Ash Recycling: Just a Dream ?

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Introduction

Waste to energy is only one way of handling waste, material recovery is another aspect of sustainable waste management. This is actually nothing new and has always been part of the operation of WTE (Waste to Energy) plants in Hamburg. In descriptions of the first waste incineration plant in Hamburg, which started operation in 1896, it was stated that "the fly ash" collected in the ash chambers was used as filler material for the insulation of ceiling cavities. Its use in the sandwich walls of money safes was expressly recommended by the members of the urban refuse collection authority. Another lucrative trade was the sorting of scrap iron. It was separated from the incineration slag with magnets. The slag itself was said to be as sterile as lava, as hard as glass, as useful as bricks, and it was a profitable side product of waste incineration. The crushed incinerator slag was evidently so much in demand in road construction and as an aggregate in concrete production that demand could often not be met in the building season, even though it was stored through the winter, [1,2,3].

Because the composition of waste has changed since and because methods for analysing the ingredients of fly ash have been improved, we no longer use fly ash from waste incineration in any way expressly recommended in the past. In fact fly ash from waste incinerators today is considered hazardous waste and has to be disposed of in a safe manner (e.g. underground landfill) according to German law.

The description of the values and properties of slag may have changed somewhat in recent years, but it is still considered a valuable material for constructional purposes that is too good to waste in landfills [4].

In the following only the term "bottom ash" will be used for the residues of waste incineration which are otherwise also termed as "slag" or simply "ash".

Mass flows in the MVR-plant

The waste incineration plant at Rugenberger Damm in Hamburg (MVR) consists of 2 units which can be operated independently to meet the demand for uninterrupted steam delivery to a refinery [5]. Among other goals it was designed to produce reusable materials from the residues of waste incineration and the flue gas cleaning process.

Looking at the mass flows in MVR (Fig. 1), it becomes evident that the largest mass flow besides flue gas and steam (heat, power) is bottom ash, with about a quarter of the waste input by weight. Hence it is worth while taking a closer lock at this material if it is desired to obtain a marketable product made from crude bottom ash.

How to produce reusable bottom ash

Quality control starts right at the bunker. Good mixing and homogenising of the waste ensures good combustion and thus low carbon contents in the bottom ash at the end of the incineration process. According to German regulations [6,7], boiler and filter fly ash have to be kept separate from bottom ash if bottom ash is to be recycled, because they are usually contaminated with heavy metals and organic material like dioxins and furans. Grate riddlings should preferably be returned to the bunker to improve the quality of the bottom ash (Fig. 2). Even though it is hardly possible to analyse the effect of this measure, its positive influence is logical, since there is no mixing of insufficiently thermally treated material with bottom ash. Good fire control on the grate with high temperatures ensures complete combustion, maximum evaporation of volatile heavy metals and sintering of the bottom ash. Especially the last aspect is important with respect to obtaining low leachates in the final product.

Using surplus water in the ram ash expeller (similar to a quench tank) reduces the content of readily soluble salts in the bottom ash by about 50%. The surplus water subsequently has to be cleaned prior to reuse in the flue gas cleaning system (Fig. 3), because the emission of waste water from the waste incineration process is prohibited in Germany. In the scrubbing process lightweight materials are also separated from the bottom ash. Such scrubbing of bottom ash takes place in only two WTE-plants in Germany, MVR being one of them, thus broadening the scope for bottom ash applications in the construction sector. In the next step, the bottom ash is stored for approximately 2 days to dry. Experience at other plants indicates that it would be better to store the bottom ash even longer for up to 2 weeks before processing in order to dry it and thus aerate the surface of the bottom ash particles. Unfortunately a longer preliminary storage period is not possible at MVR due to limited storage capacity. After this preliminary storage the bottom ash is mechanically treated as indicated in Fig. 4. Scrap iron and non-ferrous metals are extracted and the required particle size distribution is obtained by crushing and screening to achieve good load bearing capacity (Fig. 5).

After this treatment an intermediate storage period of at least 3 months is required for maturing [5]. This ageing process is necessary to assure constant specific volume and to reduce leachates. Both are the results of chemical reactions that start after water is added in the ram ash expeller to lower the temperature of the bottom ash for transportation within the plant and for reducing the salt content by scrubbing, and air is introduced during transportation and processing.

Silicates and oxides are stable mineral phases of bottom ash, but sulphates and carbonates are responsible for the reactions during the maturing process that determine volume stability [8]. The ageing process is visualized in a chart showing the relationship between “calcite” and “anhydrite” levels in the bottom ash (Fig. 6). After the bottom ash has reached “calcite” levels of more than 14% and “anhydrite” levels of less than 4% the volume will be stable and ageing is practically finished.

Because in some cases the bottom ash hardens like concrete while maturing, it has to be crushed and screened again before being marketed. At MVR the aged bottom ash is processed once more in the same way as fresh bottom ash to ensure the right particle size distribution for best construction results. As a side effect the metal content is reduced by another 2 to 3% to near 0%. In Fig. 7 the application of bottom ash is demonstrated in the construction of a new container terminal in the port of Hamburg. Here over 300,000 Mg of bottom ash were used for the base layer (30 cm thick), which was covered with 12 cm of bituminous material, thus ensuring very high values of load-bearing capacity. Figure 8 shows the construction of a road as another example for the use of bottom ash.

By-products of bottom ash processing that are recovered for reuse include metals, mainly ferrous metal (steel), which is extracted by magnets, and non-ferrous metals such as aluminium, brass, copper and stainless steel, which are recovered with the assistance of eddy current separators. The amount of steel recovered is about 2.5% of the waste input, amounting to about 7,500 metric tonnes per year out of a total of 320,000 Mg of waste in the case of MVR. Non-ferrous metals are recovered at a rate of about 0.25% of waste input, i.e. about 700 Mg per year, of which about 40% is stainless steel. After incineration the metal is sterile, and once the metal has been cleaned from adhering bottom ash in a separate process the metal can easily be sold to scrap dealers.

