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Non-Ferrous Metals in Waste Incineration Bottom Ash

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Municipal waste incineration creates bottom ash, which can be then processed and recycled further. Companies who process bottom ash are usually trying to optimize non-ferrous metal recovery because it is the most valuable material stream to recover. This is a small percentage of the total bottom ash volume but there are different ways to recover metals.

Dry bottom ash processing has been covered in this thesis. How much metals bottom ash contains and what are the possibilities to recover them. Companies, which are processing bottom ash are also covered and their methods what they are using for processing research.

When trying to optimize non-ferrous metal recovery out from the bottom ash the process and recovery streams should be tested. Testing was done to compare different kind of sampling methods, which are presented.

It was found that metal recovery process can be economically wise to companies if they can recover and reuse the different recovered fractions. The sampling of non-ferrous metals would need more research and testing.

Keywords	Bottom ash, non-ferrous metals, metal recovery

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Kunnallisesta jätteidenpoltosta syntyy pohjakuonaa, jota voidaan lopulta käsitellä ja käyttää uudelleen. Yritykset, jotka käsittelevät pohjakuonaa yrittävät useimmiten optimoida ei-rautametallien talteen ottoa, sillä ne ovat kallisarvoisimpia eroteltavia materiaaleja. Vaikka prosentuaalisesti vain pieni osa pohjakuonasta sisältää ei-rauta metalleja, löytyy metallien erotteluun monia tapoja.

Pohjakuonan kuivaerotteluprosessi on käyty läpi tässä insinöörityössä. Kuinka paljon metalleja pohjakuona sisältää ja mitkä ovat mahdollisuudet niiden erotteluun. Yrityksiä jotka käsittelevät pohja kuonaa on käyty läpi ja heidän tapojaan prosessoida tuhkaa ja erotella metalleja tutkittu.

Kun yritetään optimoida ei-rautametallien erottelua pohjakuonasta on prosessia ja erotteluvirtoja tutkittava. Testauksia eri näytteenottometodien välillä tehtiin ja nämä on esitetty tässä työssä.

Metallien erottelu prosessi voi olla yrityksille taloudellisesti järkevää jos he pystyvät erottelemaan ja uudelleen käyttämään erilaiset eroteltavat jakeet. Ei-rautametallien näytteenotto tarvitsee vielä lisää tutkimusta ja testausta.

Avainsanat	Pohjakuona, ei-rautametallit, metallien erottelu

Abbreviations

BA	= Bottom ash
FCA	= Fast conveyor belt analyser
FeM	= Ferrous metal
HNFeM	= Heavy non-ferrous metal
MSWI-BA	= Municipal solid waste incineration bottom ash
NFeM	= Non-ferrous metal
WtE	= Waste to energy

Contents

1 Introduction

Waste handling and recycling plays a major role in today's society. We are producing increasing amounts of waste and at the same time the demand for recycling grows. Incineration of waste has been used for years and during the past ten years it has become more popular also in Finland. Incineration is a good way to handle the waste, but it also creates bottom ash, which is the unburned material of the furnace. Technologies for processing the remaining bottom ash has been developed and used for years. This is an environmentally friendly and smart process because there are various useful and valuable materials that can be recovered from the bottom ash. Example metals can be recycled back to the industry use and mineral fractions can be utilised example in road construction or in a building material. The machinery and the process are expensive and there are also environmental legislations and laws giving guidelines and restrictions on how to do this processing. In order for companies to do this, it must be profitable and therefore the process needs to be optimized as well as possible. (ISWA, 2015)

The goal of this thesis was to study on site sampling methods from the non-ferrous metal recovery stream and try to find solutions and ideas for how this process could be done more efficiently. The sampling method was analysed by studying how sampling was done in the processing plant of Suomen Erityisjäte Oy and comparing this to the method, which could improve the sampling process. Non-ferrous metal recovery is one of the most effective means to make the bottom ash processing profitable therefore optimising it, in order to get more Non-ferrous metal (NFeM) out from the Bottom ash (BA) is important.

2 Background

The basic background for bottom ash production and the metals in the bottom ash is presented here. The section will also cover the common separation techniques for metals and companies, which are doing this kind of business.

