Chapter

The Thermal Waste Treatment Plant in Kraków, Poland: A Case Study

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Abstract

The thermal waste treatment plant (TWTP) in Kraków (eco-incinerator) was created as a response to the energy and ecological needs of Kraków as part of the project "Municipal Waste Management Program in Krakow." The TWTP is able to process 220,000 tons of municipal waste during the year. Estimated values of the 65,000 MWh of electricity and 280,000 MWh of heat are produced as a result of the waste combustion. The energy obtained by way of the thermal transformation process is largely organic and renewable. The TWTP is equipped with a state-of-the-art exhaust purification system that meets strict emission standards for air. The emission standards will meet the requirements the Ordinance of the Minister of the Environment of November 4, 2014 on emission standards for certain types of installations, sources of fuel combustion and devices for incineration or co-incineration of waste (Journal of Laws of 2014, item 1546, including further amendments). The cleaning process takes place in the exhaust aftertreatment process and is based on the following steps: (*i*) denitrification of exhaust gases, (*ii*) flue gas cleaning by means of a semi-dry method and (*iii*) dust extraction. As the project's general contractor was POSCO E&C from South Korea.

Keywords: Poland, emission standards, waste incineration, exhaust aftertreatment process, heat, electricity

1. Introduction

The term "thermal treatment" is used to describe a range of technologies that use heat to degrade the constitution of solid matter. These include incineration and its variations, as well as advanced thermal conversion (ATC) technologies such as pyrolysis and gasification [1, 2]. Incineration of waste has been practiced for more than a century in the industrialized world [3].

For many people, thermal treatment technologies for waste management represent an image of hell on earth [2]. In line with Moberg et al. [4], waste is generated as a consequence of most of our daily activities. Waste incineration is often (but not always) the preferable choice when incineration substitutes landfill disposal of waste [5]. According to Hauck et al. [6], modern WTE facilities process approximately 13% of the total municipal waste in the United States. There is potentially more than 16,000 MW of electric power that currently a "missed opportunity" in the United States alone. The average gross and net electrical power generation of

WTE facilities has increased over the past decade to approximately 550 kWh per net ton of waste processed, assuming a typical municipal solid waste (MSW) heating value of 5000 Btu per pound (deg. F) (*Note: 5000 Btu per pound (deg. K = 20,934 kJ/kg (deg. K) = 20.934 MJ/kg = 20.934 GJ/ton*) [6].

The first incinerators were developed in the United kingdom in the last part of the nineteenth century [3]. Germany introduced the technology in Hamburg in 1895 followed by Brussels, Stockholm and Zurich in 1904. British technology was used for the first plants in other parts of Europe. This includes Denmark where the first incinerators were constructed in the Copenhagen area in 1903 by the British company Hughes & Stirling and steam boilers from Babcock and Wilcox [3]. More reading on the history of waste incineration is available in Chandler et al. [7] and Kleis and Dalager [8].

The list of waste conversion technologies includes advanced combustion, anaerobic digestion, catalytic depolymerization, fermentation, gasification and pyrolysis [6]. Several cited technologies are currently being evaluated in various stages of testing, with funding provided by the US Department of Energy and private investors, and by 2020, it is possible that several of the presented above waste conversion technologies will advance to commercial status (HAUCK). The WTE industry is still evolving and be used and implemented into a municipal waste management process.

As reported by Chromec and Ferraro [9] in December 2007, the United Nations Framework Convention on Climate Change (UNFCCC) took place in Bali. Key mitigation technologies in the waste sector, landfill gas (LFG) methane recovery, waste incineration with energy recovery, composting of organic waste, controlled waste water treatment, recycling and waste minimization, biocovers and biofilters to optimize methane oxidation have been proposed. In the presented above mitigation technologies for the waste sector, the categorization was carried out regarding specific waste treatment scenarios, whose efficiency is expressed in kg CO_2 equivalent emitted per ton of waste. In the USA, with a population of over 300 million people, about 230 million tons per year of the waste are generated which represent about 760 kg per inhabitant per year (OECD). Based on the scenarios discussed above, if all wastes were landfilled, waste disposal would correspond to 425 million tons of CO_2 equivalents. Furthermore, Chromec and Ferraro [9] presented the policies of the European Union (EU) on climate and energy. EU has proposed reducing greenhouse gas emissions by at least 40% below 1990 levels. The EU is committed to reducing greenhouse gas *emissions* by at least 40% below 1990 levels by 2030 [9]. In comparison with Europe, annual GHG emissions (CO_2-eq/person year) in the USA today are on a level about double that of the Europe. Moreover, in the USA, the EFW concepts are based on the most advanced state of the art, solve a space and pollution problem and guarantee economical and environmentally robust processing and disposal [9].

Chromec and Ferraro [9] determined that if all wastes were incinerated in EFW plants, the emissions could be reduced by about 500 million tons of CO_2 equivalents (about 9% of today's USA CO_2 output) and make the waste management sector a GHG emission sink. Finally, the total electricity generated from EFW plants could be as high as 15,000 MW replacing about 50 standard 300 MW power plant units [9].

In the other paper, Chromec and Burelle [10] discussed that the maximum environmental benefits from a new EFW facility may require locating the new plant close to both the source of the waste and the potential energy customers. Placing the EFW facility directly into an urban community leads to the following: (*i*) minimizes the cost and the environmental impact of waste transport, (*ii*) allows electrical power to be generated at the point of consumption, (*iii*) provides thermal energy for district heating and cooling, (*iv*) reduces the dependence on imported fossil fuel for electrical generation and for heating/cooling, (*v*) provides secure and well-paying jobs for members of the community and finally reduces the carbon foot print of the community. The two case studies included in this paper described the Isséane EFW plant in Paris and the EFW plant in London [10].

