) are that high that a recovery looks promising. Investigations in that direction started already around 1990 but came to the conclusion, that this was not commercially viable at that time. Due to rising metal prices on the world market the idea became recently attractive again.

The high expenses for sustainable final disposal of boiler and filter ashes were reason for numerous attempts to detoxify these materials in order to get access to less expensive disposal routes. A broad spectrum of different processes has been proposed and tested in different scales, however almost all of them failed to enter the market in Europe due to high costs.

An exemption is again Switzerland where a process called FLUWA is used in 50 % of the plants [Frey 2004, Schlumberger 2010]. The principles of this process have been developed with the 3R Process in the mid 1980s already. This process combines acid extraction of soluble heavy metal compounds by using the acid flue gas cleaning solution with thermal treatment of the compacted extraction residues in the furnace [Vogg 1984, Vehlow 1990]. A scheme of the process is shown in Fig. 13.

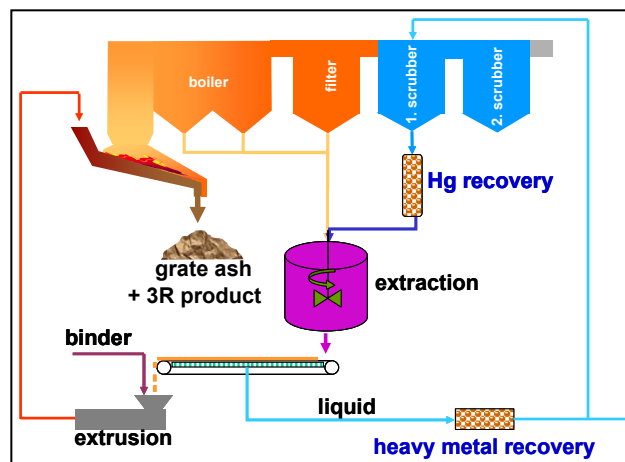


Fig. 13 Scheme of the 3R Process

5.2 Metal recovery

When the 3R Process was developed in the mid 1980s recovery of metals from the filtrate was already considered. This looked especially promising for Zn at that time, however, such recovery was economically not feasible and the research was not continued. This changed with time and Swiss research groups started recently to use the FLUWA process for Zn recovery [Frey 2004].

Table 4 shows concentration ranges of selected metals in filter ashes as published in a review in 1997 [IAWG 1997] and new data from four Swiss incineration plants [Bühler 2010]. The third column of the table contains averaged data for estimation of recovery potential.

Table 4 Concentration ranges of selected metals in filter ashes (data in mg/kg)

	<i>IAWG</i>	<i>Swiss data</i>	<i>average</i>
<i>Cu</i>	50 – 5,000	1,200 – 1,350	1,300
<i>Zn</i>	5,000 – 80,000	40,000 – 44,000	45,000
<i>Cd</i>	50 - 450	550 - 650	600
<i>Sn</i>	1,700	--	1,500
<i>Pb</i>	5,300 – 26,000	15,000 – 18,000	16,000

Published extraction rates achieved in the FLUWA and 3R Process for selected metals are compiled in Table 5.

As the table points out, the efficiencies of both processes are, as expected, similar for Zn and Cd, those for Cu and Pb are higher in the FLUWA Process, most likely due to addition of H₂O₂ to the effluents from the acid scrubber.

Table 5 Extraction rates in % obtained in the 3R Process at low pH and in the FLUWA Process

	<i>3R Process</i>	<i>FLUWA Process</i>
<i>Cu</i>	25 - 35	20 - 45
<i>Zn</i>	70 - 80	60 - 83
<i>Cd</i>	90	85 - 93
<i>Sn</i>	20 - 30	-
<i>Pb</i>	25 - 40	40 - 70

Processes suited for recovery of metals from acid solutions comprise hydroxide precipitation, ion exchange, solvent extraction and electrolysis. Especially for Zn new investigations were started which resulted in the development of the FLUREC Process for electrolytic Zn recovery [Schlumberger 2010]. The process is actually operated in demo scale in Switzerland [Bühler 2010].

