MARTIN plants and technologies

„Solutions for the recovery of energy and materials from waste“
Materials recovery from waste by means of thermo-recycling in grate-based Waste-to-Energy (WtE) plants is an important contribution to resource recovery. The combustion residues bottom ash and fly ash contain substantial amounts of raw materials which are finite resources and whose primary production results in high power consumption and high environmental impacts. Bottom ash accounts for the largest output at approximately 20 – 25 % by weight. It is usually discharged by means of wet-type dischargers. Various advanced techniques and concepts for the recovery of resources from bottom ash have been installed. Typically, ferrous and non-ferrous bulk metals are recovered, but precious metals (e.g. gold, silver), glass and stainless steel are also of great interest (Figure 1).
The reuse of the mineral fractions, which amount to approximately 80 – 85 % by weight differs in various European countries (e.g. aggregates, additives, landfill). Specific analyses and tests are conducted to identify processing and recycling opportunities.

Particularly in Switzerland, but also in several other European countries, dry bottom ash discharge has generated a great deal of interest. On the one hand, the discharge of classified dry bottom ash is economically viable due to effective metal separation, maximization of revenues from metal recovery, reduction of disposal costs as a result of weight reduction, and associated lower transport costs. On the other hand, there are additional benefits due to the enhanced quality of the discharged dry bottom ash and simpler bottom ash handling in subsequent treatment, preparation and recovery processes.

1. Dry bottom ash discharge

In conventional grate-based WTE plants, bottom ash is removed from the furnace via a wet-type discharger. The dry bottom ash discharge system (Figure 2) [5, 6, 7], employed in the two lines of the Monthey WtE plant (CH), consists of the following components:

- ram-type discharger,
- air separator enclosed in container,
- dust extraction system,
- air system.

For dry bottom ash discharge, the discharger is operated without water. By piling up the bottom ash, the combustion is kept air-tight without any influence on combustion control or plant safety. The dry-discharged bottom ash is conveyed directly to an air separator and is extracted in a defined manner. The air separation area is enclosed by a container preventing false air from entering the furnace and dust from getting into the boiler house. The exhaust air from the air separator is conveyed to a dust extraction system, where the fine fraction is separated. The nearly dustfree air could be conveyed to the combustion air system.

Three material flows are separated from the dry-discharged bottom ash by means of air and cyclone separation:

- coarse fraction (> 1 mm),
- fine fraction (≤ 1 mm),
- bottom ash dust (≤ 100 µm).

The coarse fraction, in which almost all metals are present, undergoes appropriate separating processes in order to extract the metals. The mass-dependent separation of a nearly metal-free fine fraction through application of the air separation principle produces a different qualitative and quantitative bottom ash fraction as compared to size- and shape-dependent separation by means of screening. Due to its outstanding pozzolanic properties, the largely mineral fine fraction can be used without further
treatment as a cement substitute for the solidification of wastes or as a basic material for the production of ceramic materials (Chapter 4.). The small quantities of bottom ash dust that accumulate are returned to the combustion process with the overfire air but the dust can also be separated by means of appropriate filter systems and recycled together with the fine fraction.

Figure 2: Martin dry bottom ash discharge system


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At the Zürich Hagenholz WtE plant (CH), the Martin dry bottom ash discharge system is installed in both lines without air separation. The entire bottom ash is conveyed to a container discharge station and transported to the ZAV Recycling AG at the Hinwil WtE plant (CH, Chapter 2.) in water- and dust-tight containers. At the Hinwil WtE plant itself, a different dry bottom ash discharge system is used [1]. Following combustion, the dry bottom ash is discharged via a temperature-resistant conveyor belt into the ZAV recovery facility [10] directly.

2. Recovery facilities

Various advanced techniques and concepts for the recovery of resources from bottom ash have been developed and installed in large-scale implementations on-site WtE plants and processing facilities. The environmental and economic benefits of bottom
ash processing are limited by the efforts and economics of different processing concepts. System boundaries for integrated on-site processing must be identified and a sensitivity analysis for specified system parameters must be conducted. A pre-concentration of reusable materials on-site and final recovery in special facilities could be one approach.

The Martin bottom ash treatment system (Slagline; Figures 3 and 4) [5, 6] is suitable for wet- and dry-discharged bottom ash, modular in design and comprises the following components:

- tipping hall / material feeding system,
- grading,
- removal / refining of ferrous metals,
- removal of non-ferrous metals / stainless steel / glass (optional),
- receiver tanks for mineral residues.

Figure 3: Process flow diagram Martin Slagline

Figure 4:

Martin slagline (bottom ash treatment facility)


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At the Hinwil WtE plant (CH), the Development Center for Sustainable Management of Recyclable Waste and Resources (ZAR) [9] had developed several processing steps for the treatment of bottom ash fractions obtained by dry discharge. At the ZAV Recycling AG [10] treatment plant, these have been implemented on an industrial scale (Figure 5).