2. Example of Incineration plants. Literature review

In Europe, the recovery of EFW has been adopted by the European Commission as one of the sustainable waste management options, with the scope to decrease the amount of nonhazardous waste going to landfill [11]. In the context of waste-to-energy, it is worth noting the European Environmental Citizen Organization for Standardization (ECOS), nonprofit association established in 2002, funded by the European Commission and based in Brussels [12]. ECOS acknowledges that incineration of biomass contribute to climate protection, in addition ECOS admits that energy recovers only if performance is higher (LCA), and waste with low net calorific value or high level of pollutants shall not be used as "fuel" [12].

Waste incineration practices were discussed in the framework of project "QUOVADIS Waste-to-fuel Conversion — A Thinkshop," which took place in Ispra, Italy, between 28 April 2005 and 29 April 2005 [13]. Workshop was the forum for discussion and debate on the exchange of various experiences concerning the use of waste in waste-to-fuel conversion and its subsequent application [13]. In the draft paper untitled "Survey on the on-going scenario for SFR (solid recovery fuels) production and use in Italy" prepared by MP Maranzana presented 44 waste-to energy plants in Italy [13].

With the introduction of legalization, the situation in the EU has been improved markedly, but with pressure to minimize landfill and limited option for recycling, thermal treatment occupies a key role in waste management [14] (ENERGY]. The main challenges to incineration plant operation are maximizing thermal efficiency for energy recovery [14]. The *Clean and Efficient Waste Incineration, Waste-to-Energy and Biomass Combustion* (CLEANWEB) project addresses these challenges. The other project *Performance, Reliability and Emission reduction in Waste INcineration* (PREWIN) Network provides the forum for collaboration among pan-European organizations for waste incineration [14]. One of the objectives of the project is to improve the performance, efficiency and reliability of thermal treatment plant (**Figure 1**).

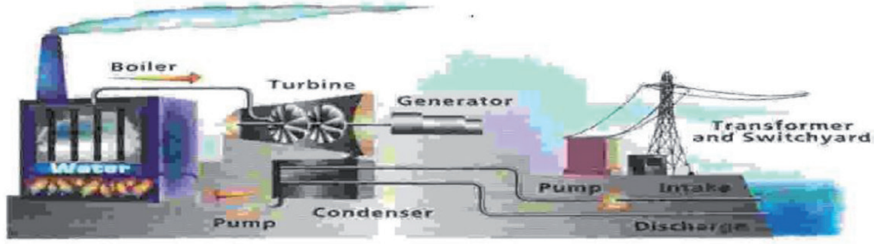

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Figure 1.
Process flow diagram related to CLEANWEB and PREWIN projects [14].

2.1 Maishima incineration plant

Maishima ("dancing island" in Japanese) is a man-made Island in the Bay of Osaka. Osaka is Japan's third largest city, with a population of 2.6 million and with seven completed Von Roll plants [15]. Impressed by a facility in Vienna that had been embellished by the world famous Austrian artist, Osaka's planners decided to entrust him with the design and ornamentation of the building, the stack and the surrounding area (**Figure 2**). The facility consist of two waste processing lines, each of which is able to incinerate 450 tons of MSW every 24 hours, and is typical of today's large scale.

The energy produced in the incineration process is used to generate power in the power generator with a capacity of 32 MW [15].

2.2 AVI Moerdijk incineration facility

The Dutch provinces of Zeeland, North Brabant and Limburg funded study in 1990 to determine how much waste was being generated in the southern Netherlands. Based on the 600,000 tons of waste, new waste incineration plant AVI Moerdijk linked to thermal power plant was built. The facility being operation since 1996/1997 and consists of three separate lines. Waste heat generated in a year amounts to 2,000,000 tons of high-pressure steam at temperature of 400°C. The photo and schematic of the AVI Moerdijk incineration facility are presented in **Figures 3** and **4**, respectively [16].

2.3 Bergen incineration facility

In the Bergen region on the western coast of Norway, the city Bergen and neighboring communities founded Bergensområdets interkomunale Renovasjonsselskap (BiR) company with the objectives of managing the waste generated by the region's 280,000 inhabitants. The contract for erecting waste incineration plant was awarded to Von Roll Inova in 1997. Start of operation was in 1999. Energy recovery based on 90,000 tons of waste is about 60 GWh of electrical energy and 430,000 tons of process steam. The photo and schematic of the BiR Bergen incineration facility are presented in **Figures 5** and **6**, respectively [17], as well as in **Figure 7** [18].

Figure 2.
Maishima incineration plant of 900 tons/24 hours of waste [15].

Figure 3.
AVI Moerdijk incineration facility of 600,000 tons/year of waste [16].