2.1 Bottom ash

Waste incineration is a good way to reduce the amount of waste going to a landfill and manage large waste volumes because it can reduce waste size by 80%. Waste to energy (WtE) power plants burn municipal waste and produce both electrical energy and district heat. The mechanics of WtE plant are very similar than example coal fuelled power plant except WtE plants uses waste as a fuel. Heat from the burned waste is used to create steam, which is then ran through a turbine to convert the mechanical energy into electrical energy.

Municipal waste incineration bottom ash or (MSWI-BA) is created when municipal waste is burned in WtE power plant. An average 200 kg of BA is produced for every tonne of waste burned. Processing the BA is not only environmentally friendly but also economically feasible. Globally some 75 000 tonnes of bottom ash is produced daily. This has been calculated on the basis of the fact that globally there have been 650 municipal waste Incineration furnace units in 2016, and it has been assumed each unit process 500 t/day and 23 % is discharged as a bottom ash. In theory, this would be worth of 3.4 million Euros worth of recoverable metals. (Bunge, 2016)

Composition of BA varies depending on the burning process, the pre-treatment of waste, the country and area where the waste is produced. The mineral fraction of the BA varies usually from 50 % to 75 %. The other components are ferrous metals (FeM) 5-13 %, nonferrous metals (NFeM), heavy nonferrous metals (HNFeM) 2-5 %, glass and ceramic particles 15-30%, and unburned organic matter 0.2-5 %. (M.N.V Prasad & Kaimin Shih, 2015).

Mineral and metals fractions of bottom ash are both valuable to recycle. Different fractions of mineral can be embedded in with other materials just as cement, concrete or asphalt. Environmental permit is required for these mixtures and applications of utilizing mineral fractions for example as a construction material are out of the scope of this thesis.

Metal fractions can be recycled and purified back to the use of metal industry. (M.N.V Prasad & Kaimin Shih, 2015)

2.2 Metals in bottom ash

Iron is the most abundant metal in BA. It can be separated with magnets, but it is not very valuable because the scrap prices are low. It is still important to separate this because the recovery of NFeM is more efficient once the majority of the iron is out. Nonferrous metals can be divided into two categories: nonferrous and heavy nonferrous metals. They are more valuable metals to recover and the most common of them are Al, Cu, Zn, Pb. For example, the quantities of copper for example are small but the scrap prices of copper are very high, and therefore, copper is very valuable to separate.
As mentioned earlier, the composition of BA varies depending on a country and the WtE plant where it is produced. Usually the most common NFeM in BA is Al. Metals like Cu, Zn and Pb are also very common in BA. Value distribution is considerably different compared to mass distribution of non-ferrous metals. For example, in the study done at the KEZO plant in Switzerland, as little as 0.4 g of gold per tonne was found, but it was still 30 % of the total metal value that the plant was producing (ISWA, 2015). The mass of the recovered aluminium is high and its scrap prize is fairly high as well. According to the study done at KEZO, the value of aluminium was 34 % from the total metal value.

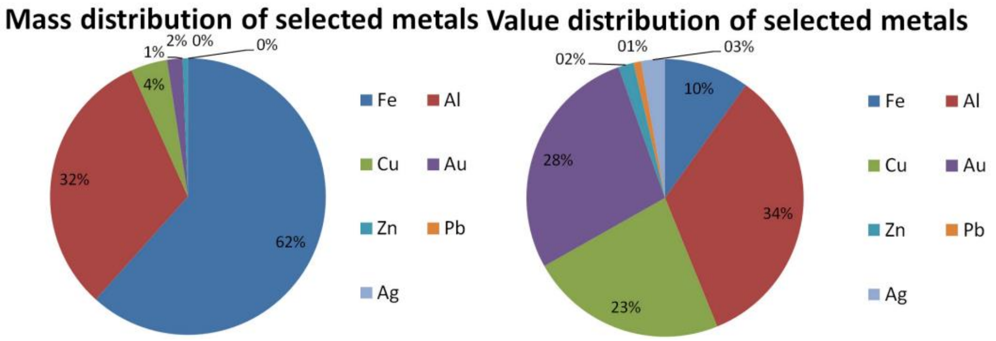

Figure 1. Mass and value distribution of selected metals in the bottom ash treated in KEZO plant (ISWA, 2015).

EU has determined critical metals what its countries cannot produce themselves. These metals are imported from outside the EU but used heavily and therefore the industry is dependent on them. (ISWA, 2015)

List of the ciritical metals:

List of critical metals can be found in Table 1 below. Element is found from the left side and on the right side is the minimum to maximum variance of that metal in the bottom ash in various plants tested.