By connecting identical separation machines in processing chains or by recirculating the material during separation, a high degree of efficiency in the separation of recyclable materials is achieved. Due to the consistent screening and selective crushing of the bottom ash, the metals enclosed in bottom ash agglomerates are almost completely exposed and can be separated directly or recirculated until they are definitively separated out. The product range includes light non-ferrous metals, heavy non-ferrous metals, iron and stainless steel. In this way, almost complete recovery of the metal fractions is achieved. At the same time, the quality of the mineral content is improved. The system is closed and operates under a slight vacuum to avoid dust emissions [10].

3. Metals recovery

Bottom ash is an extremely heterogeneous mixture whose composition is determined by the composition of the waste input. It comprises ash particles (sintered, molten), incompletely burned substances (< 1 % by weight), metals (ferrous and non-ferrous) in various forms as well as materials such as glass, ceramics and stones. Figure 6 shows the metal percentages that can be separated by recovery facilities.
The quality of recovered metals is of major importance for their marketability. Figure 7 shows matter obtained from dry-discharged (right) and wet-discharged bottom ash (left). Material adheres to the metals when the metals come into contact with the wet mineral constituents [8].

When treating wet-discharged and dry-discharged bottom ash in the same system by dry mechanical means, dry-discharged bottom ash offers a significant advantage when it comes to the recovery of ferrous and non-ferrous metals [8]. Wet-discharged bottom ash must be further treated in order to return this type of bottom ash to the metallurgic raw material cycle. Due to differing properties, treating mineral fractions in an impact mill results in selective crushing so that fractions of this type can be separated out in a subsequent grading process.

Figure 8 compares the recovery of recyclables from wet-discharged and dry-discharged bottom ash. The comparison also considers the separation of mineral incrustations. For ferrous metals, the difference is not significant. There is a considerable deviation, however, when recovering non-ferrous metals.

In particular with regard to non-ferrous metals, the dry discharge of bottom ash achieves higher yields as well as better metal qualities than wet-type discharge processes. What is more, wet-discharged and dry-discharged bottom ash must be processed with differing treatment concepts. Metal pre-concentrates from wet-type discharge processes must be further treated prior to recovery so that the quality required for metallurgic processes is achieved. All grain size fractions of dry-discharged bottom ash exhibit a higher share of agglomerates. For this reason, this type of bottom ash must be pre-crushed for optimized metals recovery in order to also expose and recover enclosed metals [8].
Metals and Minerals: Opportunities for Improved Recovery from Dry-Discharged Bottom Ash

4. Minerals recovery

The mineral fractions of bottom ash are currently used as a construction material, e.g. in road and landfill construction, or as a mining filler. Due to its pozzolanic properties, bottom ash solidifies like cement. The dry-discharged fine bottom ash fraction from the Monthey WtE plant (CH) was therefore used as a cement substitute for the stabilization of wastes and disposed of to a hazardous landfill. Nevertheless, a large amount of the bottom ash mineral fraction is still deposited in landfills.

The goal of a research project at the Imperial College London [2, 3] was to develop a novel thermal treatment technology able to transform the dry-discharged fine bottom ash fraction into an inert material suitable for the manufacturing of products. Therefore, a fine bottom ash fraction < 1 mm obtained from the Monthey WtE plant (CH) had been characterized and processed for the production of ceramics, using standard ceramic processing (Figure 9). This involved wet ball milling to increase sintering reactivity, drying and sieving the milled material to obtain a homogenized powder suitable for pressing and sintering.


Figure 8:
Comparison of the output of ferrous/non-ferrous metals after processing of dry-/wet-discharged bottom ash and separation of incrustations

Figure 9: Flow diagram of ceramic processing of the dry-discharged fine bottom ash fraction

Sources: Bourtsalas, A.: Processing the problematic fine fraction of incinerator bottom ash into a raw material for manufacturing ceramics. PhD Thesis, Imperial College London, Faculty of Engineering, Department of Civil and Environmental Engineering, 2015

Figure 8: Comparison of the output of ferrous/non-ferrous metals after processing of dry-/wet-discharged bottom ash and separation of incrustations

Optimum processing conditions to achieve maximum density, minimal water absorption and linear shrinkage of mixture compositions containing 70 to 100 % by weight dry-discharged fine bottom ash fraction are listed in Table 1. For comparison, data for clay ceramics are reported in the last row.

Table 1: Optimum conditions for ceramic processing of the dry-discharged fine bottom ash fraction

<table>
<thead>
<tr>
<th>Fine bottom ash fraction</th>
<th>$T_{\text{calcination}}$ °C</th>
<th>$T_{\text{sintering}}$ °C</th>
<th>density g/cm³</th>
<th>water absorption % by wt.</th>
<th>linear shrinkage %</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1,200</td>
<td>1,130</td>
<td>2.4</td>
<td>0.9</td>
<td>5.1</td>
</tr>
<tr>
<td>90</td>
<td>1,100</td>
<td>1,100</td>
<td>2.52</td>
<td>0.1</td>
<td>5.3</td>
</tr>
<tr>
<td>80</td>
<td>1,080</td>
<td>1,080</td>
<td>2.72</td>
<td>0.0</td>
<td>5.4</td>
</tr>
<tr>
<td>70</td>
<td>1,060</td>
<td>1,040</td>
<td>2.74</td>
<td>0.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Clay ceramics</td>
<td></td>
<td></td>
<td>2.1 – 2.3</td>
<td>0.0 – 5.0</td>
<td>7.0 – 14.0</td>
</tr>
</tbody>
</table>

Sources: Bourtsalas, A.: Processing the problematic fine fraction of incinerator bottom ash into a raw material for manufacturing ceramics. PhD Thesis, Imperial College London, Faculty of Engineering, Department of Civil and Environmental Engineering, 2015


The optimum mixture composition contained 80 % by weight dry-discharged fine bottom ash fraction and 20 % by weight waste glass and formed ceramics with improved properties compared to commercial clay ceramics.