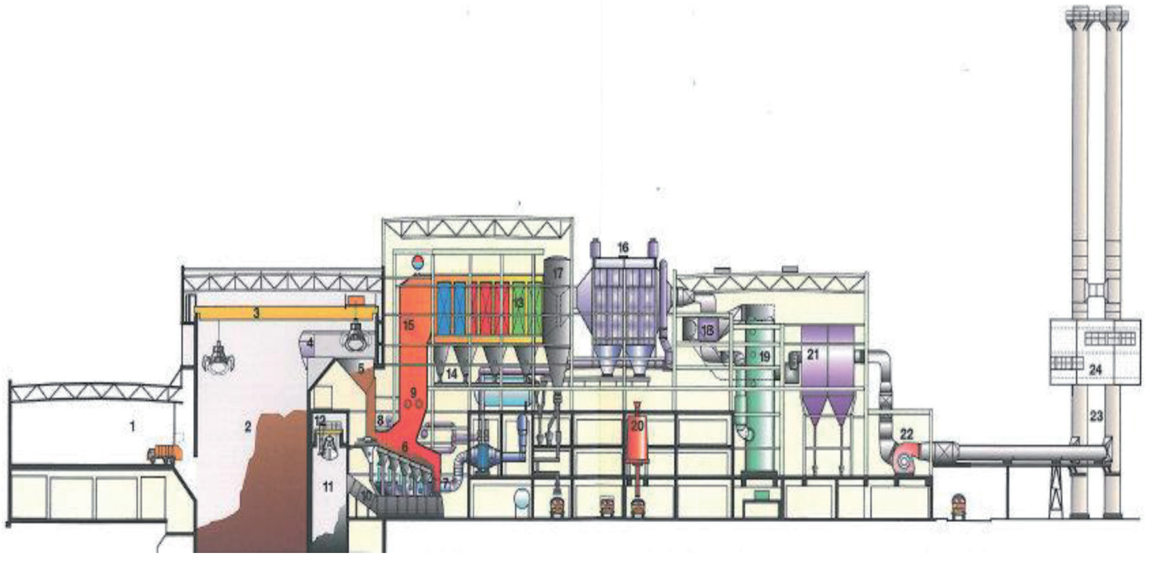

Figure 4.
Scheme of the AVI Moerdijk incineration facility of 600,000 tons/year of waste [16]. 1-Tipping hall, 2-waste pit, 3-overhead crane, 4-crane pulpit, 5-feed hopper, 6-reciprocating grate, 7-primary air supply, 8-secondary air supply, 9-auxilary burners, 10-wet deslagger, 11-slag pit, 12-slag crane, 13-two-pass boiler, 14-boiler ash removal, 15-SNCR DeNOx system, 16-electrostatic precipitator, 17-ash silo, 18-gas-to-gas heat exchanger, 19-wet scrubber, 20-gypsum silo, 21-fabric filter with activated carbon injection, 22-inducted draft fan, 23-stack, 24-emission monitoring.

2.4 KEBAG waste incinerator plant, Zuchwil

According to DOKA [19], Switzerland has 28 municipal solid waste incinerator (MSWI) plants in operation 1 (2000). The majority of them [23] have two or three furnace lines. All Swiss MSWIs utilize the energy contained in the waste to produce useful heat and/or electricity. In 2000, Swiss MSWIs gross production was 2,526,800 MWh heat and 1,284,200 MWh electricity, and the total energy input was 9,880,262 MWh [20]. **Figure 8** displays the general photo of the KEBAG waste incinerator plant in Zuchwil, Switzerland. In its four incineration lines, Zuchwiler KEBAG treats 220,000 tons of flammable domestic waste a year from the cantons of Berne and Solothurn—i.e., from around 473,000 residents in 208 municipalities, as opposed

Figure 5.
BiR Bergen incineration facility of 90,000 tons/year of waste with energy output about 60 GWh. Waste return in form of electricity and heat [17].

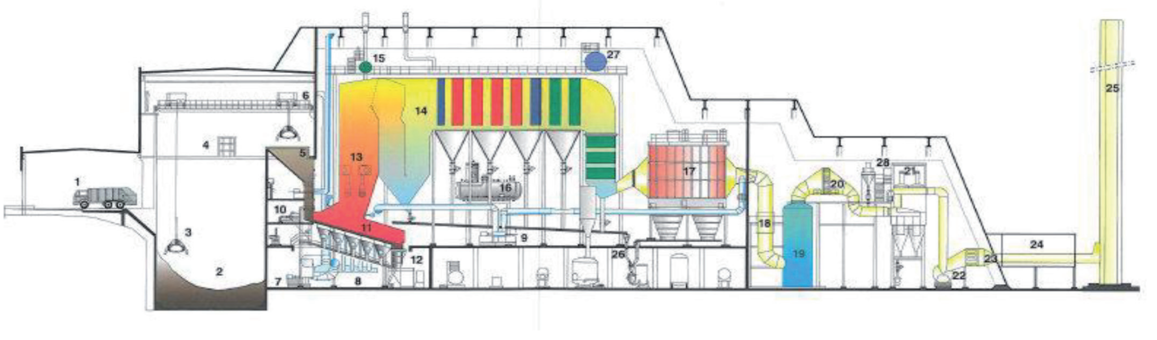

Figure 6.
Scheme of the BiR Bergen incineration facility of 600,000 tons/year of waste [17]. 1-Truck unloading area, 2-waste pit, 3-, 4-crane operating pulpit, 5-feed hopper, 6-primary air intake, 7-primary air fan, 8-primary air distribution, 9-recirculated flue gas fan, 10-ram feeder, 11-reciprocating grate, 12-wet deslagger, 13-auxilary burners, 14-four-pass steam generator, 15-steam drum, 16-feedwater storage tank, 17-electrostatic precipitator, 18-quench, 19-wet scrubber, 20-steam-to-gas heat exchanger, 21-fabric filter, 22-induced draft fan, 23-silencer, 24-emission monitoring, 25-stack, 26-ash removal system, 27-emergency water tank, 28-adsorbent metering station.

Figure 7.
View general of the BiR Bergen incineration facility (photo from 2018) [18].

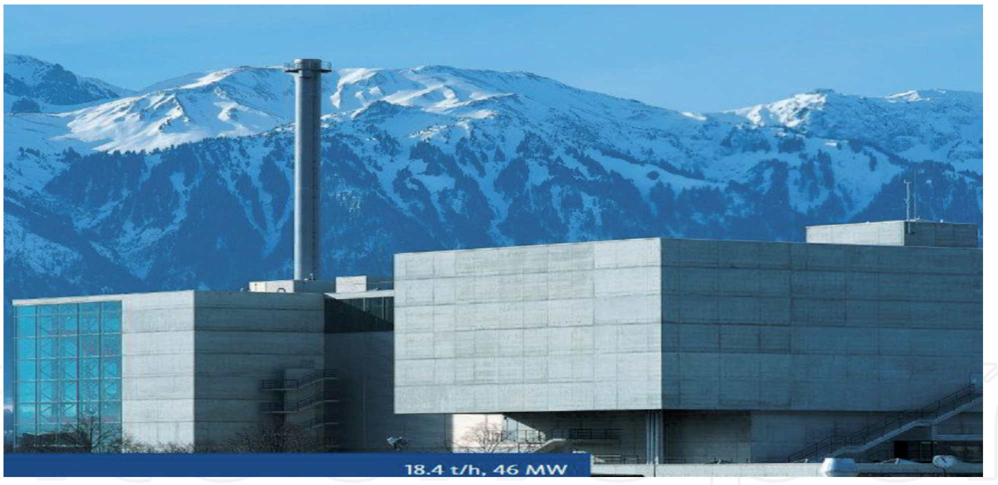

Figure 8.
KEBAG waste incinerator plant, Zuchwil, Switzerland [20]. Note: The name KEBAG comes from the German words for waste disposal.

to 2002 year, when train 4 enters service, and the service area has around 350,00 habitants who generated some 200,000 tons of wastes. The energy produced in the incineration process is used to generate electricity and prepare hot water [21, 22].

