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EVALUATION OF ALTERNATIVE FLY ASH MANAGEMENT CONCEPTS: A CASE STUDY FROM THE CITY OF VIENNA

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Abstract

As prevailing disposal practices for waste incineration fly ash (disposal at an underground landfill or stabilisation with cement and subsequent disposal at a non-hazardous waste landfill) are either associated with significant costs or climate impacts, three alternative scenarios, namely acidic washing with integrated metal recovery, thermal treatment in a dedicated facility and thermal co-treatment with combustible hazardous waste, were investigated and evaluated in respect of five indicators based on selected objectives of Vienna's Waste Management Plan. These objectives are minimisation of greenhouse gas emissions, minimisation of pollutant emissions, conservation of resources, safety of disposal and autarchy and economic efficiency. The results of our analysis indicate that the alternative scenarios mostly perform worse in comparison to the current practice, except for the thermal co-treatment of fly ash in an existing hazardous waste incinerator. This alternative may represent a more cost efficient and more environmentally friendly solution. However, further investigations are necessary in order to finally evaluate this treatment, as so far only data from short term experiments exist.

Keywords: Fly ash, waste incineration, MSWI residues, hazardous waste, fly ash treatment

Introduction

Approximately one million tons of waste are thermally treated in Vienna every year. For this purpose, there are four incineration plants, namely Flötzersteig, Spittelau, Pfaffenau and Simmeringer Haide. At Flötzersteig (three incineration lines), Spittelau (two incineration lines) and Pfaffenau (two incineration lines) municipal solid waste and commercial waste similar to municipal solid waste are treated in grate furnaces. At Simmeringer Haide three fluidised bed incinerators are used for the treatment of municipal sewage sludge, one fluidised bed incinerator is used for the thermal treatment of pre-treated municipal solid waste and two rotary kilns are used for the combustion of hazardous waste. In Vienna's waste incineration cluster approximately 170,000 t a-1 of bottom ash, 37,000 t a-1 of fly ash and 2,500 t a-1 of filter cake are generated (Wien Energie, 2015). The composition of these solid residues depends on the composition of the incinerated waste, the type of furnace and the air pollution control system installed. Bottom ash and fluidised bed incinerator fly ash may be disposed of at a non-hazardous waste landfill while grate furnace and rotary kiln fly ash as well as filter cake are classified as hazardous waste. They have to be stabilised with cement prior to disposal at a non-hazardous waste landfill or transported to an underground landfill for hazardous waste in Germany. Because of the high phosphorus content, the fly ash from sewage sludge incineration (19,000 t a-1) is considered as potential resource for the production of

phosphate fertiliser (Egle et al., 2016). Fly ash from the incineration of municipal solid waste, commercial waste and hazardous waste (18,000 t a-1) has to be disposed of at hazardous waste sites or are to be treated prior disposal at non-hazardous waste landfills.

To date numerous studies suggesting alternative fly ash treatment methods have been published (Ecke et al., 2000; Margallo et al., 2015; Quina et al., 2008; Zacco et al., 2014). Such treatment must be associated with lower costs and/or lower environmental impacts compared to current practice.

Therefore, possible alternatives for fly ash management to the current practice are investigated in a study co-financed by the municipal department 48 (MA48) of the City of Vienna. The aim of this case study is to assess potential advantages and disadvantages as well as the technological and economical feasibility of these alternatives in Vienna.

Methods

Five possible scenarios for the fly ash management in the City of Vienna were evaluated and subsequently compared. Thereby, it was considered that all scenarios are in accordance with Austrian legislation.

The following scenarios were investigated:

Underground landfill (hazardous waste landfill) in Germany

Stabilisation with cement and disposal at a non-hazardous waste landfill in Vienna

Acidic fly ash extraction with integrated zinc recovery (FLUREC process)

Thermal treatment in a facility exclusively dedicated to this purpose

Thermal co-treatment together with combustible hazardous waste in the already existing rotary kilns

Currently, scenarios A and B are applied for the management of fly ash from hazardous waste and municipal solid waste incineration. Hence, the potentials and limitations of the alternative scenarios C, D and E compared to the current practice are evaluated.