Chemistry of bottom ash

Bottom ash is analysed frequently in Germany, at least if it is to be recycled. Also in Germany bottom ash for constructional applications is classified as ”waste for recovery” and has to possess certain chemical properties, from an environmental protection point of view, and physical properties for technical reasons.

Table 1 shows the required properties (LAGA) and the measured values of MVR bottom ash for the last 3 years, while Table 2 presents the results of leachate tests. These analyses have to be performed by licensed laboratories 4 times per year and must be approved by the competent authorities before the material can be sold to customers. As stated before, the particle size distribution is very important for construction applications to assure good bearing capacity (Fig. 5).

Bottom ash produced by MVR satisfies all present requirements, and it has thus been possible to market 100% of it since operation started in 1999. Thanks to the way combustion is controlled, the care taken to ensure that nothing else is mixed with the bottom ash, and the bottom ash treatment process, better results are obtained than in other WTE plants, as can be shown by a comparison with bottom ash produced by 14 other waste incineration plants in Germany (Figures 9 and 10).

Long term trends influencing the composition of bottom ash, such as changes in waste composition over the years or changes in the municipalities where the waste originates, have also been monitored for several years [9]. All important parameters of bottom ash (material composition and leachates) have now been analysed for a period of more than 6 years. The results of the leaching tests indicate that all environmentally relevant parameters are well below the limits, with the measured values at about 30% of the threshold values. It was not possible to detect any considerable upward or downward trends in the measured values. As noted above scrubbing of bottom ash reduces the chloride-content by about 50%, the sulfate content is reduced by a smaller margin. It is also very important to ensure proper handling of the test samples, and many aspects have to be taken into consideration in sampling the materials to be tested. With regard to a debate that has been going on for many years, there is hardly any variation in leachates whether or not the particles of bottom ash are crushed to a diameter of less than 10 mm for the leaching test. In other words bottom ash particle size is of no importance for the environmental impact if the bottom ash is scrubbed in a similar way to the method used at MVR.

The economics of bottom ash recycling

Fields of ash application

In Germany today, bottom ash is used in various fields. The main use is as the bearing layer of roads or parking lots in the public or private sector. The bottom ash is mostly used without any additives, but for high bearing capacities 8 to 10% of cement is added to produce a concrete-like (hydraulically bonded) material, which is sold under the name of "emvau-mix". Also, bottom ash is used in sound embankments or other comparable applications.

To protect the ground and groundwater from bottom ash leachates, the bottom ash usually has to be sealed with an impermeable layer such as bituminous material or concrete or by a near watertight covering in sound embankments. In construction application bottom ash usually has to compete with recycled demolition waste. As a result, the price for the construction material sets the prices that can be obtained for bottom ash.

The cost of bottom ash processing and alternatives

MVR produces about 80,000 metric tonnes of raw bottom ash annually. In addition about 6,000 tonnes of boiler and filter fly ash are obtained in the flue gas cleaning process. Three possible disposal/recycling scenarios are compared below:

In Germany a mixture of bottom ash and fly ash would be considered hazardous waste because of the high contamination by heavy metals and dioxins and furans in the fly ash. This mixture, which is produced in many US WTE-plants, would in Germany require disposal in special landfills for hazardous waste (underground) at a price of about 100 $/tonne, resulting in total yearly disposal costs of approx. 8.6 million $/year in the case of MVR.

Since fly ash needs to be treated or disposed of as a hazardous waste at a price of $100/tonne and bottom ash can be disposed of as a non-hazardous waste at a price of $30/tonne, disposing fly ash and bottom ash separately saves money. In the case of MVR, by disposing fly ash and bottom ash separately the total yearly disposal costs could be reduced by 70% to about 3 million $/a.

The costs for separate disposal of bottom ash and fly ash can be reduced further if the bottom ash is treated properly for recycling. Treating bottom ash at MVR as previously described costs about 25 $/tonne including capital costs, costs for intermediate and external storage (if it is not possible to sell bottom ash directly from the site), and the cost for marketing and transportation to the customer's construction site. These costs of 2 million $/year for the recycling of bottom ash (80,000 tonnes/year at 25 $/tonne) are reduced by returns for recovered steel (7,500 tonnes/year at 20 $/tonne → 150,000 $/year) and for recovered non-ferrous metals (700 tonnes/year at 250 $/tonne → 175,000 $/year) to 1.675 million $/year. For the comparison the costs for the separate disposal of fly ash (600,000 $/year) have to be added, resulting in total costs of approx. 2.275 million $/year for recycling bottom ash and metals and disposing of fly ash. This is by far the most economical and effective alternative for a sustainable waste management, at least under

German environmental standards and economic conditions.

New developments

In Hamburg all treated bottom ash is recycled and marketed in the manner described. Marketing is executed by a separate company that sells the bottom ash of all four waste incineration plants serving the larger Hamburg area. As a result, a high standard of bottom ash recycling has already been achieved, and has thus even brought an improvement in the economics of waste-to-energy plants.

But the market in the construction business with applications of bottom ash is becoming increasingly crowded, with more and more recycled demolition waste pushing into the market. Thus we have to look at further alternatives for treating bottom ash in an effort to add value to this material for use in new fields of application. There are two current developments worth mentioning.

The first development is coating the particles of bottom ash with wax, thereby improving the leaching characteristics. Tests revealed that only a very small amount of wax is actually needed (1% or less by weight) to reduce leaching values considerably. Unfortunately, this also reduces the degree of consolidation, possibly because the wax acts like a lubricant so that the particles do not adhere as well as in the untreated state. Permeability of the waxed bottom ash is comparibly high and it seems that there might be some applications, for which not even natural products fulfill the requirements of relatively good bearing properties combined with high permeability. However, the volume of this market has to be evaluated before deciding upon further steps.