2.5 KVA Thun energy-from-waste plant

The KVA Thun energy-from-waste plant handles some 100,000 tons of combustible waste (domestic and bulky) a year. Thun is the city, located on Lake Thun, is the economic hub of the Bernese Mittelland and Oberland with the population of 300,000 residents in 150 communities. The facility produces about a third of the electricity consumed in the city of Thun, as well as provides district heating for different customers facilities (e.g., adjacent public sector facilities [23]). Energy recovery type is extraction-condensation turbine produced electric power of 12 MW (maximum) and district heating output about 25 MW (maximum) [23]. The photo and longitudinal section of the KVA Thun energy-from-waste plant are presented in **Figures 9** and **10**, respectively [22].

The applicable emissions guarantees are below Swiss air quality regulation (LRV) limits, as show in the **Figure 11** below [24].

Figure 9.
KVA Thun energy-from-waste plant of 100,000 tons/year of combustible waste with energy recovery: electric power about 12 MW (maximum) and district heating output about 25 MW (maximum) [23].

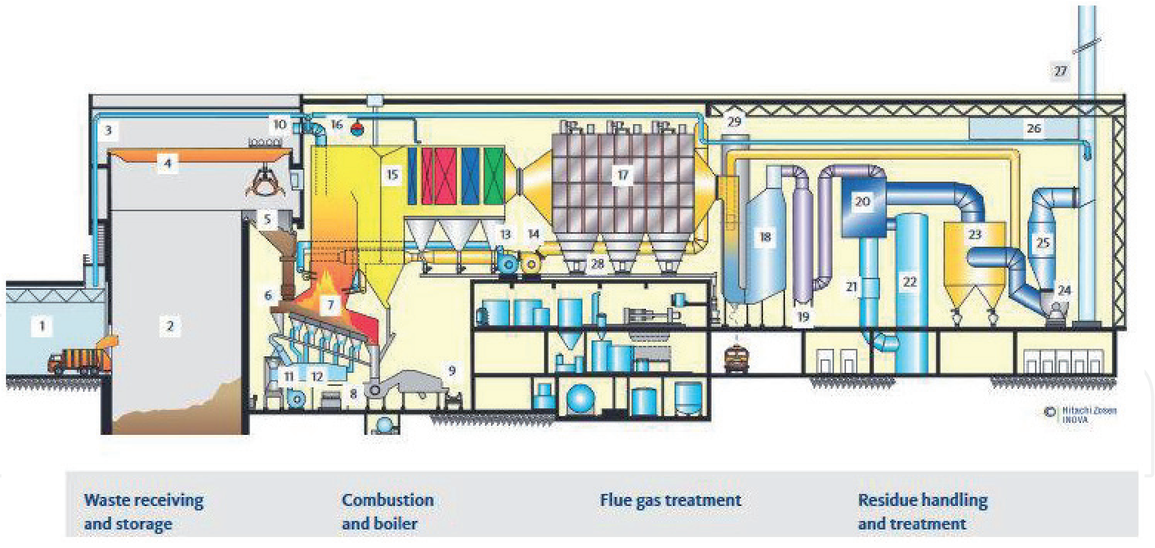

Figure 10.
Longitudinal section of the KVA Thun [23]. 1-Tipping hall, 2-waste bunker, 3-waste pit ventilation, 4-waste crane, 5-feed hopper, 6-ram feeder, 7-hitachi zosen inova grate, 8-ram bottom ash extractor, 9-bottom ash handling, 10-primary air intake, 11-primary air fan, 12-primary air distribution, 13-secondary air fan, 14-recirculation fan, 15-four-pass boiler, 16-boiler, 17-electrostatic precipitator, 18-SCR DeNox with catalyst, 19-economizer, 20-gas/gas heat exchanger, 21-quench, 22-wet scrubber, 23-fabric filter, 24-inducted draft fan, 25-silencer, 26-emissions measurement, 27-stack, 28-ash conveying system, 29-residue silo.

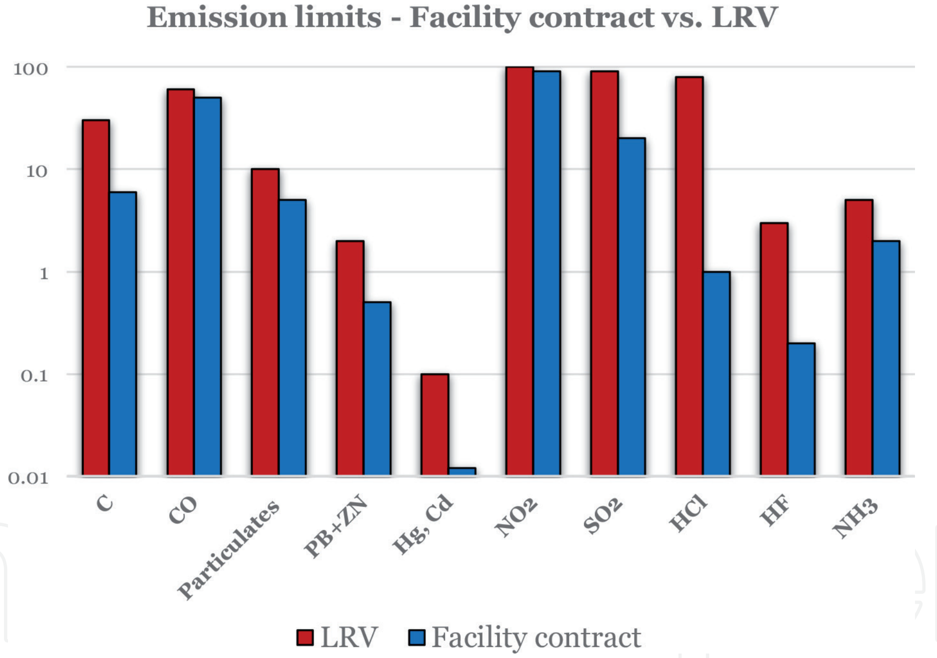

Figure 11.
KVA Thun facility emission limits [24].

