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The Role of Fluidized Bed Technology for Waste to Energy, Its Current Status and Potential – An Austrian Perspective

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Abstract

In Austria, besides co-incineration of waste, a total capacity of annually 2.7 million tons of pure waste incineration exists. As combustion technologies grate furnaces (GF), rotary kilns (RK) and fluidized bed combustors (FBC) are used. About thirty percent of the installed capacity uses fluidized bed combustors. The main aim of this work is to investigate the Austrian waste to energy infrastructure, especially the sites of waste incineration, to understand the role of fluidized bed technology, its limitations, advantages and future potential with a focus on residue management.

As in many European countries, in Austria residues of waste incineration plants are classified as hazardous waste and, therefore, have to be deposited on landfills for hazardous waste. However, if the non-hazardous character can be proven by chemical analysis similar to the national landfill restrictions, a residue landfill is suitable for the disposal. In general, grate furnaces produce higher amounts of slag and less air-pollution-control (APC) residues than fluidized bed combustors, whereas fluidized bed combustors have an increased fly ash formation rate, since attrited bed material often ends up in the fly ash stream. Slags usually fulfill the landfill criteria and can be classified as non-hazardous waste, whereas APC residues do not fulfill the criteria and, therefore, increased disposal costs may arise.

Commonly, bottom ashes of fluidized bed combustors are less polluted with organic materials and are discharged in dry mode, whereas grate furnace slag is often discharged in wet mode. Currently, several research projects focus on optimizing the recovery rate of valuable metals from slag. Since most of the investigated treatment methods are mechanical treatment methods, dry subtracted material is preferred. Wet slags are sticky in general and are therefore less suitable.

The investigation revealed that FBCs contribute around 35 % to the annual waste incineration capacity. Moreover, waste pre-conditioning and bottom ash properties simplify the recovery of recyclables in FBCs compared to GFs.

Keywords: fluidized bed combustion, waste to energy, residue management, urban mining

1. Introduction

In the last decades the treatment of waste changed from direct landfilling to pre-treating prior to disposal in order to minimize the amount of disposals. Among others, an often used pre-treatment method is incineration. Incineration reduces the quantity to dispose to approximately on third [1]. However, the resulting solid residues often have to be stabilized or treated before disposal in order to comply with legal regulations. In Austria, three furnace technologies are used for waste incineration: rotary kilns (RK), grate furnaces (GF) and fluidized bed combustors (FBC). RK are only employed for the incineration of hazardous wastes, while GFs and FBCs are usually employed for non-hazardous wastes [1]. According to Austrian legislation [2] the residues of the air pollution control (APC) are classified as hazardous waste and, thus, have to be treated or disposed on landfills for hazardous wastes. In general, APC residues are the fly ash found in different plant parts like the heat transfer zone, fabric filters or electrostatic precipitator and the filter cake from the wet scrubber waste water treatment [3]. This work focuses on bottom ashes (terminus for FBC ash), slags (terminus for GF ash) and APC residues, neglecting filter cake.

This work tries to give an insight in the Austrian waste incineration history. Moreover, an overview of the annually incinerated waste amounts beginning with the year 2000 is created. Additionally, an allocation according to either grate or FB furnace technology is conducted. In a further step, the advantages and disadvantages of grate and FB furnaces are discussed for waste incineration and the subsequent recovery of valuable compounds is examined.

2. Waste incineration equipment in Austria

The incineration of pure waste has a long history in Austria and started with the construction of the GF waste incineration plant Flötzersteig in Vienna in 1964. Until 1980 two additional waste incineration sites were built in Vienna (Spittelau and Simmering). The incineration sites Flötzersteig and Spittelau employ the GF technology, while the incineration site Simmering employs two RKs for hazardous wastes and three FBCs for waste and sewage sludge incineration, although the three FBCs have been permitted for hazardous waste too. In the nineteen nineties, three additional incineration plants were constructed; one in Carinthia (Arnoldstein), a FBC for hazardous waste, and two in Upper Austria, one FBC (Lenzing) and one GF (Wels). In the first decade of the 21st century, a total of five new waste incineration sites were built and four existing sites were extended. Five of the nine new waste-to-energy facilities use the GF technology, whereas three use the FBC technology and one uses the RK technology. The last waste incineration site was commissioned in 2012 in Linz. At the moment eleven waste incineration sites with an annual capacity of approximately 2.7 million tons and two incineration sites for hazardous wastes with an annual capacity of approximately 160,000 tons exist in Austria.