The second promising development is treating matured bottom ash in a gravel processing plant (Fig. 11), which is designed to clean gravel and separate it into fractions of different particle sizes. The gravel is then used as an aggregate in the production of concrete. About 100 tonnes of aged bottom ash were treated at this plant and very "clean" fractions of bottom ash gravel were obtained with particle sizes of 0.5 to 2 mm, 2 to 8 mm, 8 to 16 mm, and 16 to 32 mm (Fig. 12).

Laboratory test results revealed that the "bottom ash gravel" obtained is of good quality according to the relevant standards [10,11] and could even be used in reinforced concrete because of its low chloride content. At present, lengthy tests with different concrete mixtures have started with the goal of developing a lightweight concrete with high strength. There is an advantage of replacing natural gravel by bottom ash: the weight of bottom ash is much lower than natural gravel because the mineral "bottom ash" is very porous. Thereby transportation costs can be reduced. Should this plan prove effective, it will permit a reduction in bottom ash recycling costs. Even though the cost of treating the bottom ash in this type of plant is about 2 $/tonne, the revenues from selling the aggregate would be much higher and would thus reduce the total cost of recycling bottom ash by 15 to 20%, i.e. to about 22 $/tonne compared with 25 $/tonne today.

Summary

In the Hamburg area, more than 200,000 tonnes of bottom ash are recycled annually as construction material. It is important though to treat bottom ash properly to obtain a marketable product. Chemical properties and constructional characteristics have to comply with environmental and constructional standards or guidelines if bottom ash is to be used beneficially. New developments are underway to broaden the fields of application for treated bottom ash and to improve the economics of recycling bottom ash. This will be a further step in the development of waste to energy as part of a sustainable waste management.

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Table 1: Bottom ash 0/32 mm, aged 3 months

parameter	dimension	2001 average	2002 average	2003 average	2003 min	2003 max	LAGA
appearance		granular	granular	granular			1)
colours		dark/gray	dark/gray	dark/gray			1)
smell		slightly moldy	slightly moldy	slightly moldy			1)
dry matter	%	86.9	89.2	88.9	86.8	90.7	1)
heat loss	%	2.42	1.85	1.68	1.60	1.80	1)
TOC	%	0.64	0.65	0.78	0.5	0.9	1
EOX	mg/kg	0.46	0.33	< 1.0	< 1.0	< 1.0	3
PCDD/F	ng I-TEQ/kg	7.44	3.06	5.34	5.34	5.34	
Pb	mg/kg		1567	1212	824	1937	6000
Cu	mg/kg		5396	6340	5172	7940	7000
Ni	mg/kg		288	474	163	1071	500
Zn	mg/kg		2882	3386	2482	3961	10000
Mo	mg/kg		26	7	7	7	
Sb	mg/kg		33	36	32	40	

I-TEQ = toxicity equivalent
1) has to be indicated, no reference value
Measurements below the detection limit have been evaluated at 50% of the detection limit.

Table 2: Bottom ash 0/32 mm, aged 3 months, leachate test S 4

	dimension	2001 average	2002 average	2003 average	2003 min	2003 max	LAGA
colour		gray	gray	gray			1)
turbidity		light	light	light			1)
smell		neutral	neutral	neutral			1)
pH		11.2	11.3	11.1	10.4	11.3	7 - 13
conductivity	µS/cm	1056	1073	1002	769	1250	6
Cl_-	mg/l	60.78	75.07	84.18	64.00	104.00	250 (125) 2)
SO_4^{--}	mg/l	268.50	244.83	166.64	123.00	223.00	600 (250) 2)
CN_-	mg/l	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02
AOX	µg/l	1.3	21.4	4.0	< 1.0	19.0	
DOC	µg/l	4277	8247	10200	6300	18500	
As	µg/l	< 6.0	< 6.0	< 6.0	< 6.0	< 6.0	
Cd	µg/l	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	5
Cr	µg/l	49	48	45	27	68	200
Cu	µg/l	102.55	83.52	81.87	38.80	180.00	300
Hg	µg/l	< 0.20	< 0.20	0.17	< 0.20	0.90	1
Ni	µg/l	3	2	3	< 4	6	40
Pb	µg/l	9.03	< 8.00	6.04	< 8.00	11.20	50
Zn	µg/l	32	22	22	12	32	300
Mo	µg/l		35	30	< 20	38	
Sb	µg/l		33	37	30	55	

I-TEQ = toxicity equivalent

1) has to be indicated, no reference value

2) for application under pavement

Measurements below the detection limit have been evaluated at 50% of the detection limit.