Ceramic processing transforms the major crystalline phases from quartz (SiO₂), calcite (CaCO₃), gehlenite (Ca₂Al₂SiO₇) and hematite (Fe₂O₃) to the pyroxene group minerals diopside (CaMgSi₂O₆) and clinoenstatite (MgSi₂O₆), together with some andradite (Ca₃Fe₂Si₃O₁₂) (Figure 10).

Ceramic processing also had the effect of reducing the leaching of metals of environmental concern present in the fine bottom ash fraction by over 95 %. These are encapsulated within the glassy phases present in the calcined and sintered materials. The addition of waste glass as sintering promoter was also investigated and liquid phase sintering was achieved at temperatures significantly lower than those needed for vitrification. The sulphates and chlorides concentration in the leachate were reduced by about 99 %. This is associated with the evaporation of metal sulphates and chlorides above 1,000 °C and 900 °C, respectively. Chlorides are reduced by approximately 65 % after wet milling due to the reaction with water.

The processed calcined powders can be pressed and sintered to form dense (> 2.5 g/cm³), hard ceramics (Figure 11) [2, 3, 4] that exhibit low firing shrinkage (< 7 %) and zero water absorption.
Metals and Minerals: Opportunities for Improved Recovery from Dry-Discharged Bottom Ash

Figure 10: X-ray diffraction data of as-received/milled/calcined/calcined and sintered fine bottom ash fraction

Sources: Bourtsalas, A.: Processing the problematic fine fraction of incinerator bottom ash into a raw material for manufacturing ceramics. PhD Thesis, Imperial College London, Faculty of Engineering, Department of Civil and Environmental Engineering, 2015

In addition, the production of a lightweight foamed material (Figure 12) from waste glass and the dry-discharged fine bottom ash fraction was tested successfully.

Sources: Bourtsalas, A.: Processing the problematic fine fraction of incinerator bottom ash into a raw material for manufacturing ceramics. PhD Thesis, Imperial College London, Faculty of Engineering, Department of Civil and Environmental Engineering, 2015

Figure 11: Ceramic tile produced from the dry-discharged fine bottom ash fraction

Sources: Bourtsalas, A.: Processing the problematic fine fraction of incinerator bottom ash into a raw material for manufacturing ceramics. PhD Thesis, Imperial College London, Faculty of Engineering, Department of Civil and Environmental Engineering, 2015

Figure 12: Lightweight foamed material produced from the dry-discharged fine bottom ash fraction

Sources: Bourtsalas, A.: Processing the problematic fine fraction of incinerator bottom ash into a raw material for manufacturing ceramics. PhD Thesis, Imperial College London, Faculty of Engineering, Department of Civil and Environmental Engineering, 2015
The water absorption values went through a significant decline with the addition of the dry-discharged fine bottom ash fraction. This decrease can be attributed to fine bottom ash significantly inhibiting foaming of the sintered materials at quantities greater than 5% by weight. An increase in strength was observed with samples containing the dry-discharged fine bottom ash fraction. This is due to fine bottom ash inhibiting the foaming process creating smaller pores.

5. Conclusions

The described technologies and processes for the recovery of reusable materials from dry-discharged bottom ash point to the key role that grate-based WtE plants and recovery facilities are able to play in the efficient conservation of resources. Qualitatively high-grade metals (ferrous/non-ferrous metals / stainless steel), glass and minerals can easily be recovered from dry-discharged bottom ash and returned to the raw material cycle with low consumption of primary energy.

Depending on the objective, metal recovery or mineral recycling, the subsequent processing chains for bottom ashes can be optimized. The type of discharge (wet / dry) of the bottom ash clearly influences the concepts. If the focus is on metal recovery, dry discharge is a promising option, which shows advantages especially with regard to non-ferrous metal recovery. However, the environmental and economic benefits of bottom ash processing are limited by the efforts and economics of different processing concepts.

The dry-discharged fine bottom ash fraction can be effectively transformed into an inert material suitable for the production of ceramic powder, ceramic tiles and lightweight foamed materials. The addition of waste glass aids liquid phase sintering and improves the appearance of the ceramic body formed. The major crystalline phases are transformed to pyroxene group minerals reducing the leaching of metals of environmental concern significantly. Processed calcined powders can be pressed and sintered to form dense, hard ceramics that exhibit improved properties compared to commercial ceramic tiles.

6. References

Metals and Minerals: Opportunities for Improved Recovery from Dry-Discharged Bottom Ash


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