The total amount of incinerated waste in Austria rose from about 410,000 tons in 1993 [4] to about 2,280,000 tons in 2013 ([5], estimated from [10, 11, 12, 13]). Table 1 shows the historic development in numbers as well as other plant details like the maximum waste throughput capacity, commission year and furnace technology.

Furthermore, Figure 1 illustrates the historic development of the total annual waste throughput and the breakdown according to incineration technology. Since the data for the hazardous waste incineration plants is sparse, only the incineration plants for non-hazardous waste are considered for the breakdown. The steep increase of the total amount of treated waste from 2003 to 2004 is explained by the commissioning of four incineration plants with a total capacity of approximately 500,000 tons per year. Similarly, the increase of the annual incinerated waste amount between 2007 and 2011 is caused due to the commissioning of more than 900,000 tons annual incineration capacity in the same time.

In general, the waste amount annually treated in FBCs is lower than the treated amount in GFs. This is probably caused by the circumstance that the average annual throughput capacity of GFs is about one fourth higher than that of FBCs.

The figure indicates an increase of the FBC share starting with 2011, but this trend should be considered with caution due to the estimations in the data. In addition, the 2001 data should be considered with caution due to a rough estimation caused by poor data.

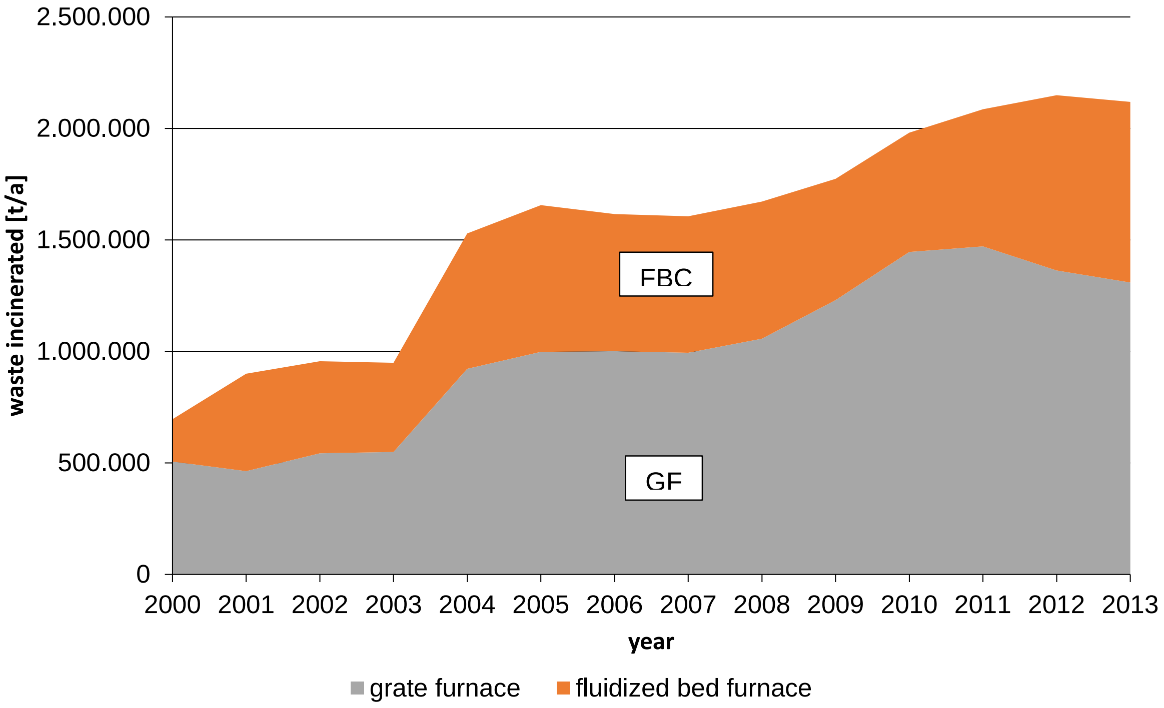

Figure 1. Annual non-hazardous waste incineration amount breakdown according to incineration technology from 2000 to 2013; grate furnace (GF), fluidized bed furnace (FBC). Sources: see Table 1

The investigation revealed a considerable share of FBC furnaces according to annual waste throughput capacity, thus in a further step, the differences, advantages and limitations of grate and FBCs are examined.