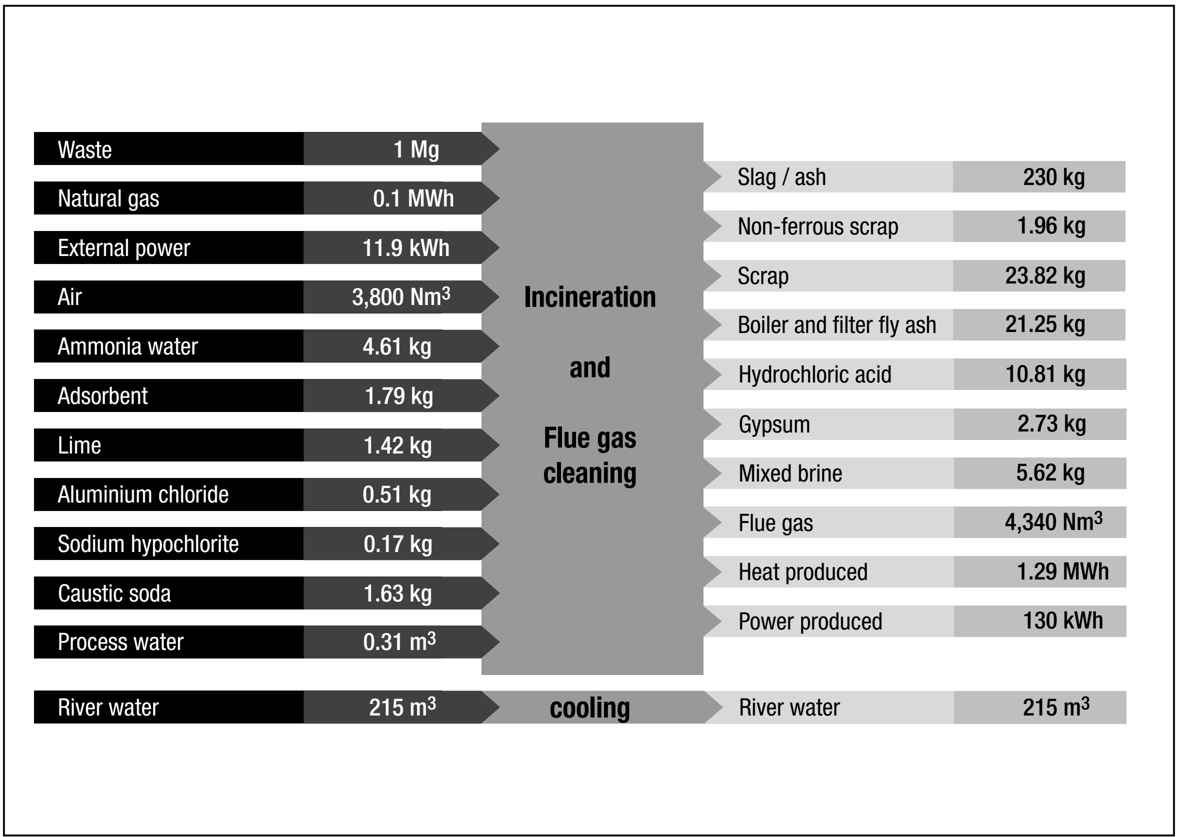

Fig. 1: Mass flow rates in MVR per Mg of waste, 2003

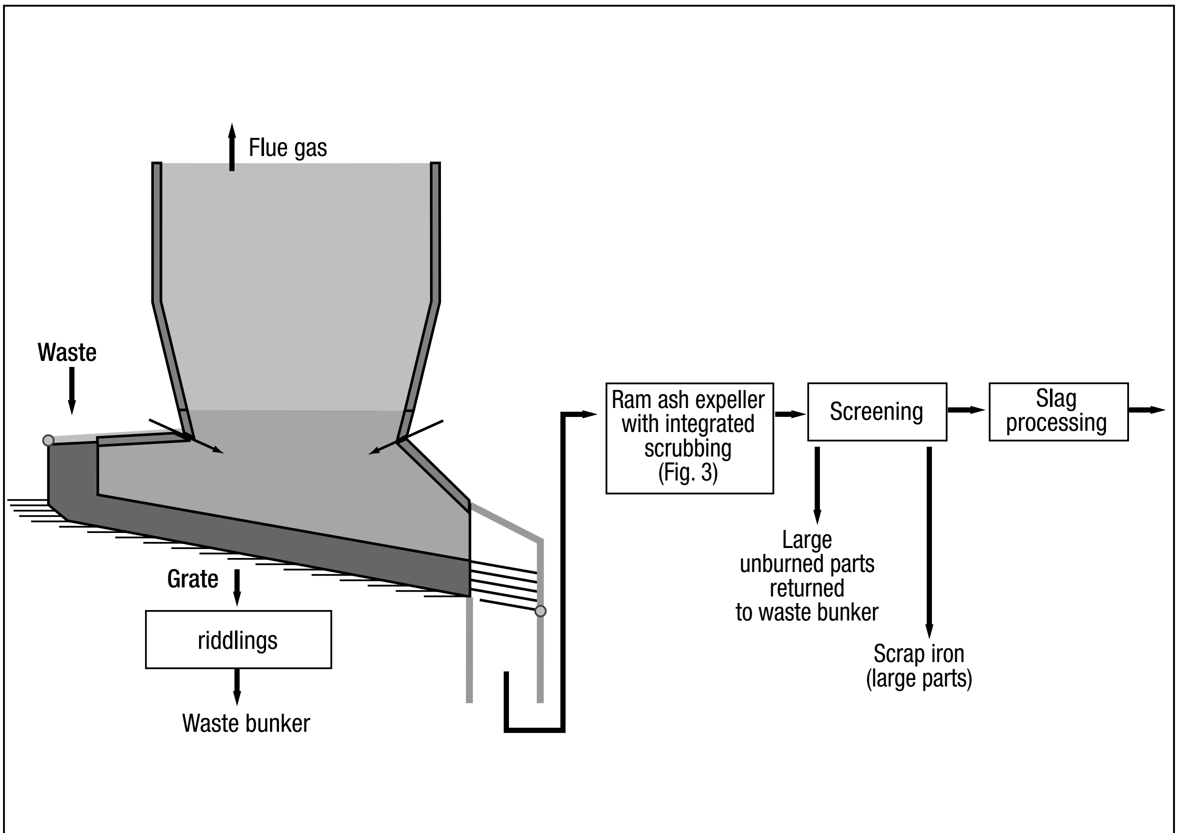

Fig. 2: Schematic diagram of slag processing for grate and ram ash expeller

