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WtE TREATMENT PROCESSES AND COMBUSTION TECHNOLOGIES

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Abstract: Waste management is a significant environmental challenge, and energy recovery from waste addresses issues linked to poorly managed waste. Thermal treatment aims to mitigate the environmental impact of waste. However, this process generates emissions and energy consumption, influenced by the facility's design and operation. This article will summarize key environmental challenges and solutions associated with thermal waste treatment technology. The operating characteristics of each technology affect air and water emissions, residue generation, and energy consumption. Insights from Europe and developed countries will provide a technological comparison, particularly concerning combustion technology in waste-to-energy plants. The focus will be solely on the combustion process used in these facilities.

Key words: waste, thermal treatment, combustion, waste – to – energy, air emissions

1. INTRODUCTION

The municipal solid waste (MSW) production will reach 3.4 billion tons per year in 2025, influenced by increasing population and urbanization [1]. Around 90% of global societies still utilize landfilling as only waste management process [2]. Waste management hierarchy in EU regards energy recovery with energy-efficient MSW incineration, often called waste-to-energy (WtE), as a more favorable preces than landfilling. The WtE process has advantage over landfilling. The volume of waste to be land-filled is significantly reduced it, with reductions of around 75 percent by weight and 90 percent by volume [3].

The energy utilization of non-recyclable waste represents a great social challenge. WtE plants present an important step towards utilization of available energy sources and reduction of fuel import dependence.

WtE is an integral part of the waste hierarchy and as such falls within the circular economy as the European Commission perceives. [4] Of course, it should not negatively affect the reducing, reusing and recycling of waste, which are the preferred methods of waste management.

Currently, WtE plants in Europe can supply 21 million European citizens with electricity and 17 million Europeans with heat. This is based on 103 million tonnes of remaining household and similar waste that was treated in 2021 in Europe. [5]

Depending on the fuel you replace – gas, oil, hard coal or lignite – between 10 – 56 million tonnes of fossil fuels emitting 22 – 44 million tonnes of CO_2, would not need to be used by conventional power plants to produce this amount of energy.

Waste-to-Energy technology is one of the most robust and effective alternative energy options to reduce CO_2 emissions and to save limited fossil fuel resources used by traditional power plants. [5]

In 2006, the first Best Available Techniques Reference for Waste Incineration document was adopted, which presented an overview of the actual operating data of incinerators in Europe. This document was updated at the end of 2019. [6] Based on it, BAT conclusions were prepared, which have the status of a Commission Implementing Decision (EU) 2019/2010 [7] and apply directly in all EU countries since the day it was adopted for new devices, and from the end of this year for existing devices.

WtE of waste on a grate is the most common waste combustion system. Fluidized bed combustion is less commonly used for this purpose. Several studies have been conducted by various authors comparing these two main combustion systems, and they are also presented in the document on the best available techniques.

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Both combustion systems have certain advantages and disadvantages. When deciding which to employ, it is necessary to weigh up all technically available arguments, because there is no technology that would be absolutely dominant.

The disadvantages of the fluidized bed are mainly the need for fuel preparation and the consumption of fluidized bed material, but it also has some advantages, such as better combustion due to sorted fuel and lower ash content. Quartz sand as a fluidized bed material has a positive property, since it is alkaline.

The environmental and energy efficiency of WtE on a grate has also been improved, and several advanced solutions have been proposed.

2. WtE TREATMENT PROCESSES

There are three main types of thermal waste treatment: [6]

- combustion – complete oxidative combustion (by far the most common process);
- pyrolysis – thermal decomposition of organic material in the absence of oxygen;
- gasification – partial oxidation.

Table 1 provides an overview of thermal processes and the main operating characteristics and products of the thermal process.

Table 1 – Overview of combustion, pyrolysis and gasification processes [6]

	Combustion	Pyrolysis	Gasification
Reaction temperature (ºC)	800 – 1,450	250 – 700	500 – 1,600
Pressure (bar)	1	1	1
Atmosphere	Air	Inert/Nitrogen	Gasification agent: O_2, H_2O
Stoichiometric ratio	>1	0	<1
Products from the process in the			
gas phase:	CO_2, H_2O, O_2, N_2	H_2, CO, hydrocarbons, H_2O, N_2	H_2, CO, CO_2, CH_4, H_2O, N_2
solid phase:	Ash, slag	Ash, coke	Slag, ash
liquid phase:		Pyrolysis oil and water	

3. COMBUSTION PROCESSES TECHNOLOGIES

Different combustion systems are used for different types of waste. Table 2 gives a typical range of the different combustion chamber designs and thermal processes, which are generally divided into:

- moving grate;
- rotary kilns;
- fluidized bed;
- pyrolysis and gasification systems.