According to the German landfill ordinance, an underground landfill has to keep the deposited wastes permanently apart from the biosphere and aftercare is not necessary. These requirements will be met if the waste is completely enclosed in halite (DepV, 2009). As such landfills do not exist in Austria, in this scenario fly ash has to be transported to Germany (scenario A).

Stabilisation of fly ash with cement (scenario B) produces a material which encloses the harmful heavy metals and salts contained in fly ash. As a result the total dissolved solid and heavy metal content in the leachate are low and disposal at a non-hazardous waste landfill is possible. As such a non-hazardous waste landfill is available in Vienna, only short distance transports are necessary. However, the required landfill volume is increased by addition of cement and water to fly ash.

The FLUREC process (acidic fly ash extraction with integrated zinc recovery) is a process for combined decontamination of fly ash and metal recovery. This process is already utilised in a waste incineration plant in Switzerland (Kehrichtbeseitigungs-AG (KEBAG), 2013) and is described in detail by Schlumberger (2010). After removal of Hg from the acidic scrubber water, this water is used to extract the metals Zn, Pb, Cu and Cd from the fly ash to be treated. Subsequently, metallic zinc is added to the extract as a reducing agent, whereby a mixture of metallic Cd, Cu and Pb is precipitated. Zn is separated from the liquid by reactive extraction with a selective chelating agent in a liquid-liquid extraction step and metallic Zn with a purity of >99.99 % is produced by electrolysis. This Zn can be sold and the mixture of Cd, Cu and Pb can be separated at a non-ferrous metal smelter. Results from Fellner et al. (2015) show that this process is only economically feasible at Zn concentration of more than 50,000 mg/kg or Zn prices above 2,500 € t-1, which is significantly above the recent market of Zinc (on average 1,500 € t-1 during the last years).

Thermal treatment of fly ash is mainly applied in Japan. In general thermal processes are categorised into sintering, melting and vitrification. In sintering processes the temperature is below the melting point of the main constituents, in the case of fly ash between 700 °C and 1,200 °C (Mangialardi, 2001; Wey et al., 2006). Vitrification typically takes place at temperature between 1,100 °C and 1,500 °C (Quina et al., 2008). In order to immobilise toxic compounds like heavy metals, additives which form a homogenous glass matrix are used. Melting differs from vitrification in the absence of additives. All these processes destroy organic substances like polychlorinated dioxins and furans, if still present in the fly ash. Additionally, volatile heavy metals like Hg and Cd are vaporised due to high temperatures. The density of thermally treated fly ash is higher compared to untreated fly ash, which results in a lower demand for landfill volume. Furthermore, the mobility of heavy metals is decreased which might allow disposal on non-hazardous waste landfills. The energy needed for thermal treatment con be supplied in the form of fossil fuels (blast furnace, rotary kiln) or electricity (electric arc furnace, plasma furnace) (Ecke et al., 2000).

The largest hazardous waste incineration plant of Austria is located in Vienna. The incineration takes place in rotary kilns with a minimum temperature of 850 °C (AVV, 2010). Additional fuel may be necessary for wastes with a low calorific value in order to keep this minimum temperature. In Vienna's hazardous waste incinerator heavy fuel oil is used in this case. First experiments indicated that it is possible to co-treat waste incineration fly ash together with combustible hazardous waste and more than 90 % of the inserted fly ash is transferred to the bottom ash of the rotary kiln (Huber et al., 2016). The continuous operation of the kiln is not impaired and sintering of the inserted fly ash takes place, immobilising heavy metals contained in the fly ash. The bottom ash generated at this process and its leachate comply with the legal requirements for non-hazardous waste landfills in Austria. If fly ash was merely mixed with bottom ash, this would not be the case (Huber et al., 2016). In this scenario only the environmental impacts that can be attributed to the fly ash treatment are accounted for. Environmental impacts of the plants resulting from the common treatment of combustible hazardous waste are not considered as they occur independently from the co-treatment of fly ash.

Vienna's Waste Management Plan (Sturn et al., 2012) mentions and describes 14 objectives for waste management. In the present paper five of these objectives are used as exemplary indicators for the evaluation of the above mentioned scenarios:

Climate impact: The emission of greenhouse gases should be minimised.