3. Forms of recycling in Poland

One recycling method is energy (thermal) recycling, understood as total or partial energy recovery. The waste incineration process must take place under certain conditions due to the toxic substances formed during combustion, such as dioxins or furans emitted and polluting the atmosphere.

The choice of recycling method depends on the type and properties of the post-consumer product. Due to changes in the prices of raw materials and energy, limited possibilities of using material recycling, as well as the fact that raw material recycling can already be considered cost-effective, the role and importance of this form of recycling should increase.

The thermal methods of waste removal that we can distinguish are as follows: combustion, pyrolysis (degassing/gasification), hydrogenation and bios drying. The main waste disposal system is of course incineration, which removes waste that is unusable and cannot be managed further.

Incineration is intended to make the waste residues neutral to the environment and minimize waste gas emissions. It is also important to reduce the volume and use the energy generated during combustion.

The industry must also be guided by several important principles related to the combustion of precipitation:

- operational safety
- investment value
- land demand
- process efficiency and efficiency.

The pyrolysis process breaks down organic waste under the influence of temperature. The product is energy carriers useful for storage. Most combustion technologies are still in the testing phase and are being gradually introduced to the market in mature forms.

Another thermal process to mention is hydrogenation, which uses refinery waste and in some cases plastic waste. However, the goal of the bios drying process is the production of alternative fuel from a biodegradable fraction segregated from mixed municipal waste. The biological drying process is preceded by separation of biodegradable fraction (0–60/80 mm) from mixed municipal waste, followed by mechanical treatment of the dried fraction to produce fuel.

4. The thermal waste treatment plant in Krakow (eco-incinerator)

The main objective of this study is to share the art knowledge about the TWTP (eco-incinerator) in Krakow, Poland, that has operated since 2016. Description of TWTP case study is based on the thermal waste treatment plant in Krakow presentations given in [25–28].

In recent years, waste incineration has been frequently preferred to other waste treatment or disposal alternatives due to advantages such as volume reduction, chemical toxicity destruction and energy recovery [29].

According to the study by Pfeiffer [30], energy recovery is a secondary goal of waste incineration: thermal waste treatment and energy recovery are "married" within the waste-to-energy plant [30]. From an economic point of view, a WTE plant treating MSW is an enterprise using a special fuel [1].

Thermal waste treatment plant (TWTP) in Krakow (eco-incinerator) is being constructed in answer to concepts link economic, ecological and social aspects and needs of Krakow as key factor of project "Waste Management Program in Krakow" under the Operational Program Infrastructure and Environment 2007–2013 [27]. On October 31, 2012, a contract was signed with the POSCO Engineering and Construction Co., Ltd., South Korean company, for delivery of a TWTP. On November 6, 2013 began the construction of the eco-incinerator. The contract covered delivery, installation and commissioning the entire electromechanical parts. Series of tests at the plant began from December 3, 2015 until June 27, 2016. According to [26], the total contract amount (net cost) of the project was approximately PLN 666 million (approximately PLN 819 million gross). The subsidy from the European

Union amounted to approximately PLN 372 million (approximately 55.8% of eligible expenses). The contribution of Krakowskiego Holdingu Komunalnego S.A. (KHK) amounted to approximately PLN 294 million and was covered by its own resources and a loan from the National Fund for Environmental Protection and Waste Management (NFEP & WM). The plant is located in the district Nowa Huta, part of the Kraków city. General view and longitudinal section of the TWTP are depicted in **Figures 12** and **13**, respectively [27].

Eco-incinerator allows to process 220,000 tons of municipal waste a year. Selected by the inhabitants mixed municipal solid waste (MSW) and other waste (e.g., resulting from mechanical processing of municipal waste) and following waste recovery processes (i.e., material waste, bulk, rubble) are subject to thermal processing. The wastes are collected only from the municipality of Kraków.

The emissions come from TWTP production process meet the requirements of the best available techniques (BAT), guaranteeing the highest standards of environmental protection.

Figure 12.
The thermal waste treatment plant in Krakow [31].