Like in the case of metal recovery from bottom ashes a rough estimate will be made to evaluate the economic potential of metal recovery from filter ashes. The total European generation of filter ashes in 2005 was in the order of 1.75 mill. Mg. The respective figure for Germany was 650,000 Mg. Using the averaged concentrations in Table 4 and optimistic extraction yields, the amount of recyclable metals and their share in terms of consumption will be calculated for Germany. The results for Cu, Zn, Sn and Pb are listed in Table 6.

Table 6 Recovery potential of selected metals and their value on the market in Germany

	<i>Cu</i>	<i>Zn</i>	<i>Sn</i>	<i>Pb</i>
<i>content in filter ash (kg/Mg)</i>	1.9	45	1.5	16
<i>total recovery (Mg)</i>	500	25,000	300	750
<i>total consumption (Mg)</i>	1,700,000	350,000	300,000	320,000
<i>potential (%)</i>	0.03	7	0.1	0.25
<i>value (1,000 €)</i>	1,500	21,000	2,500	800

The rough calculation documents that the recovery of Zn has a high economic impact since almost 7 % of the Zn consumption can be recovered from waste incineration filter ashes. The contribution of the other metals looks marginal and might not be worth the effort.

5.3 Amount and management practice

Actual data on production and disposal of boiler and filter ashes are rarely found in literature. Most statistics do not separate the two ashes and often only APC residues as sum of boiler and filter ashes as well as residues from chemical gas cleaning are published. In the context of this report, however, the practiced management strategy per country is more interesting than the precise amount of ashes. Data on filter ash production found in 2006 annual reports published by CEWEP are compiled in Table 7.

Table 7 Filter ash production and management in selected countries [CEWEP 2012]

<i>Country</i>	<i>Year</i>	<i>Production [Mg]</i>	<i>Comments</i>
<i>Austria</i>	2004	40,000	mainly salt mine backfilling, hazardous landfill
<i>Belgium</i>	2004	50,000	solidification and hazardous landfill
<i>Czech Republic</i>	2004	6,000	5000 hazardous landfill, 1000 underground mine
<i>Denmark</i>	2004	86,834	100% recycled (salt mine after special treatment)
<i>France</i>	2004	400,000	hazardous landfill
<i>Germany</i>	2005	650,000	utilisation in salt mine, minor amount hazardous. landfill
<i>Hungary</i>	2005	13,585	hazardous. landfill
<i>Italy</i>	2004	71,814	hazardous. landfill
<i>Netherlands</i>	2003	82,200	50% utilised in mines and construction (e.g. asphalt filler)
<i>Portugal</i>	2005	40,000	inertisation before hazardous landfill
<i>Spain</i>	2005	94,420	hazardous. landfill
<i>Sweden</i>	2004	138,000	landfilling + utilisation in Norway (Langøya)
<i>United Kingdom</i>	2000	78,125	hazardous landfill

As can be seen, most filter and boiler ashes in Europe are disposed of on hazardous waste landfills, in many cases in old salt mines. In Germany filter ashes packed in big bags can get a permit to be used for backfilling old salt mines. This practice is even acknowledged as utilisation respectively recovery. Similar regulation exists in Norway where filter ashes are used to fill an old quarry on the island of Langøya. On this island also gas cleaning residues from Sweden are accepted.

A peculiar management practice is performed in the Netherlands where filter ashes are partly used as filler in asphaltic layers in road construction.

6 APC Residues

APC residues are those from chemical gas cleaning, either from wet or dry systems. All of these residues are classified hazardous and typically disposed of on hazardous landfill sites. Specific data are hard to get.

Attempts have been made to utilise parts of the ingredients of these residues in order to minimize the disposal problem. The challenge is the closing of the chlorine cycle. Different processes for recovery of single salts have been tested. NaCl and Ca(Cl)₂ can be recovered from the effluents of the acid scrubber by crystallisation. This technology is still applied in few plants, e.g. in Germany.

Crystallisation is also applied to recover gypsum from the neutral scrubber effluents of Ca based wet scrubbing. In case the scrubber is neutralised using NaOH, lime is added.