Minimisation of emission: The emission of pollutants to air, water and soil should be kept as low as possible.

Conservation of resources: Vienna's Waste management should be oriented towards maximum conservation of resources

Safety of disposal and autarchy: Municipal waste generated in Vienna should be disposed of in Vienna.

Economic efficiency: Waste management measures should be optimised regarding economic aspects.

In addition to these objectives, the technological feasibility of the scenarios was assessed. The attainment of the objective climate impact was based on the emissions of CO2. The objective minimisation of emissions was evaluated based on the emission of pollutants during processing and after deposition on a landfill. As only scenario C comprises a recovery of resources, the other scenarios are assessed regarding the concentration of metals as an indicator for possible future recovery. Additionally, the depletion of the resource landfill volume was considered. The objective safety of disposal and autarchy relates to the share of processes required for each scenario that can be performed in Vienna and the share of processes that have to be performed in the hinterland. For the determination of economic efficiency the specific costs for the treatment and disposal of fly ash were estimated for each scenario.

Results and discussion

In scenario A waste incineration fly ash is transported to Germany and disposed of at an underground landfill. In this scenario only two processes are relevant. This is on the one hand the transport and on the other hand the deposition. A process scheme for scenario A is illustrated in Fig. 1.

Fig. 1. Process scheme of scenario A (export and underground disposal of fly ash)

The energy required for transport is approximately 0,03 L Diesel t-1 km-1 (Laner et al., 2015). Depending on the transportation distance the transport associated CO2 emissions are 30-120 kg t-1 fly ash (+). Assuming that the underground landfill is not impaired by earthquakes or similar events, the deposited fly ash does not cause any emissions to its surrounding (++). As the composition of fly ash is not changed in this scenario, it would be available for later resource recovery. However, it is unlikely that underground landfills will be opened for this purpose and the available underground landfill volume is more limited than non-hazardous waste landfill volume, which means the attainment of the objective conservation of resources is low (--). As the disposal takes place completely abroad, the evaluation result for the objective safety of disposal and autarchy is also negative (--). Because of the considerable gate fees of underground landfills the economic efficiency of this scenario is moderate (0). As this scenario is partly implemented in Vienna, its technological feasibility is proven.

The processes transport and disposal at a landfill are also part of scenario B. However, as a suitable landfill is available in Vienna, the environmental impact of the transport is by far lower and therefore negligible. However, cement is needed for the stabilisation of fly ash. A process scheme of scenario B is shown in Fig. 2.

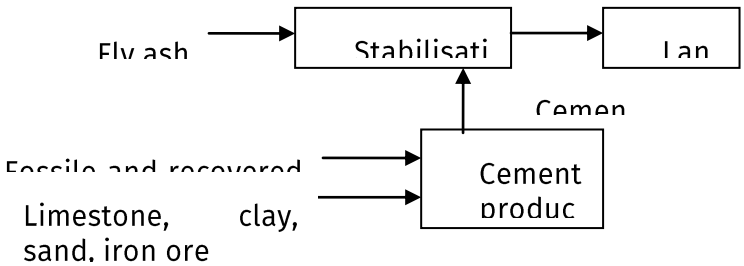
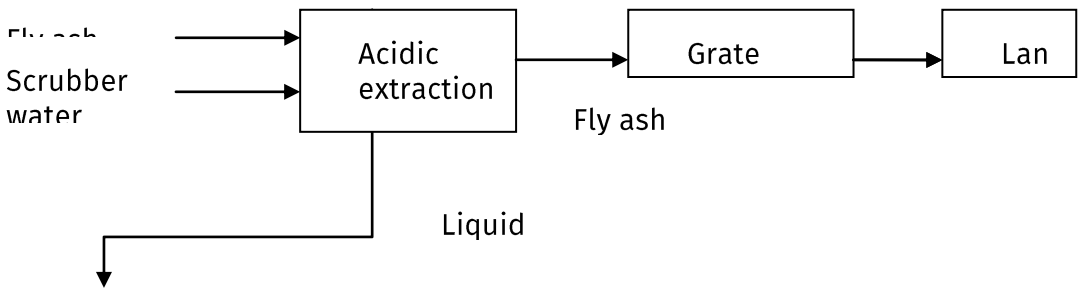