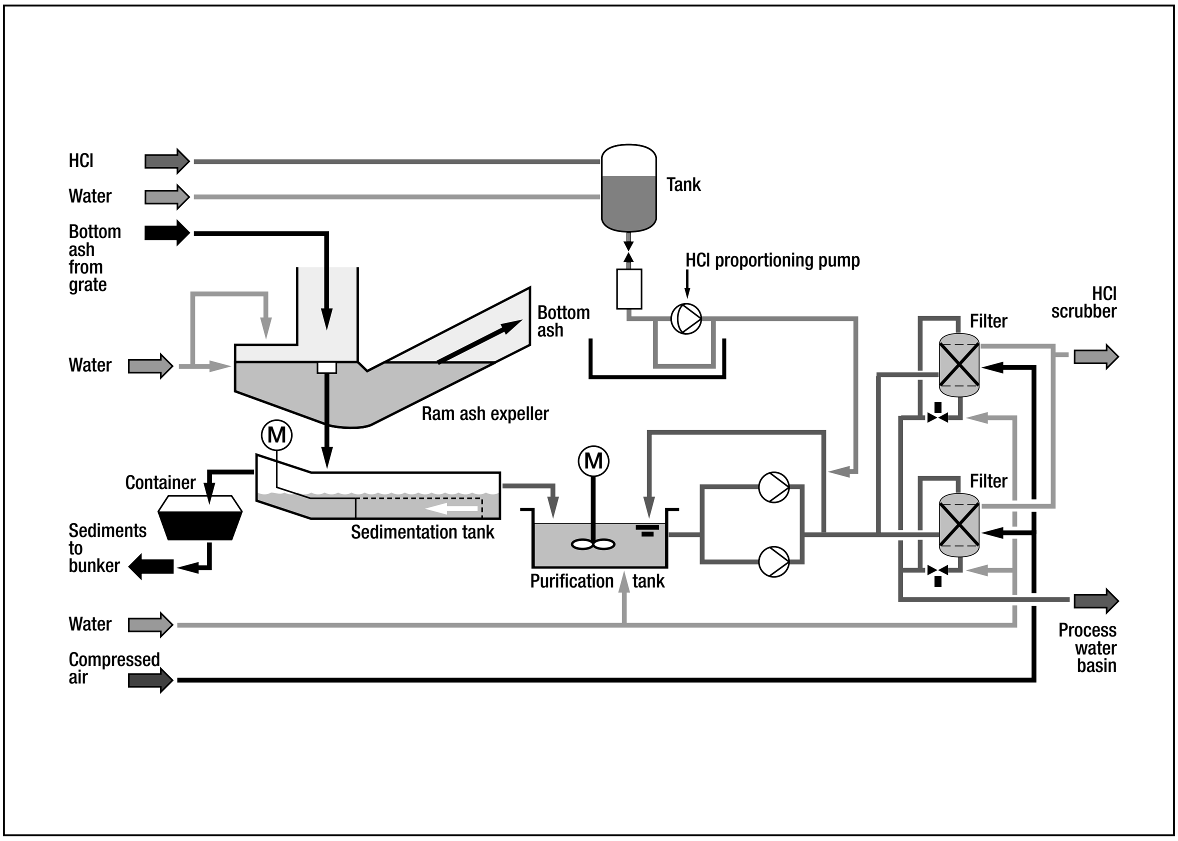

Fig. 3: Integrated scrubbing of bottom ash in the ram ash expeller

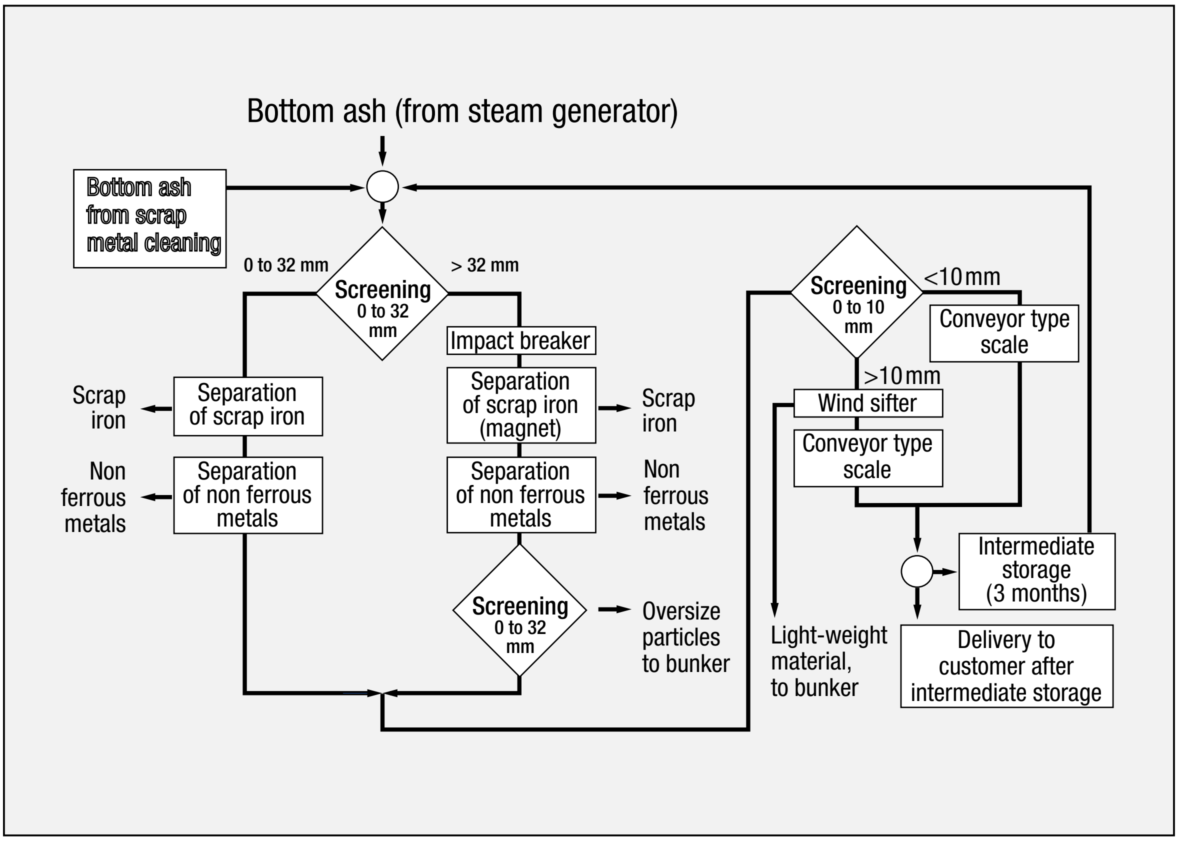

Fig. 4: Bottom ash processing

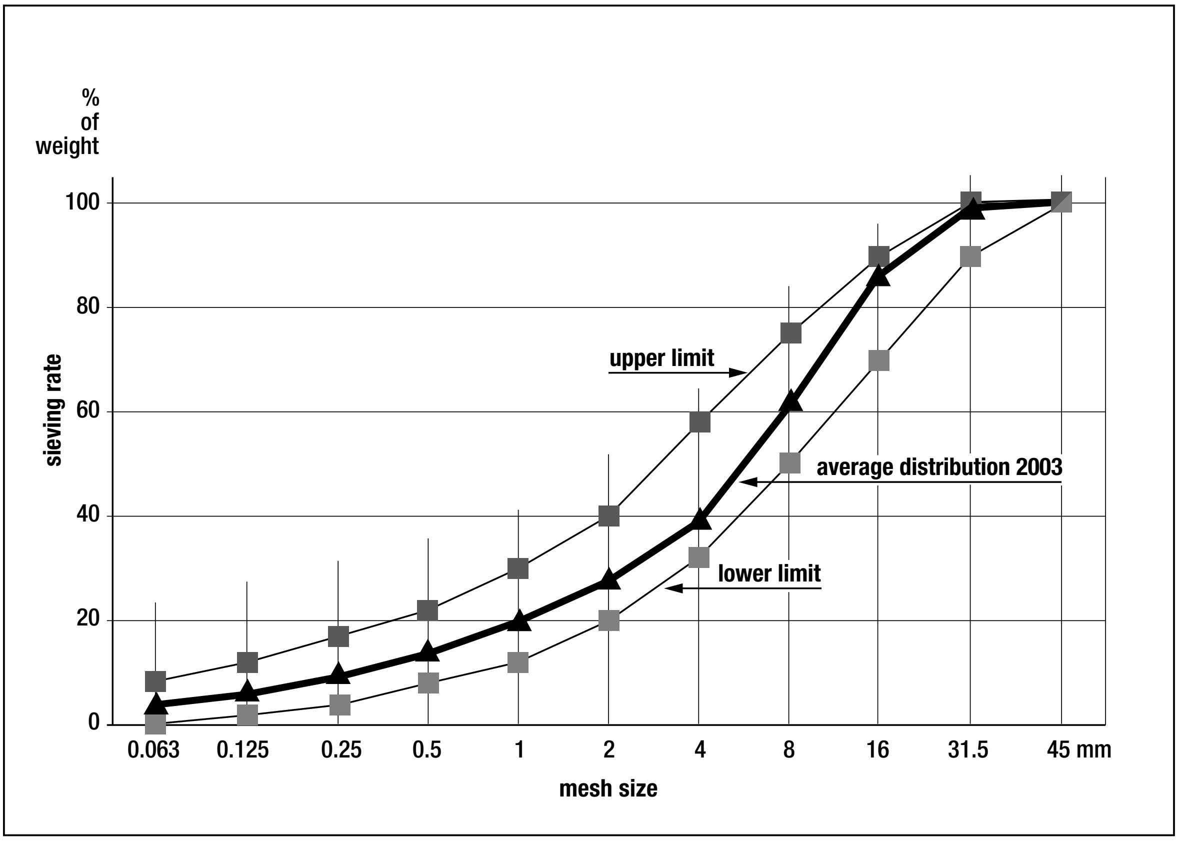