Table 1. Observed ranges for elemental content of bottom ash (M.N.V Prasad & Kaimin Shih, 2015).

Element	**Concentration Range in bottom ash (mg/kg) (Minimum to Maximum)**
Beryllium (Be)	1.2 - 6
Cerium (Ce)	11 - 51
Cobalt (Co)	6 - 350
Chromium (Cr)	20 - 3400
Dysprosium (Dy)	0.54 - 3
Erbium (Er)	0.31 - 2
Europium (Eu)	0.25 - 2.6
Gallium (Ga)	7.8 - 24
Gadolinium (Gd)	0.88 - 5
Germanium (Ge)	0.78 - 2.7
Holmium (Ho)	0.11 - 0.45
Indium (In)	<1.7
Iridium (Ir)	0.00072 - 0.0075
Lanthanum (La)	2 - 30
Lutetium (Lu)	0.02 - 0.23
Niobium (Nb)	2 - 14
Neodymium (Nd)	4.0 - 37
Palladium (Pd)	0.03 - 1.8
Praseodymium (Pr)	1.1 - 10
Platinum (Pt)	0.074 - 0.53
Rhodium (Rh)	<0.030
Ruthenium (Ru)	<0.0174
Antimony (Sb)	7.6 - 430
Scandium (Sc)	1.3 - 22
Samarium (Sm)	0.93 - 5

Terbium (Tb)	0.18 - 3
Thulium (Tm)	0.01 - 0.18
Tungsten (W)	10 - 320
Yb	0.31 - 5

In BA these metals occur in very small amounts so the recovery is minimal and it is not cost efficient to try to optimize the process for these metals. (European Comission, 2014)

Separation techniques for metals:

Dry bottom ash processing as a process has a general outline what it follows. Although different companies are using different equipment and methods the order and outline of the processing still remains similar.
Comminution is the first stage of the processing which frees the metal particles locked in a mineral stack. This is done by crushing the bottom ash into smaller pieces. Crushing phase can be passed if the quality of the bottom ash is decent and it's not stacked together too much. (Bunge, 2016)

Classification:
In the second part, bottom ash is sorted by the particle size. Screening is an effective way to do this. Different types of screens are used but the most common one is vibrating one, which has multiple layers. The screen is on an angle resting on springs, which is then put on a circular motion with a motor. The material coming from a crushing phase or fed with an excavator hops over the vibrating screen and small particles drop down and are collected on the bottom when bigger particles remain on the top and are collected there.
With screening there are always problems with material sticking to the screen and affecting the efficiency of the screen. (Bunge, 2016)

Sorting:
Sorting is the phase where metals are separated from the minerals. The most common techniques are magnetic separators and eddy current separators.

Magnets:

Magnets can be used for ferrous metals and there are three types of magnetic devices used. In order to choose which magnet type is the best to use depends on the recovery goals of ferrous metals.

Deflecting and extracting drum magnets:

With the deflecting drum magnet, most of the ferrous metals can be removed but not in a very high quality. A lot of minerals are coming as well because the material flow will be thick. With an extracting magnet, which is more commonly used the quality of ferrous metals recovered is good but the amount recovered is much smaller. The difference of these magnets is shown in the figure 2. (Bunge, 2016)