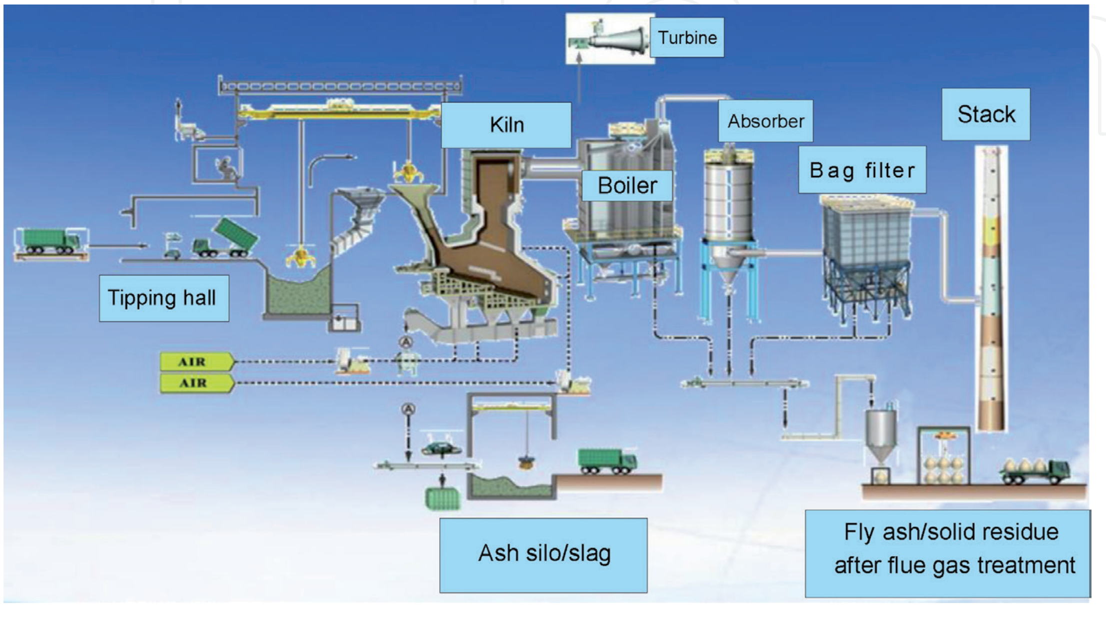

Figure 13.
Longitudinal section of the TWTP plant in Kraków [32].

On October 1, 2016, the educational pathway, an integral part of the eco-incinerator, was launched in the eco-incinerator area with the goal of increasing the ecological knowledge of the inhabitants as well as bringing the technology and thermal plant operation processes closer to them. This educational pathway is the tour throughout the plant, showing the key steps of the system such as delivery and unloading of waste into the bunker, the process of thermal conversion of municipal waste, the flue gas scrubbing process, the electricity and heat production process and the process of managing residue after incineration [27].

4.1 The TWTP-a cost-effective and safe solution

Naturally, very stringent environmental regulations are applied to the process. Using BAT, the TWTP in Krakow meets the highest environmental and legal standards applicable in the European Union. The amount of waste is limited, and thus securing energy to the city has increased.

In the line of [27], energy security signifies a prospective condition of meeting consumer demand (including the citizens of Krakow) for fuel and energy through alternative sources of acquiring gas [27].

4.2 Emission standards

According to [28], the plant is equipped with a state-of-the-art exhaust purification system that meets strict emission standards for air.

The exhaust aftertreatment process consists of the following stages:

- Denitrification of exhaust gases
- Flue gas cleaning by means of a semi-dry method
- Dust extraction.

Line 1	**Emission value**	**Emission value**	**Emission value**	**Emission limit value**
Date	27 July 2019	13 August 2019	20 August 2019	Standards
Dust	1.070	0.990	1.090	30
Hydrogen chloride	0.300	5.500	1.500	60
Hydrogen floride	0.000	0.000	0.055	4
Sulfur dioxide	1.100	19.750	12.900	200
Carbon monoxide	12.200	7.850	6.300	100
Nitric oxide	138.200	127.400	87.500	400
Total organic carbon	0.300	0.300	0.600	20
Line 2				
Dust	1.250	1.220	1.060	30
Hydrogen chloride	0.100	0.500	0.300	60
Hydrogen floride	0.000	0.000	0.020	4
Sulfur dioxide	6.150	11.500	0.400	200
Carbon monoxide	18.750	21.900	20.100	100
Nitric oxide	163.400	154.600	114.100	400
Total organic carbon	0.000	0.600	0.400	20

Concentration magnitude 11% content of oxygen in flue gases (mg/m^3), on average in 30 minutes in mg/m^3.

Table 1.
Emission values of the TWTP derived from measurements of 27 July and 13 August 2019 [28].

The emission standards comply with the Ordinance of the Minister of the Environment of 4 November 2014 on emission standards for certain types of installations, sources of fuel combustion and devices for incineration or co-incineration of waste (Journal of Laws of 2014, item 1546, including further amendments).

Below you can find in **Table 1** [28] a sample of selected emission values derived from measurements of 27 July, 13 August and 20 August this year.

As mentioned above, the eco-incinerator was created as a response to the ecological and energy needs of Krakow as part of the project "Municipal Waste Management Program in Krakow" (TWTP). It is the latest and most important part of this system; it enables to utilize municipal waste generated by the inhabitants of Krakow and the recovery of energy from it.

The thermal recycling technology is the most mature and environmentally esponsible solution to waste. This is confirmed by many years of European experience in which thermal processing of waste with recovery of energy forms the basis of the entire waste management system.

The eco-incinerator allows to process 220,000 tons of municipal waste during the year. Approximately 65,000 MWh of electricity and 280,000 MWh of heat are produced as a result of the combustion. The energy obtained by way of the thermal transformation process is largely organic and renewable [27].

4.3 Green energy factory

The thermal waste treatment plant in Krakow called Green-energy factory [26] provides background material for this part.

Concept of the furnace-grate furnace integrated into the boiler.

- Grate incinerator technology
- Boiler—drum-type heat recovery steam generator (HRSG) with natural circulation
- Turbine—based on the extraction condensing process [26].

4.4 The TWTP receives

- Municipal solid waste mixed with secondary raw materials separated.
- Combustible ballast from other installations for processing municipal [26].

4.5 Selection of waste, unloading and loading in the combustion chamber

The overall objectives of the TWTP are to increase thermal efficiency and heat recovery, as well as reduce emissions through improving and developing a better plant characteristics. For this purpose, the wastes are discharged in the unloading hall of the bunker that ensures stocking waste for 5 days. To obtain a uniform mixture, which improves incineration efficiency, the waste is mixed together in the bunker. Next the waste is mixed together in the bunker, and then the cranes equipped with 6-teeth grapple buckets transport mixed waste to feed hoppers where it feeds into the loading shaft [25].

In the TWTP were installed radioactive material detectors so as to protect the installations against damage. The TWTP also monitors waste delivered for thermal processing [26].

4.6 Facility (TWTP) concept

The concept of the thermal waste treatment process is based on the five following steps:

4.6.1 Drying process

Radiation or convection is used for the waste drying in the grate zone. Thanks to temperature at approximately 100°C the moisture through evaporation is eliminated [26].

4.6.2 Degassing process

The waste continued heating at above 250°C is used to releases gases (e.g., moisture and carbonization gases) [26].

4.6.3 Combustion process

Third grate zone is suitable for waste incineration where loss on ignition is below 0.5% of the mass share production [26].