Fig. 5: Grain size distribution of bottom ash, 2003

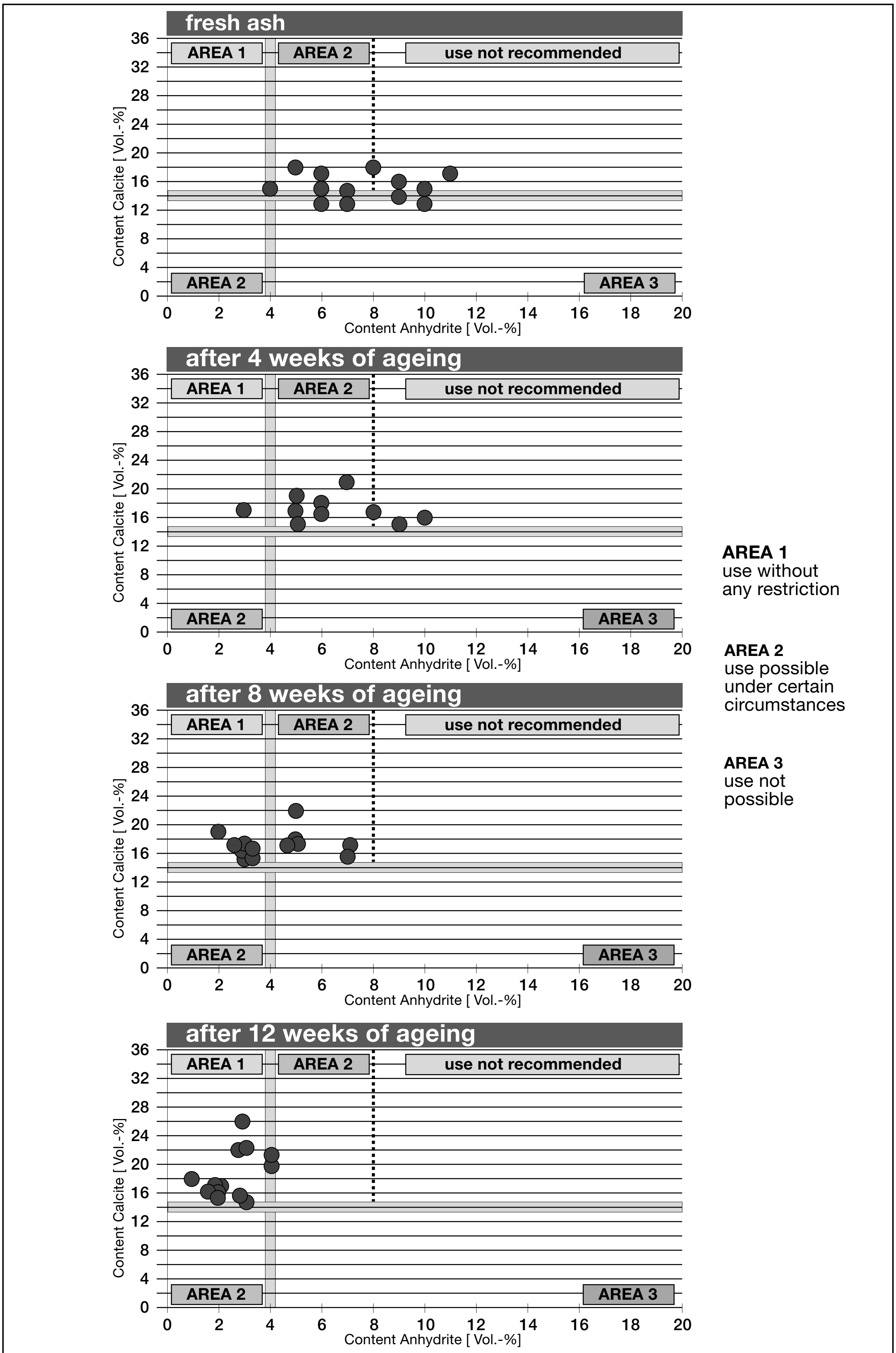

Fig. 6: Mineral transformations during ash ageing

Fig. 7: Application of ash at the new Container Terminal Altenwerder
more than 300,000 Mg used as bearing layer