Table 2 – Typical application range of combustion process technologies [6]

Technology	Typical application range (tons/day)
Moving grate (mass burn)	120 – 720
Fluidised bed	36 – 200
Rotary kiln	10 – 350
Pyrolysis	10 – 100
Gasification	250 – 500

Table 2 shows capacities per day per processing line. They are rather large and can easily cover the needs of societies living in middle and south-eastern Europe.

Table 3 gives the data on average MWS incinerator capacity in thousand tons per year. Some EU countries have rather small average capacities, but others have only very large plants. The ratio between the largest average capacity and smallest is more than 8, indicating the specifics of each society.

Table 3 – Average MWS incinerator capacity in thousand tons per year [6]

Country	Average MWS incinerator capacity (kilotons/year)
Austria	178
Belgium	141
Denmark	114
Finland	180
France	113
Germany	256
Italy	161
Netherlands	488
Portugal	390
Spain	364
Sweden	136
United Kingdom	246
Norway	60
Switzerland	110
AVERAGE	**193**

An overview of the share of each technology used for each type of waste is given in Table 4. This is a statistical estimate provided by the 2019 Best Available Techniques document [6]. In the table, in addition to the first column, it is also necessary to look at the second column for municipal waste, which provides data for non-hazardous waste, as this also includes all types of waste-based fuels that can also be produced from municipal waste. The table shows that the most used combustion system is the grate combustion system.

Municipal waste can be incinerated on moving grates, in rotary kilns and with a fluidized bed. The fluidized bed technology requires that the waste has an appropriate particle size, which usually requires a certain level of pre-treatment, even if the waste is collected separately.

In practice, MSW is thermally treated in Europe with grate and fluidized bed technology. Other technologies are used for hazardous waste and sewage sludge from wastewater treatment plants.

Table 4 – Summary of current use of thermal treatment processes for different types of waste [6]

Technique	Municipal solid waste	Other non-hazardous waste	Hazardous waste	Sewage sludge	Clinical waste
Grate - intermittent/reciprocating	56%	43%	0%	0%	0%
Grate - vibration	0%	0%	11%	0%	0%
Grate - moving	24%	27%	0%	0%	0%
Grate - roller	12%	10%	0%	0%	0%
Grate - water-cooled	22%	48%	17%	0%	0%
Grate plus rotary kiln	0.50%	0%	2%	0%	0%
Rotary kiln	2%	0%	70%	0%	0%
Static hearth	0%	0%	0%	0%	67%
Static furnace	0%	0%	16%	0%	0%
Fluidised bed - bubbling	2%	13%	0%	90%	0%
Fluidised bed - circulating	3%	8%	0%	10%	0%
Pyrolysis	0%	0%	0%	0%	0%
Gasification	0.50%	0%	0%	0%	33%

Figure 1 is a schematic presentation of individual combustion chambers and shows the main parts of the chamber and the material flows that take place in the combustion chamber from the fuel entry to the flue gas entry into the steam boiler.