Fig. 2. Process scheme of sceanrio B (cement stabilization and disposal at non-hazardous waste landfill)

Depending on the mixing ratio of fly ash and cement the CO2 emissions from cement production are 200-500 kg t-1 fly ash (-). The stabilised fly ash is disposed of at a non-hazardous waste landfill. The heavy metal content of the leachate is considerably lowered, but heavy metals can still be mobilised at very low or very high pH values (Liang et al., 2008). However, as it can be assumed that no relevant amount of heavy metals is leached for several thousands of years, the attainment of the objective minimisation of emissions is positively evaluated (+). Due to the mixing of fly ash and cement, the concentration of precious metals decreases which lowers the resource potential of this residue. Additionally, the amount of material which has to be deposited at a landfill is increased which causes an accelerated depletion of the resource landfill volume (--). The stabilisation and deposition take place in Vienna. However, as there are no more cement plants operating in Vienna the cement has to be supplied by the hinterland. Therefore, the disposal safety and autarchy is moderate (0). The economic efficiency for this scenario is high (++) and, as this treatment is applied in Vienna as well as in other places, the technological feasibility is proven.

As in scenario C a relatively complex process would be implemented, the need for equipment and operation materials is high. Fig. 3 shows a simplified process scheme of this scenario. The process is described in detail by Schlumberger (2010).



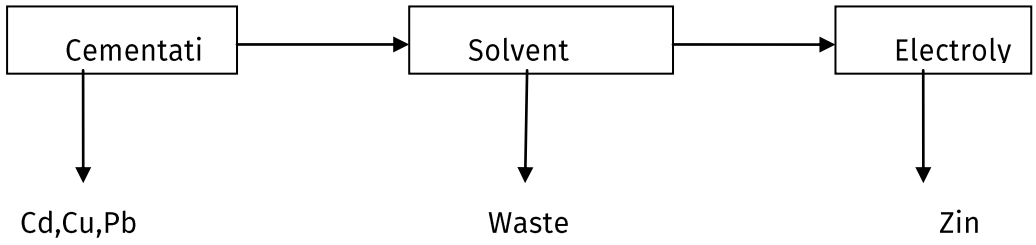


Fig. 3. Process scheme of scenario C (integrated Zinc recovery, FLUREC)

After extraction fly ash is brought back into the furnace, whereby wet fly ash has to be heated to the temperature prevailing in the furnace (at least 850 °C) and the contained water has to be vaporised. Assuming that 20 % of the fly ash mass are extracted (Fellner et al., 2015) and the water content of wet fly ash is 25 %, the CO2 emissions for this heating are 115 kg t-1. The production of electrical energy required for electrolysis causes CO2 emissions of 60-120 kg t-1 (Oesterreichs Energie, n.d.). However, depending on the Zn concentration about 15-35 kg Zn are produced per t of fly ash. As the production of primary Zn causes emissions of 3 kg CO2 kg-1 Zn (International Zinc Association, 2015), 45-105 kg CO2 t.1 fly ash can be avoided. The total emissions account approximately 125 kg t-1 fly ash (0). The fate of the fly ash after extraction and thermal treatment allows disposal at a non-hazardous waste landfill. As the heavy metal content is decreased by extraction and the organic substances are destroyed at high temperatures, the risk of potential emissions from the landfill is low. Though, the use of solvents causes emissions of NMVOC (non methane volatile organic compounds) (Umweltbundesamt, 2015), which leads to a moderate overall attainment of the objective minimisation of emissions (0). The FLUREC process enables the recovery of pure metallic Zn, but the overall amount of recoverable Zn in fly ash in Vienna would be rather marginal (< 200 t a-1). The metals Cd, Cu and Pb are recovered in concentrated form and can be recycled by non-ferrous metal smelters. As a part of the fly ash is extracted and thermal treatment increases the density, the required landfill volume is reduced. In total, the objective conservation of resources is attained best in scenario C (+). The entire treatment and disposal takes place in Vienna, which results in a high safety of disposal (+). Only the equipment and operation materials are produced outside of Vienna. As the Zn concentration in waste incineration fly ash from Vienna is below 30,000 mg kg-1, an economic recovery of Zn is impossible (-). The FLUREC process is not widely applied, but as there is a plant in Switzerland in operation (Kehrichtbeseitigungs-AG (KEBAG), 2013), it can be seen as technologically feasible.