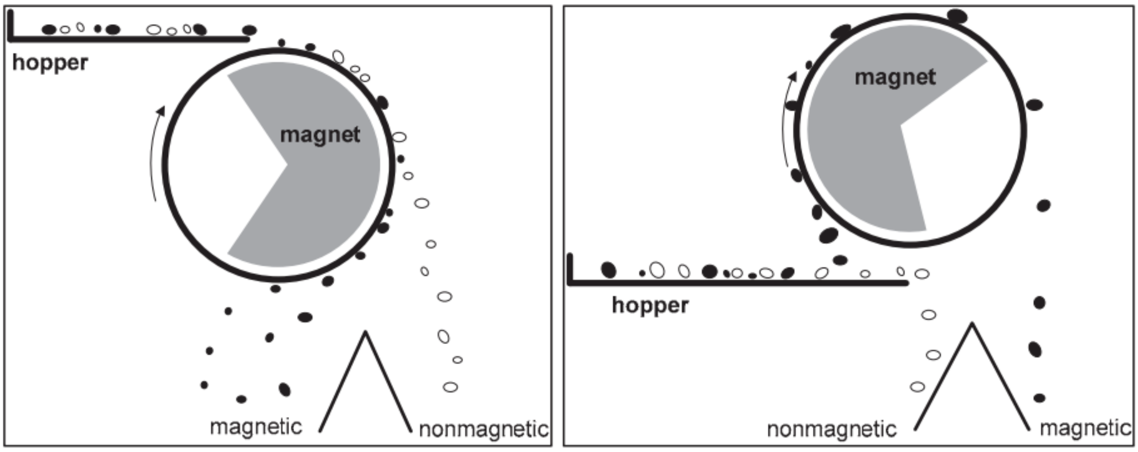

Figure 2. Deflecting drum magnet (left), extracting drum magnet (right). (Bunge, 2016)

Overhead magnets can be electromagnetic or permanent. The advantage of electromagnets are that they can be switched off and this helps the cleaning of the magnet. Overhead magnets can be installed above the conveyor belt either perpendicular to or along the belt. Installation of overhead magnet along the belt is shown in the figure 3.

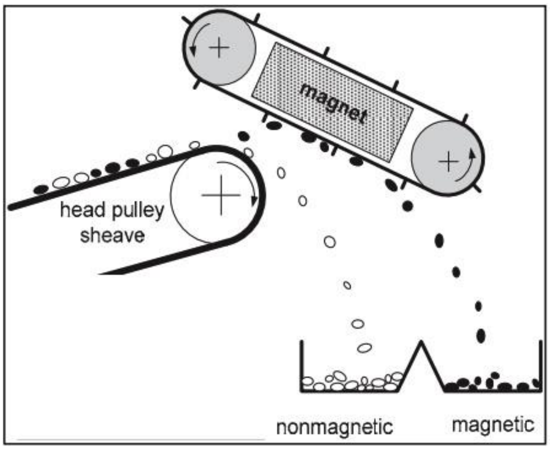

Figure 3. Overhead magnet (Bunge, 2016)

Installing the overhead magnet across the conveyor belt has its own risks. Larger pieces of metal can get stuck between the magnet and the belt and therefore easily damage the belt.

ADR technology:

The finest fractions 0-0.2 mm are difficult to separate because the fine particles are usually attached to the bigger particles so therefore the separation with sieves is almost impossible. ADR technology is developed to do this using gravity and air. The incoming material falls onto a fast rotating rotor blade, which breaks the sticky material. The fine particles will fall near the blade and bigger particles will fly much further. This is the first separation phase and it removes fine particles.

The second part where the bigger particles continue operates with an “air knife”. Thin layer of air is blown downwards and when the material hops through that air, the finest and lightest material will be blown down and the bigger heavier particles will go through. The operation principle of the ADR is demonstrated in the figure 4. (Bunge, 2016)