Table 1. Overview of the operating hazardous and non-hazardous waste incineration plants in Austria

non-hazardous waste																	
	commissioning	**furnace[#]**	**capacity**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Flötzersteig	1964	GF	200[j]	197[a]	176[a,b,+]	202[c]	202[c]	210[c]	209[c]	175[e,f,+]	174[e,+]	175[f,+]	190[d]	189[d]	185[h]	194[h]	202[h]
Spittelau	1971	GF	250[j]	269[a]	221[a,b,+]	268[c]	269[c]	269[c]	258[c]	218[e,f,+]	217[e,+]	219[e,+]	212[d]	197[d]	200[h]	109[h]	66[h]
Simmering I, II, III	1980 - 1992	BFBC	195[j]	55[a]	172[a,b,+]	198[c]	178[c]	160[c]	178[c]	170[e,f,+]	169[e,+]	170[e,+]	236[d]	210[d]	282[h]	294[h]	298[h]
Wels I and II	1995 (I) / 2006 (II)	GF	300[j]	40[a]	66[a,b,+]	73[c]	78[c]	79[c]	126[c]	262[e,f,+]	260[e,+]	262[e,+]	231[d,f,+]	244[d,f,+]	250[h,f,+]	230[f,i,+]	240[f,j,+]
Lenzing	1998	CFBC	300[j]	135[a]	265[a,b,+]	215[c]	215[c]	295[c]	300[c]	262[e,f,+]	260[e,+]	262[e,+]	231[d,f,+]	244[d,f,+]	250[h,f,+]	230[f,i,+]	240[f,j,+]
Simmering IV	2003	BFBC	110[j]				7[c]	83[c]	102[c]	96[e,f,+]	96[e,+]	96[e,+]	*	*	*	*	*
Dürnrohr I, II and III	2004 (I, II) / 2010 (III)	GF	525[j]					323[c]	323[c]	262[e,f,+]	260[e,+]	262[e,+]	231[d,f,+]	428[d,f,+]	438[h,f,+]	403[f,i,+]	420[f,j,+]
Arnoldstein	2004	GF	96[j]					41[c]	82[c]	84[e,f,+]	83[e,+]	84[e,+]	74[d,f,+]	78[d,f,+]	80[h,f,+]	89[f,i,+]	77[f,j,+]
Niklasdorf	2006	BFBC	100[j]					69[c]	78[c]	87[e,f,+]	87[e,+]	87[e,+]	77[d,f,+]	81[d,f,+]	83[h,f,+]	78[f,i,+]	80[f,j,+]
Pfaffenau	2008	GF	250[j]									55[e,+]	192[d]	204[d]	209[h]	192[h]	200[f,j,+]
Zistersdorf	2009	GF	130[j]										100[d,f,+]	106[d,f,+]	109[h,f,+]	146[f,i,+]	104[f,j,+]
Linz	2012	BFBC	240[j]													184[f,i,+]	192[f,j,+]
		Total (1,000 t/year)	**2696**	**696**	**900**	**956**	**949**	**1529**	**1656**	**1616**	**1606**	**1672**	**1774**	**1981**	**2086**	**2149**	**2281**
hazardous waste																	
	commissioning	**furnace**	**capacity**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Simmering	1980	RK	100[+]	90[a]	-	31[c]	29[c]	29[c]	29[c]	-	-	-	68[d]	75[d]	76[h]	70[h]	74[h]
Arnoldstein	1994	BFBC	30[+]			67[c]	86[c]	96[c]	91[c]	-	-	-	-	-	-	-	-
Arnoldstein	2005	RK	30[+]						4	-	-	-	-	-	-	-	-
		Total (1,000 t/year)	**230**	**90**		**98**	**115**	**125**	**124**	**-**	**-**	**-**	**68**	**75**	**76**	**70**	**74**

[a] [7]
[b] [6]
[c] [1]
[d] [9]
[e] [8]

[f] [10]
[g] [13]
[h] [5]
[i] [10]
[j] [11]

* included in Simmering I, II and III
[+] estimation
[-] no data available
[#] GF … grate furnace, BFBC … bubbling fluidized bed combustor, CFBC … circulating fluidized bed combustor, RK … rotary kiln

3. Differences between FBC and GF technology

The differences between GFs and FBCs start with the combustion process. The GF technology is characterized by relative long residence times of a large waste amount in the combustion chamber whereas the FBC technology is characterized by short residence times with small waste amounts in the fluidized bed. In general, due to the heat capacity of the bed material, the combustion process in a FBC takes place at almost constant temperatures and, thus, produces less harmful substances than the combustion process in a GF. As a consequence of the combustion conditions and fuel size in FBCs, the combustion is more complete resulting in a lower share of unburnt substances and solid residues than for GFs. Since the combustion temperature is lower in FBCs than in GFs, the total and, especially, the thermal NO_x emissions are lower for FBCs compared to GFs. However, the low combustion temperatures promote the formation of N_2O. Lower SO_2 emissions emerge from FBCs than from GFs in the flue gas. The reason therefore is that in FBCs more SO_2 is fixed in the ash due to physical and chemical processes. Additionally, in FBCs limestone can be added continuously to the combustion process, in order to reduce SO_2 in-situ. [14, 15]