In scenario D fly ash would be treated in a plant dedicated to this purpose at about 1,000 °C to 1,400 °C. A process scheme of this scenario is illustrated in Fig. 4. The major part of fly ash can be disposed of at a non-hazardous waste landfill, but secondary fly ash with an increased heavy metal concentration is generated in the air pollution control system of the fly ash treatment plant. This secondary fly ash is transported to an underground landfill. Depending on the type of furnace the energy has to be supplied in the form of electricity (electric arc furnace, plasma furnace) or fossil fuels (blast furnace, rotary kiln).

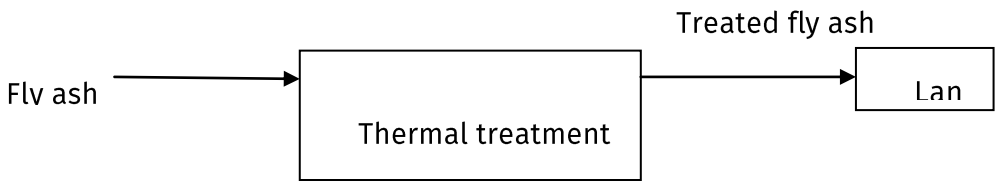


Fig. 4. Process scheme of scenario D (thermal treatment in a new plant to be constructed)

The specific energy demand for electrically heated furnaces is about 1,000 kWh t-1 fly ash (Ecke et al., 2000), which causes CO2 emissions of 170 kg t-1 based on the average Austrian electricity mix (Oesterreichs Energie, n.d.). Thermal treatment in a blast furnace required approximately 330 kg coal per t of fly ash, thereby emitting 1,200 kg CO2 t-1 fly ash. Organic substances are destroyed almost completely and the heavy metal content of the treated fly ash deposited at a non-hazardous waste landfill is decreased compared to original fly ash. Therefore, the potential emission of pollutants is decreased in this scenario (+). Volatile metals are concentrated in the secondary fly ash, which makes this residue a potential future resource. However, as a direct utilisation is not included in this scenario and a part of fly ash is deposited at an underground landfill the attainment of the objective conservation of resources is moderate (0). The thermal treatment and disposal take place in Vienna, but the fossil fuels have to be imported and secondary fly ash is exported. This causes a negative assessment of the attainment of the objective safety of disposal and autarchy (-). Existing plants in Japan show the technological feasibility, but the required energy causes considerable costs (Ecke et al., 2000). For this reason the economic efficiency of this scenario is low (-).

In scenario E fly ash is moistened and thermally treated together with combustible hazardous waste in an existing rotary kiln. This scenario is assessed only based on the additional environmental impact caused by the addition of fly ash and not on the impact caused by the incineration of combustible hazardous waste. A process scheme of scenario E is illustrated in Fig. 5. Bottom ash from the rotary kiln is disposed of at a non-hazardous waste landfill and fly ash is transported to an underground landfill.

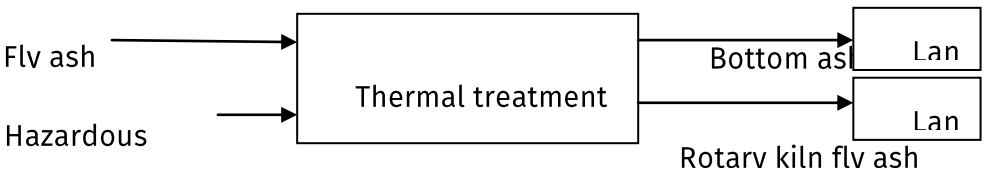


Fig. 5: Process scheme of scenario E (thermal co-treatment of fly ash in existing hazardous waste incinerator)