HCl can be recovered from the effluents of the acid scrubber by distillation. To achieve a marketable product, however, several cleaning stages have to be added. The technology applied at the Hamburg MVR waste incineration plant for HCl recovery is depicted in Fig. 14 [MVR 2012].

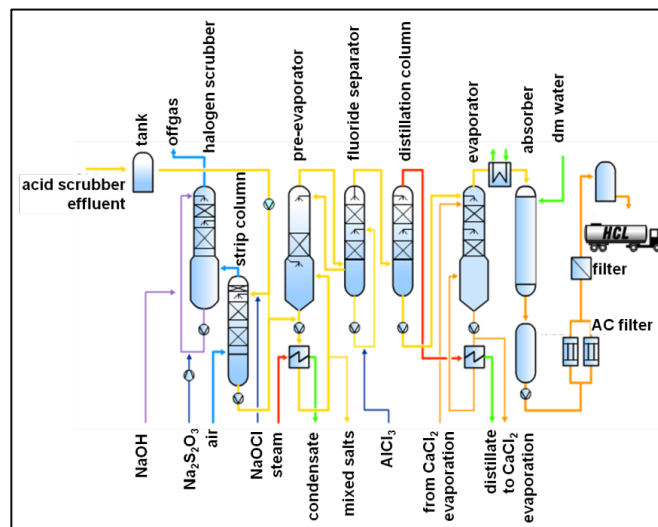


Fig. 14 HCl recovery at the Hamburg MVR plant ([MVR 2012], modified)

As the flow sheet points out it needs a lot of efforts to produce clean HCl. At the Hamburg MSW incineration plant the recovered HCl is used in processes inside other plants operated by the owner company.

7 Conclusions and Outlook

The 1980s were the decade of rapid tightening air emission regulations for waste incinerators which of course became a strong driver for the development and implementation of highly efficient APC systems. Almost at the same time first attempts were seen to improve the quality of solid residues, too. These were mainly focussed on inertisation and safe disposal of filter ashes.

Since that time intensive research and development activities have been started for improving the quality of the various residues and enabling their safe disposal or even utilisation. In many countries the bottom ash, the main residue stream, found its way to utilisation as aggregate in road construction.

Switzerland decided to landfill bottom ashes due to their high inventory of heavy metals, regardless of their leaching stability.

Another aspect concerning bottom ashes came into focus since the late 1990s: their metal content. Ferrous scrap has all the time been separated, initially to improve the aggregate quality. With increasing metal prices this separation became profitable and finally also the inventory of non-ferrous metals became economically interesting. Meanwhile all bottom ashes undergo intensive separation stages for both types of metals. To improve metal recovery dry bottom ash discharge is being practiced in a number of plants and it can be expected, that this technology will be used by more plants in future.

Filter and boiler ashes are hazardous residues due to their high loads of water soluble salts, heavy metals, and PCDD/F. The main problem concerning disposal are salts, especially alkali chlorides. Technologies for stabilisation by washing, solidification, melting/fusion, or leaching have been developed. Melting is applied in Japan, leaching with eventual stabilisation of the leached ashes in Switzerland.

The latter technology lead to the revival of an idea followed already in the 1980 but given up due to missing economic interest: recovery of Zn from filter ashes. It is expected that this technology will be improved with time and will find widespread application, most likely in centralised treatment plants.

APC residues are also hazardous materials, their main problem is the salt content. Processes have been developed to recover Cl as marketable HCl or NaCl. For the time being these processes do not really pay and are practiced by few incineration plants only. Better use of gypsum and recovered chlorine products, the latter ones for industrial use, could be expected in centralised plants in co-operation with chemical industry. This area, too, leaves room for research and development.

The challenge in all residue management scenarios is the definition of final sinks of pollutants. PCDD/F and other organic pollutants can thermally be destroyed and heavy metals can to a great extent either be recovered or widely stabilised. This is not that easy for water soluble salts which cannot be stabilised and for which there is no stable and promising market to be seen today.

These problems have not only scientific and technical aspects, essential prerequisites for long-term sound and aftercare-free solutions have to take socio-economic effects into account and can only be realised with public involvement.

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