Moreover, in case of waste incineration, the FBC technology has the advantage that fuels with a wide range of calorific values can be utilized. The lower limit is approximately 3.5 MJ/kg and the upper around 30 MJ/kg and even higher. Furthermore, fuels having moisture contents above 70 percent can be utilized in FBCs without any problem. In contrast, the GF technology requires a calorific value range, starting from around 6 MJ/kg to around 15 MJ/kg for air-cooled grates. By employing water-cooled grates, the upper limit of the calorific value increases. If the calorific value is lower, problems with fuel ignition may arise. In contrast, if the calorific value is higher, wear rates significantly increase on the grate. [14]

Concerning waste pre-treatment, GFs have the advantage that size distribution and maximum size are almost irrelevant. The maximum waste size is only restricted by the capabilities of the fuel feeding system. In contrast, FBCs need wastes with defined size distributions, thus solid waste has to be pre-processed, usually sieved and shred, before its feeding to the FBC. Moreover, impurities with low melting points may create deposit build-ups on the nozzle bottom or other parts of the combustion chamber and, furthermore, may create agglomerations with the bed material [14]. The agglomerations inhibit the fluidization of the bed and may increase the bed material consumption. Regardless, according to [14] FBCs can handle high amounts of impurities, if powerful ash removal systems are installed. Principally, GFs have no problems with high amounts of impurities and the ash removal is not as complicated as for FBCs.

Comparing the residues of GFs and FBCs, the composition and ratio between APC residues and slag or bottom ash, respectively, differ significantly. On the one hand, the amount of APC residues is higher for FBCs due to the fact that the fluidizing air entrains small or light ash particles. Furthermore, bed material abrasion produces fine particles which also end up in the flue gas as APC residue. Conversely, the amount of bottom ash is significant lower than the amount of slag. In consequence of the lower fly ash amount and higher combustion temperatures, the concentration of the heavy metals and soluble substances in the APC residues of GFs should be higher than the concentration in APC residues of FBCs. A long time study, conducted by [16] confirmed the increased concentrations of heavy metals in the fly ash of GFs. Moreover, they showed that the amount of totally dissolved solids and the leachability of heavy metals of GFs fly ashes is generally higher than for FBC ashes, which is relevant for the future disposal.

In any case, in Austria strict regulations for the disposal of waste incineration residues exist. In the subsequent section these regulations and the limiting values are discussed.

4. Disposal of waste incineration residues

Since solid residues of waste incineration contain different impurities with varying concentrations, disposal has to comply with certain standards. According to Austrian legal standards [2] residues of municipal waste incineration are classified as hazardous waste, thus, have to be treated, e.g. stabilized etc., before disposal on a residue landfill or have to be disposed on landfills for hazardous waste. Alternatively their non-hazardous character can be proven preliminary to its disposal. [17]

The current practice often includes an untreated disposal of waste incineration bottom ashes or slags as non-hazardous waste on residue landfills. Fly ashes are either stabilized with cement and subsequently disposed on a residue landfill or exported to Germany for disposal at subsurface landfills for hazardous waste or if the non-hazardous character is proven disposed at landfills for non-hazardous waste with prior conditioning with water for dust reduction [16].

According to Austrian standards [2, 17], restrictions for the concentrations of the inorganic compounds mercury, arsenic and cadmium exist. Furthermore, the total amount of soluble components as well as the amount of following water soluble components is regulated As, Al, B, Ba, Be, Cd, Zn, Cr, Co, Cu, Fe, Mo, Ni, Pb, Hg, Se, Te, Ag, Tl, V, Sb, Sn, CN^-, S^{2-}, F^-, NH_4^+, NO_2^- and PO_4^{3-} for a liquid to solid ratio of ten by law [2, 16]. Regulations for the European Union can be found in [18], testing methods in [19].