As moistened fly ash has to be heated to 850 °C and the contained water has to be vaporised, additional energy is required in the kiln depending on the water content of the inserted fly ash. This energy can be supplied in the form of heavy fuel oil. Assuming a water content of 23 % (cf. Huber et al., 2016), 48 kg of heavy fuel oil are required per t of fly ash dry matter in order to keep the temperature in the kiln constant. This results in CO2 emissions of 144 kg t-1 (0). The situation regarding emissions to soil, water and air is similar as in scenario D. However, the fraction of heavy metals transferred to the bottom ash is larger due to the lower treatment temperature. As a consequence, the potential emissions from material, deposited on a landfill, are assumed to be higher, and the attainment of this objective is moderate (0). Because the major part of Zn and Cu are transferred to the bottom ash and thereby diluted, their future recovery is unlikely. Therefore, the objective conservation of resources is not attained (-). The facilities required are already present in Vienna and more than 90 % of the inserted fly ash would

finally end up (via the bottom ash generated) at a landfill in Vienna (Huber et al., 2016). However, a slight increase in rotary kiln fly ash mass that is disposed of in Germany has to be expected. Furthermore, the additionally required fuel has to be imported. As the amount of fuel required and additional fly ash generated is much lower compared to scenario D, the objective safety of disposal and autarchy is attained (+). First experiments show the potential feasibility of this scenario, but the present data do not allow a serious assessment of economic efficiency.

Table 1 summarises the evaluation results for the five scenarios investigated with respect to selected objectives of Vienna's Waste Management Plan.

Table 19. Summary of scenarios A to E and their evaluation

Scenario	Climate impact	Minimisation of emissions	Conservation of resources	Safety of disposal and autarchy	Economic efficiency	Technological feasibility
A	+	++	--	--	0	++
B	-	+	--	0	++	++
C	0	0	+	+	-	0(-)
D	--	+	0	-	-	0
E	0	0	-	+	?	?

Conclusion

In this study five scenarios for the management of waste incineration fly ash in the City of Vienna were evaluated in respect of five selected indicators based on the objectives of Vienna's Waste Management Plan (Sturn et al., 2012). The results of this evaluation are summarised in Table 1.

The objective minimisation of climate impact is best attained in scenario A (underground landfill in Germany), as here only transport causes emissions. Thermal treatment in a dedicated facility causes highest greenhouse gas emissions, but also stabilisation with cement is associated with a rather large ecological rucksack.

As after disposal at an underground landfill no emissions to soil, water and air are generated, scenario A is also the best option regarding the objective minimisation of pollutant emissions. Stabilisation with cement and thermal treatment generate a residue that can be expected to cause only very low long-term emissions. This is also the case for the FLUREC process, however in scenario C the use of solvents causes emissions of non-methane volatile organic compounds.

Scenario C would theoretically enable the recovery of Zn, Cd, Cu and Pb and the mass that has to be disposed of at a landfill is decreased. Therefore, the objective conservation of resources would be best attained in this scenario. However, the fly ash generated in Vienna contains too low amounts of recoverable metals for an economic and in terms of mass reasonable resource recovery (<200 t a-1 Zn). Thermal treatment in a dedicated

facility (scenario D) produces secondary fly ash with an increased concentration of volatile heavy metals, which would potentially allow a future usage as a resource.

As for the thermal co-treatment of fly ash together with combustible hazardous waste (scenario E) equipment already existing in Vienna can be used and only a low amount of consumables are needed, the safety of disposal and autarchy are highest in this scenario. As there is no hazardous waste landfill in Austria, disposal of fly ash in scenario A is completely dependent from abroad.

Regarding economic efficiency, scenario B has the highest attainment. Thermal treatment in a dedicated facility caused high energy costs and the FLUREC process is associated with a large investment. Scenario E (thermal co-treatment with combustible hazardous waste) seems to be an interesting option according to preliminary estimations, yet there are not enough data available for detailed calculations.

However, the option that is best suitable for the attainment of a single objective does not allow a conclusion on the variant with the overall best attainment (Vadenbo et al., 2014). Therefore, a Pareto-optimisation is suggested.

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