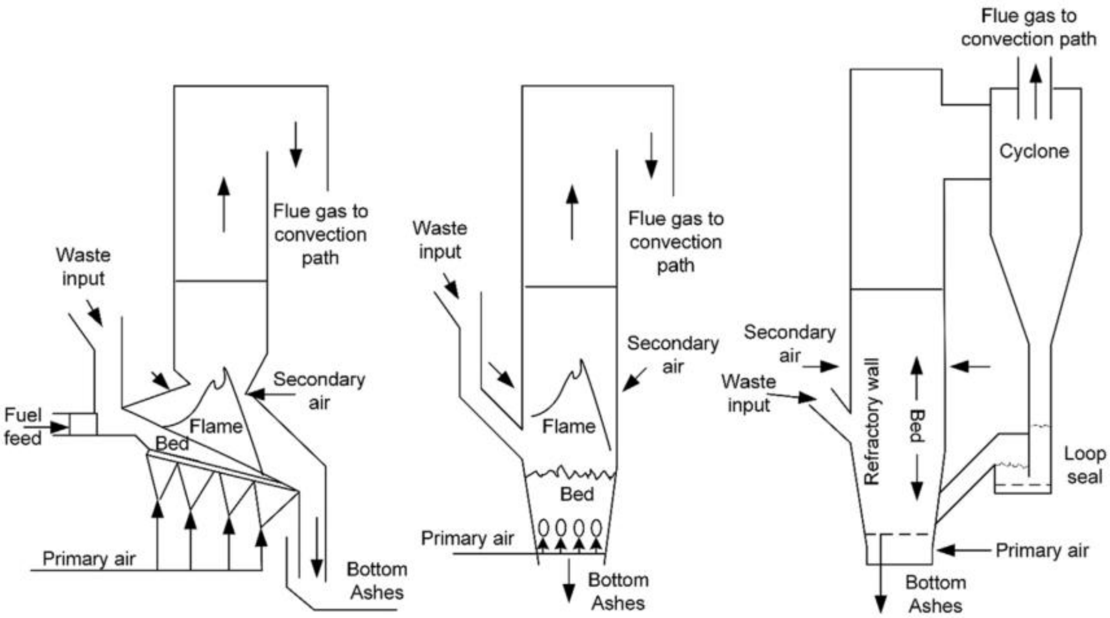

Figure 1 – From left to right: schematics of the main parts of the grate bed, the bubbling fluidized bed (BFB) and the circulating fluidized bed (CFB) [1]

The combustion systems presented in Figure 1 have quite different operating characteristics to ensure complete combustion conditions. Table 5 provides a comparison between the main systems. There are major differences in combustion temperature, excess air, waste size, plant specific energy consumption and the ratio of furnace ash to fly ash.

Table 5 – Data on different waste thermal treatment technologies. The data are indicative and may vary from case to case. Bold indicates the most common case. [8]

Parameter	CFB	BFB	Grate
Bed temperature, (°C)	850, a range of 800–950 is possible [a]	850, a range 850–920 is possible [b].	<1100 with large fluctuations (in bed)[r,s] About 1000 in the first half and then declining to about 600 at the end [t], > 1100 (in the freeboard).
Excess air (%)	20–30 [c], 20 [a].	40 [d]	80–100 [p], 50–100 [e], 50–80, 30–50 advanced [f], 80 normal, 40 advanced [g][h].
Primary/Secondary air (% of total)	60/40, 50/50 [i][a]. Primary air is evenly supplied to the bottom. Secondary air added at several levels occur also in CFB.	60/40 Primary air 35% of stoichiometric, evenly supplied to the bottom. Secondary air added at several levels: four levels mixed with flue gas [b].	60/40 [e], 66/33 [g]. Primary air is distributed to the inlet zones: less to the drying and burnout zones and more to the principal combustion zone. Secondary air may be supplied in several (two) levels [g].
Bed material, size (lm)	300, Silica sand and ashes, 200–400 [a].	500, Silica sand and ashes, 800–1200 [b].	Fuel bed, no bed material.
Max waste particle size (mm)	50–100 [m], <150 [q] Depending on air distributor design.	50–100 [m] Depending on air distributor design.	Only extremely coarse objects are removed from the fuel.
Lower heating value (MJ/kg fuel)	10 Depending on design 4.5–32 [a].	10 3–20 [b].	10 6–10 without air preheat or water cooling of grate [u].
Superficial velocity, (m/s)	5	2	< minimum fluidization
Bed height/pressure drop (m/kPa)	30/10 (estimate).	1/5–6 [b].	1–0.1 (fixed bed)/pressure drop depends on velocity
Power demand % of thermal output	4–10 [o].	4–10 [w]	2–5 [o], 150 kWhe/t [g] about 6% of thermal output [v].
Bottom ash/fly ash, (% of total ash).	50/50, 58/42 [c], 50/50 [j] 3–5 times more fly ash than bottom ash [n].	30/70 [d], 70/30 [j].	90/10 [l][k][j]

a) Bolhàr-Nordenkampf et al. (2015), b) Kolbitsch et al. (2012), c) 3.8% O_2 on wet flue gas from 100% RDF, Langenbrugge: Loumaharju and Viljanen (2014), d) Johansson et al. (2006), e) Grillo (2013), f) B&W Völund (2012), g) Martin et al. (2015), h) Strobel et al. (2018), i) Zotter and Fiedler (2008), j) Saquib and Bäckström (2015), k) Hjelmar (1996), l) Wiles (1994), m) Wilén et al. (2004), n) Nie (2008), o) BREF (2006), p) Niessen (2010), q) Huang et al. (2013), r) Yang et al. (2004), s) Frey et al. (2003), t) Waldner et al. (2013), u) Lentjes (no date), v) Reimann (2012), w) estimated from o).

4. CONCLUSION

All technologies presented in the article meet the requirements of the Industrial Emissions Directive [9] and the conclusions on the best available techniques for waste incineration [7] in terms of environmental impact and energy efficiency.

The differences between combustion systems are significant and it makes sense to check which system is most suitable according to the properties of the waste that is intended to be incinerated in WtE plant. A very important factor in the capacity of the plant since not all technologies are commercially competitive or available at small or very large capacities.

There are significant differences in investment and operating costs, but all devices can achieve approximately the same environmental impact, thus low emissions of hazardous substances into the environment.

When deciding on a combustion system, manufacturer references, proximity to production and quality of service play the most important role in the decision process.

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