Fig. 8: Road construction with ash for the bearing layer

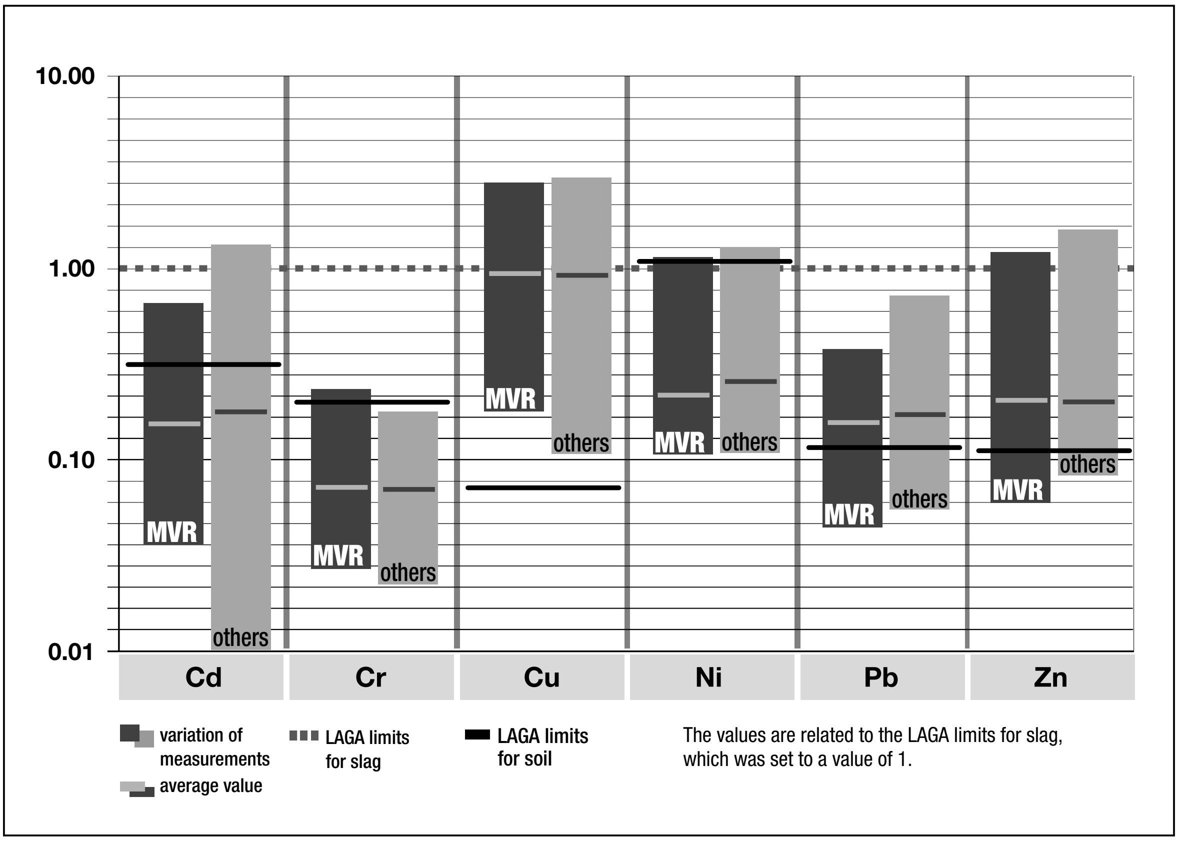

Fig. 9: Comparison of ash components of MVR with ash from other municipal waste incineration plants in Germany and with limit values