4.6.4 Gasification process

This process achieves oxidation volatile products by molecular oxygen. The majority of the waste is oxidized at 1000°C in the upper section of the furnace chamber [26].

4.6.5 After burning

The carbon dioxide amount in the combustion gases is reduced in the recuperative thermal oxidation area. The standard operating procedure used secondary air for total incineration for the minimum at 850°C and trough minimum of 2 seconds [26].

The chosen combustion technology provides in the combustion chamber the reduction of CO and NO_x, dioxins and furans emission. Produced in this thermal waste processing energy is then optimally recovered in a heat recovery steam generator (HRSG) integrated with the grate furnace [26].

4.7 Energy recovery process

Using innovative concept, the heat recovery steam generator (HRSG) is based on natural circulation of exhaust gases. In the boiler after heat exchange, exhaust gases are cooled to approximately 180°C. In the next step, heat is used to convert water, via the boiler, into superheated steam. Superheated steam at a pressure of 40 bar and a temperature of 415°C is supplied to the electricity generation and transmission node. The produced electricity is used to drive a set of steam turbines. In the last step, the actuated turbine converts mechanical energy into electrical energy [26].

According to [26], produced electricity is used (consumed) by the operator; on the other hand, energy excess is returned to the grid. Using proven cogeneration concept, produced heat is distributed to the municipal heating network [26].

4.8 Emission treatment process

In line with [26], carbon dioxide, carbon monoxide, sulfur dioxide, oxides of nitrogen, steam and unburned or partially burned hydrocarbons are generated during the waste combustion process. Pollution may be expressed both in the form of gas and dust [26].

Pollution control plays an important role in waste incineration. All existing emission limits are complied. Combustion gases pass first to the heat recovery steam generator. Next via emission treatment installation are transferred to gas exhaust fan and finally are removed to stack.

Procedure of the emission treatment consists of the following steps [26]:

- Exhaust gases denitrification used by primary and secondary methods based on the application of the selective nitrogen oxides reduction (SNCR) via the injection of aqueous urea solution containing 25% urea by weight.

- Semi-dry method based on the use of lime slurry, together with the dry entrained flow method with activated carbon. These methods reduced acidic impurities, as well as heavy metals, dust, furans and dioxins.

- Fabric filtration for the effective dedusting exhaust gases by means of fabric filtration [26].

Post-processing waste disposal:

According to the [26], by-products created during thermal processing of waste are as follows:

- slag and bottom ash

- boiler dust

- fly ash

- solid residues from the emission treatment.

Each residue resulted from thermal waste processing shall be received by authorized external entities in accordance with the provisions of the IPPC standards [26].

5. Conclusions

1. The use of waste as a fuel leads to saving of primary resources and the reduction of CO_2 emissions.

2. From an economics point of view, it is clear that waste incineration is costly for society.

3. The use of waste as alternative fuels is carried out in total compliance with permits issues by relevant authorities and meets rigorous requirements according to EU and national law and regulations as well as according to the IPPC Directive.

4. The main advantage that gasification has over incineration is its capability to retain (keep) the chemical energy of the waste in the produced syngas.

Acknowledgements

Relevant figures are reprinted with given sources.

Conflict of interest

The authors declare that they have no conflict of interest. The research does not involve human participants and/or animals.

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References

[1] Bieda B. The role of thermal treatment in an integrated waste management. Waste recycling. In: Wzorek Z, Kulczycka J, Fečko P, Kušnierowa M, editors. Kraków, Poland: Mineral and Energy Economy Research Institute of the Polish Academy of Sciences. 2005. pp. 104-113

[2] Everard M. Hot Stuff!–The Role of Thermal Treatment in a Sustainable Society. Warlines Park House, Horseshoe Hill, Upshire, Essex, UK: Waste Management World, PennWell International Publications Ltd.; 2004. pp. 37-45

[3] Hulgaard T, Vehlow J. Incineration: Process and technology. In: Christensen TH, editor. Solid Waste Technology & Management. Vol. 1. Chichester: Blackwell Publishing Ltd.; 2011. pp. 365-392

[4] Moberg A, Finnveden G, Johansson J, Lind P. Life cycle assessment of energy from solid waste–Part 2: Landfilling compared to other treatment methods. Journal of Cleaner Production. 2015;**13**(3):231-240

[5] Eriksson O, Finnveden G, Ekvall T, Bjorklund A. Life cycle assessment of fuels for district heating: A comparison of waste incineration, biomass- and natural gas combustion. Energy Policy. 2007;**35**(2):1346-1362

[6] Hauck P, Strobridge D, Sonawane A. Sustainable Solutions for the 21st Century. Santa Barbara, CA: MSW Management; Forester Media Inc.; 2012. pp. 12-21

[7] Chandler AJ, Eighmy TT, Hartlén J, Hjelmar O, Kosson DS, Sawell SE, et al. Municipal Solid Waste Incinerator Residues. Studies in Environmental Science 67. Amsterdam, The Netherlands: The International Ash Working Group. Elsevier Science; 1997. p. 973

[8] Kleis H, Dalager S. 100 Years of Waste Incineration in Denmark. From Refuse Destruction Plants to High-Technology Energy Works. Copenhagen, Denmark: Babcock and Wilcox, Vølund and Rambøll; 2004. 51p

[9] Chromec PR, Ferraro AF. Waste-to-energy in the context of global warming. In: 16th Annual North American Waste-to-Energy Conference. 2008. DOI: 10.1115/NAWTEC16-1954

[10] Chromec PR, Burelle RJ. Integration of an energy from Waste facility into an urban environment. In: 17th Annual North American Waste-to-Energy Conference. 2009. DOI: 10.1115/NAWTEC17-2320

[11] Ciceri G. QUOVADIS-quality management organisation, validation of standards, developments and inquiries for SRF. QUOVADIS waste-to-fuel conversion?–A Thinkshop. DG JRC Workshop, Ispra, 28-29 April 2005. Workshop Proceedings. In: Gawlik BM, Ciceri G, editors. EUR Report 21756 EN. European Communities. Luxembourg: Office for Official Communications of the European Communities; 2005. pp. 147-155