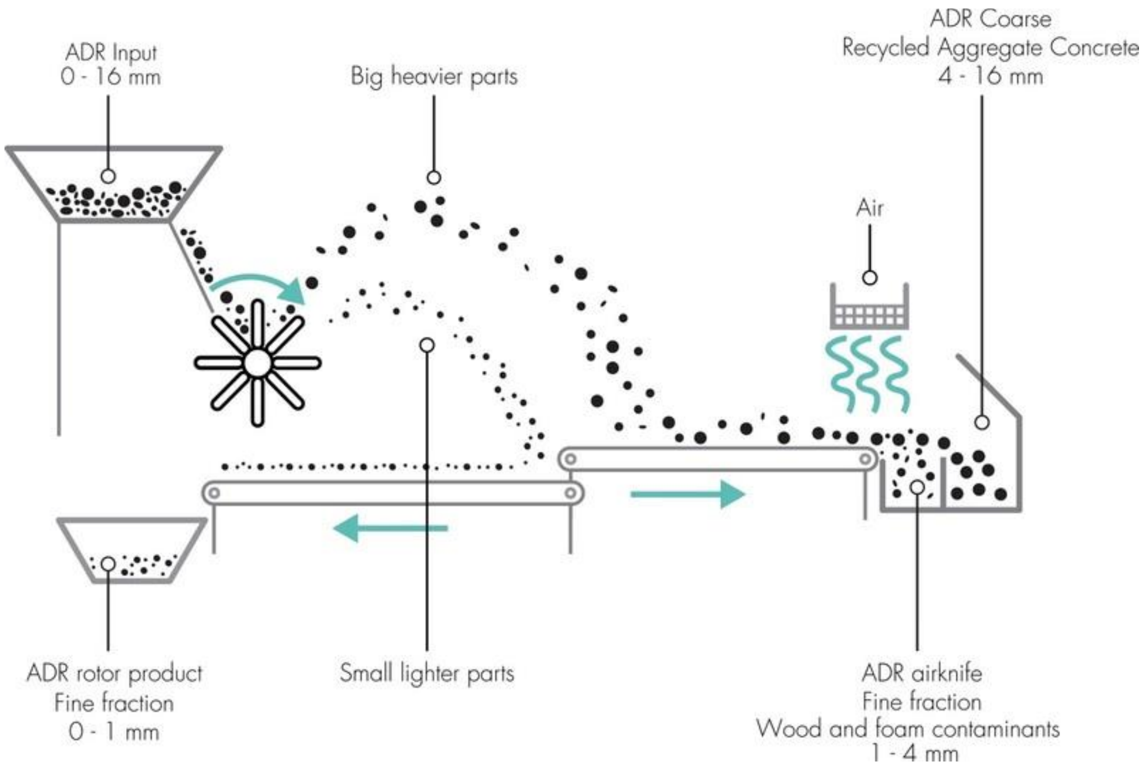

Figure 4. ADR process drawing (C2CA, n.d.).

Eddy current technology:

Eddy current separators are used to get non-ferrous metals out of the BA because they can separate electrically conducting materials. Eddy current has a conveyor belt, whose speed is usually 1-2 m/s, a rotor with a strong magnet, a head pulley and a separation knife. This is shown in the figure 5 below. Eddy current gets conductive materials to repel the rotor and hope to the other side of the separation knife. This is caused by counter magnetic field, which the rotating magnet inside the head pulley creates. (Bunge, 2016)

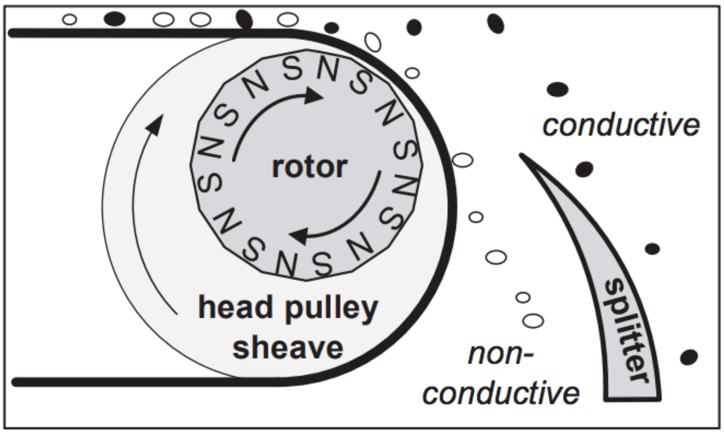

Figure 5. Eddy current schematic photo (Bunge, 2016)

Sensor sorter technology:

Sensor sorters are not so widely used like magnets and eddy currents are usually in every processing plant. They can recover well fractions >6 mm and therefore compete with hand picking.

Material travels on a conveyor belt usually 3 m/s and sensor under the conveyor belt detects the metals. A signal is sent to the computer, which calculates the time when the metal piece should drop from the belt and air nozzle shoots pressurised air to get the metal pieces over the separation knife. The schematic picture of the sensor sorter can be found in the figure 6.

The idea is similar than in the eddy current except that here air is used to get the metal pieces over the separation knife instead of creating an eddy current. (Bunge, 2016)