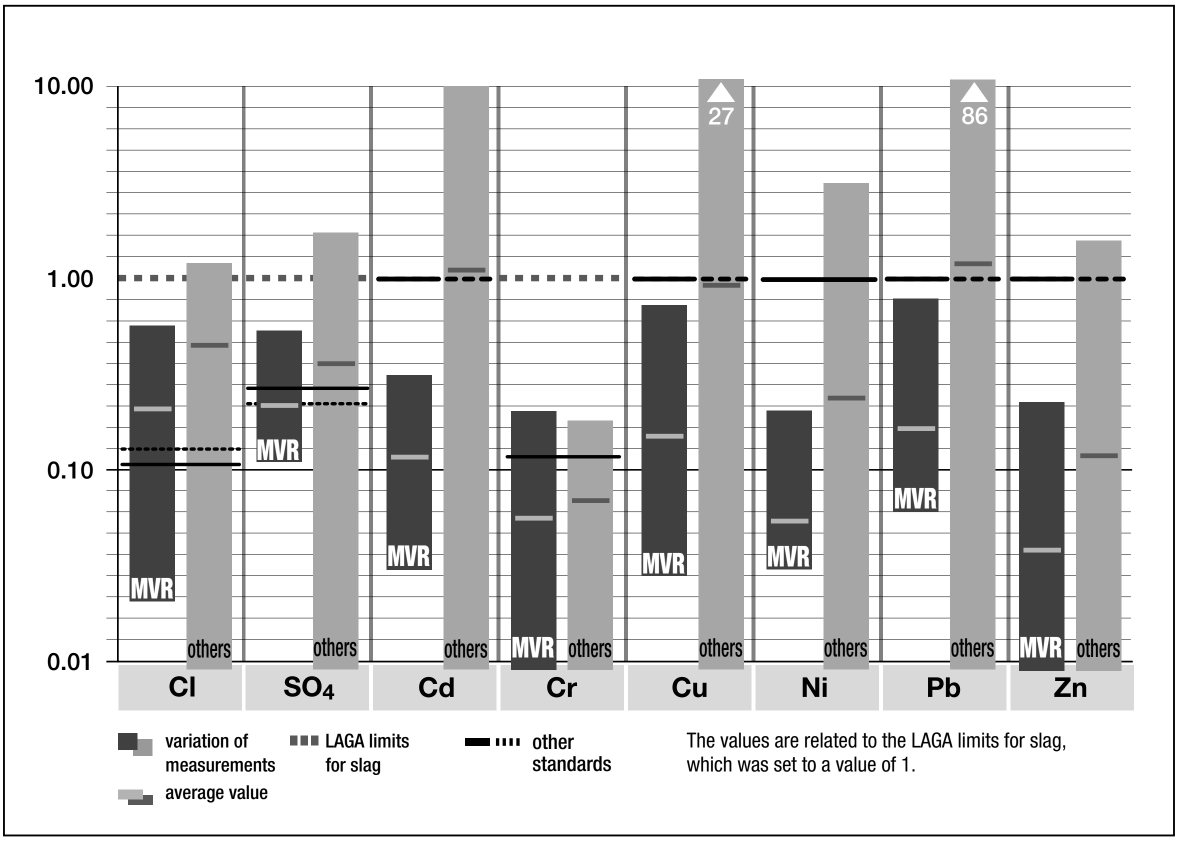

Fig. 10: Comparison of leachates of MVR ash with leachates of ashes of other municipal waste incineration plants in Germany and with limit values

Fig. 11: Gravel scrubbing and separating machine

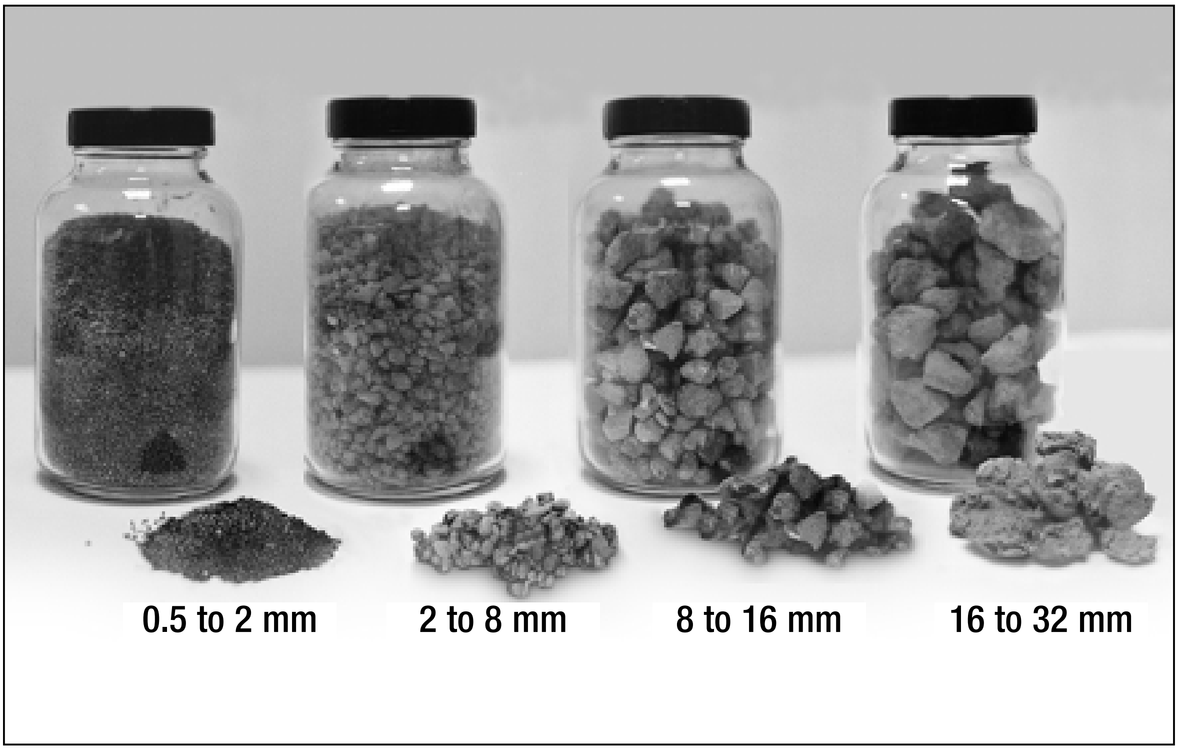

Fig. 12: Samples of "ash gravel"