[12] Tebert C. Waste-to-fuel standarisation. The public confidence aspect. QUOVADIS Waste-to-fuel conversion?–A Thinkshop. DG JRC Workshop, Ispra, 28-29 April 2005. Workshop Proceedings. In: Gawlik BM, Ciceri G, editors. EUR Report 21756 EN. European Communities. Luxembourg: Office for Official Communications of the European Communities; 2005. pp. 123-128

[13] Maranzana M. Survey on the on-going scenario for SFR (solid recovery fuels) production and use in Italy. In: Gawlik BM, Ciceri G, editors. QUOVADIS waste-to-fuel conversion?–A Thinkshop. DG JRC

Workshop, Ispra, 28-29 April 2005. Workshop Proceedings. In: EUR Report 21756 EN. European Communities. Luxembourg: Office for Official Communications of the European Communities; 2005. pp. 209-232

[14] McGarry D. Energy from Waste and Biomass for better Efficiency and a Cleaner Environment. European Commision-Directorate General, Joint Research Centre, Institute for Energy. Petten, NL: P.O. Public Relations and Communication; 2005. p. 2

[15] Ermel FW. Maishima-The Latest Technology and a Unique Design. Flas VonRoll INOVA. nr 21. Zurich, Switzerland: Von Roll Technology Environmental Ltd; 2003. 5p

[16] AVI Moerdijk. vonRoll INOVA's Leaflet. Von Roll Environnement SA. Hardturmstrasse 133, Case postale 760, CH-8037 Zurich. Available from: http://www.vonroll.ch/inova [Accessed: August 08, 2019]

[17] BiR Bergen. vonRoll INOVA's Leaflet. Von Roll Environnement SA. Hardturmstrasse 133, Case postale 760, CH-8037 Zurich Available from: http://www.vonroll.ch/inova [Accessed: August 08, 2019]

[18] Ristesund A. Bellona jubler for BIR-initiativ. Foto: Forbrenninganlegget til BIR i Rådalen. 2018. Available from: https://www.ba.no/nyheter/miljo/bir/bellona-jubler-for-bir-initiativ/s/5-8-852769 [Accessed: December 06, 2019]

[19] Doka G. Part II Waste Incineration. Life Cycle Inventories of Waste Treatment Services.ecoinvent report No. 13, Swiss Centre for Life Cycle Inventories, Dübendorf, December 2003. Available from: https://www.doka.ch/13_II_WasteIncineration.pdf [Accessed: August 10, 2019]

[20] BUWAL. Energieerzeugung und Nutzung in KVA 2000, Stand 11.12.2001. Industrie- und Gewerbeabfälle, Berne, Switzerland. 2001. Available from: http://www.buwal.ch/abfall/docu/pdf/tab10_d.pdf [Accessed: August 10, 2019]

[21] Contract successfully executed for KEBAG Zuchwil. 2012. Available from: https://www.alpiq.com/alpiq-group/media-relations/news-stories/news-stories-detail/contract-successfully-executed-for-kebag-zuchwil/ and https://www.alpiq.com/search/search-results/?L=0&id=119&tx_solr%5Bq%5D=zuchwil [Accessed: August 08, 2019]

[22] KEBAG Waste Incinerator Plant, Zuchwil, Schweitz. Available from: https://nightnurse.ch/en/portfolio/project/kebag-waste-incinerator-plant-zuchwil-schweiz-277 [Accessed: August 10, 2019]

[23] Thun/Switzerland. Hitachi Zosen Inova. Energy-from-Waste Plant. Available from: http://www.hz-inova.com/cms/wp-content/uploads/2014/11/hzi_ref_thun_en.pdf [Accessed: August 10, 2019]

[24] Surber M. Thun Waste Treatment Facility. Flas VonRoll INOVA. Nr 20. Zurich, Switzerland: Von Roll Technology Environmental Ltd; 2002. 5p

[25] The Thermal Waste Treatment Plant in Krakow. ECO-INCINERATOR. Available from: https://khk.krakow.pl/en/eco-incinerator/ [Accessed: August 08, 2019]

[26] The Thermal Waste Treatment Plant in Krakow. Green Energy Factory. Available from: https://khk.krakow.pl/en/eco-incinerator/green-energy-factory/ [Accessed: August 08, 2019]

[27] The Thermal Waste Treatment Plant in Krakow. Available from: https://khk.krakow.pl/en/eco-incinerator/about-the-plant/ [Accessed: August 08, 2019]

[28] The Thermal Waste Treatment Plant in Krakow. Available from: https://khk.krakow.pl/en/eco-incinerator/emission/ [Accessed: August 10, 2019]

[29] Sonnemann G, Castells F, Schumacher M. Integrated Life-Cycle and Risk Assessment for Industrial Processes. Boca Raton, FL, USA: CRC Press Company, Lewis Publishers; 2004. 392p

[30] Pfeiffer E. Waste or Valuable Product? Warlines Park House, Horseshoe Hill, Upshire, Essex, UK: Waste Management World, PennWell International Publications Ltd.; 2004. pp. 65-69

[31] Eco-Incinerator. Photos. Available from: https://www.google.pl/search?q=ekospalarnia+krak%C3%B3w&tbm=isch&source=iu&ictx=1&fir=ar1943G_9-iQCM%253A%252ChQN9Zq2XdEMgsM%252C_&vet=1&usg=AI4_-kQEzy-yzl0DkU7Xv8e9_8A9ABJa9Q&sa=X&ved=2ahUKEwis2tHQvJPkAhVRkMMKHVTsD54Q9QEwEnoECAUQBg#imgrc=sX8Vh7uDTuZQnM:&vet=1 [Accessed: August 18, 2019]

[32] POSCO Project Presentation. The Thermal Waste Treatment Plant Conference in Kraków. Public Presentation. Kraków, Poland. 3 December 2013