Purgar et al. [16], who investigated the inorganic pollutants of different fly ashes from waste incineration plants, concluded (regarding eluat-contents) that mainly the water solubility of Pb, Zn, Cd, F as well as the amount of total water soluble compounds are of interest for the disposal on a non-hazardous waste landfill. Additionally the total content of Hg is may exceeded. The total content of Hg in the fly ashes is more dependent on the used flue gas cleaning technology than on the combustion technology [20]. Table 2 shows the legal limits for the total inorganic contents and the solubility of Pb, Zn, Cd and F^- as well as the limit of the total amount of soluble compounds.

Table 2. Legal limits for the total content of inorganic compounds and water soluble compounds for disposal as non-hazardous waste. Sources: [2, 17]

legal limits for total contents		
element	**symbol**	**legal limit [mg/kg_{dm}]**
arsenic	As	5,000
cadmium	Cd	5,000
mercury	Hg	20
legal limits for soluble contents *		
element	**symbol**	**legal limit [mg/kg_{dm}]**
cadmium	Cd	1
lead	Pb	10[+]/30[#]
zinc	Zn	50
fluoride	F	150
total dissolvable	-	60,000

* for a liquid to solid ratio of ten

[+] default legal limits

[#] exception, may decide in the individual case by the authority

The investigations of Purgar et al. [16] also show that the investigated fly ash of FBCs fulfills the criteria for disposal on landfills for non-hazardous wastes without any prior treatment. In contrast, fly ashes of GFs may exceed the legal limits for the amount of total dissolved solids, the soluble Pb content and the total content of Hg.

Moreover, it can be concluded that the investigated FBC fly ashes need neither be stabilized nor be exported to Germany for disposal on landfills for hazardous waste.

5. Recovery of recyclables from waste incineration residues

In recent years, retrieving special fractions from the residues started, since metals accumulate in the solid residues during waste incineration. Positive effects of the recovery of recyclables is the partly decontamination of the residues due to the removal of toxic heavy metals and the decrease of the total amount of solids to dispose. A special focus is the recovery of ferrous metals and non-ferrous metals, from bottom ashes and slags, especially aluminum due to its energy intensive primary extraction. According to Fleck et al. [21] the share of ferrous metals increases with particle size, while the non-ferrous metals accumulate in the fraction between 2 and 32 millimeters. Thus, in order to achieve the highest possible recovery rate, the residues have to be classified according to small size distribution bins. According to [22], the more precise this classification is, the higher the recovery rates are. However, in order to classify the fine fractions of solid residues it is beneficial if they are dry. Otherwise particles, especially in the fine fractions, stick together and cause difficulties in the separation process. Thus, it is beneficial to discharge the residues in dry mode. Furthermore, wet mode discharging causes hard ash deposits on ferrous and non-ferrous metal parts in the residues. This ash deposits reduce the quality and, moreover, the value of the recycled metals [23].

Since FBCs require waste pre-processing, which usually includes a shredding step, valuable materials may be already separated from the waste stream before incineration. The pre-separation has the advantage, that metals can be separated with lower impurity concentrations than after incineration. Nevertheless, the incineration residues should be treated with a ferrous and non-ferrous metal separator in order to maximize the recovery rate.

Moreover, according to [24] in wet extracted residues calcium- and magnesium oxides are hydrogenated with the moisture and, thus, the pH-value rises. Under high pH-value conditions metals may be oxidized and no longer exist in the metallic state, e.g. aluminum is oxidized to aluminum hydroxide. Furthermore, during slag aging the aluminum oxidation reaction provides energy to rise the temperature and evaporate moisture of the residues [22].

A significant advantage of FBCs is the fact that the bottom ash is virtually dust-free, since pollutants usually accumulate in the fine residue fractions, like fly ash. For that reason, for the coarse residue fraction, higher metal recovery rates and better re-use of the mineral fraction in the building sector could be achieved. [23]

6. Summary

In Austria, waste incineration has a long history, which started in 1964. From that time on the installed waste throughput capacity increased continuously to approximately 2.7 million tons per year in 2014. FBC technology contributes around 35 % (approx. 950,000 tons per year) to the total waste throughput capacity with a total of 810,000 tons incinerated in 2013. The FBC capacity can be further classified to circulating FBC and bubbling FBC accounting for 300,000 and 645,000 tons per year, respectively.

Concluding, both the GF and FBC technology have their individual advantages for waste incineration. The technology to choose is closely linked with the waste to incinerate and the planned residue treatment or disposal. In general, FBCs have advantages, if recyclables shall be extracted from the bottom ash. Therefore, two reasons exist: firstly, recyclables may already be captured during waste conditioning and, secondly, bottom ashes are dry and low polluted. Fly ashes from FBC are more likely to fulfill standards for direct landfilling as result of the dilution by attrited bed material [16].

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