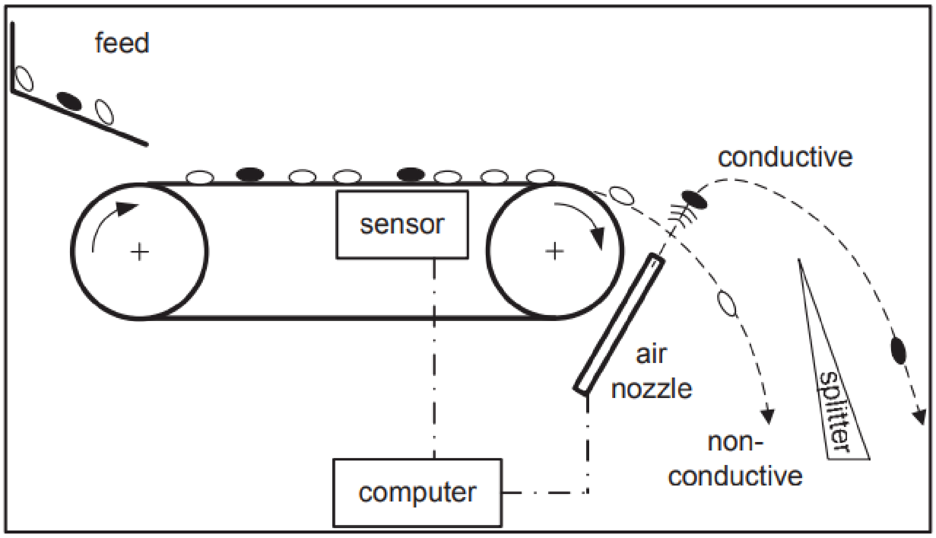

Figure 6. Sensor sorting function principle (Bunge, 2016)

Handpicking:

Handpicking is commonly used for separating the larger metals out. For example, big aluminium thermal bottles and copper wired iron cores would go as a residue with big mineral particles after the first sieve without the handpicking line.

The speed of the conveyor belt where the material comes to the handpicking is low usually 0.15 m/s. Workers stand along the conveyor belt and throws the target materi-als to a container. Rest of the material continues as a residue.

Magnet can be installed before the workers to remove most metals from the fraction.

The fraction coming to the handpicking line is usually at least 100 mm. (Bunge, 2016)

2.3 Companies

Recycling and specifically bottom ash processing and recycling is a big business. There are a lot of companies operating in this field of industry. The following section will cover some of those companies also the techniques and technologies they are using.

Kiverco:

They are UK based company and offer a lot of waste management services. For bottom ash processing they have a mobile plant. The separation techniques they use are sieves, magnets, eddy currents and a handpicking line. (Kiverco, 2017)

The company was contacted to get more information about the process but they did not answer.

NRC:

Non-ferro Recovery Company is specialised for metal recovery and based in Netherlands. They offer mobile plants with a crew to be ordered to the client's site anywhere in the world to process waste materials. Their business model is that the customer can select to pay for the processing and keep the recovered materials or not pay for the processing and NRC will take care of the recovered materials. The latter option requires material testing first so that it can be calculated if there are enough valuable metals to recover.

They have developed their own machinery and technology. Sieves, magnets and eddy currents are used but most likely something else as well. Specifications for their Phairon machinery say it can separate fractions 0-2 mm, which example ADR technology can do. Their other machine NeomaQ promises to recover non-ferrous metals down to 0.125 mm, which is very small fraction.

The company was also contacted to get more information about the process but there was no answer. (NRC, 2015)

Inashco:

Inashco is a large company based in the Netherlands. They have developed and patented the ADR technology. They usually have stationary plants but also semi mobile plants, which do not use the ADR technology. In addition, the basic sieves, magnets and eddy currents are in use. (van de Weijer, n.d.)

Inashco also further processes the recovered metals and they do different products from the recovered mineral fractions like blocks, tiles and pipes.
Suomen Erityisjäte Oy co-operates with Inashco and is the only company in Finland who is using the ADR technology.

KEZO:
Kezo is a dry bottom ash processing plant in Switzerland. It is not a mobile plant and it's designed to treat 200 000 tonnes of bottom ash annually. The processes are completely closed and dust free, which lowers the risk of
health issues.
Technologies used in a plant are crushers, sieves, magnets eddy currents but they have also stainless steel and glass sorting machines. Stainless steel from and iron can also be separated.
Benefits of this kind of plant are the big possible processing volume of the bottom ash and the efficiency and quality of the separation process. It's also clean environment because of the dust free process.
Without to mobility all the bottom ash needs to be delivered into the plant so this kind of a solution is suitable to near big WtE power plants. (Müller, 2016)

3 On-site sampling tests

Results and methods for on-site sampling can be found in appendix 1.

4 Conclusion

The research and on-site tests were successful. It was found that metal recovery and especially non-ferrous metal can be improved by doing on-site sampling. This is the part what is important to optimise in the process. On-site sampling methods still need to have more research in order to conclude anything specific from the results. These results are sensitive information and cannot be shown in this version of the thesis.

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Appendix 1.

This information is censored because of its the sensitive nature.