Energy Recovery from Municipal and Other Waste

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Abstract

The article summarizes possibilities of energy recovery from municipal and other waste. It describes the history of incineration and energy recovery from municipal waste in Czechoslovakia and then in the Czech Republic. The attention is paid to the three currently operated plants for energy recovery from municipal waste in the Czech Republic (ZEVO Malešice, SAKO Brno, TERMIZO Liberec, and ZEVO Chotíkov). The following are the characteristics of the planned plants for energy recovery from municipal waste in the Czech Republic. All these plants operate essentially based on grate boilers with flue gas treatment at the highest technical level. The article also lists other technologies, which can be used for energy recovery from municipal waste - these are gasification and pyrolysis units. The final part of this contribution is devoted to the emission values of flue gases from pyrolysis plant.

Keywords: municipal waste, energy use, incinerators, flue gas treatment, gasification, pyrolysis, emission

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Introduction

In the Czech Republic from about 3,2 million tonnes of mixed municipal waste (MMW), 600 thousand tonnes per year can be processed in existing incinerators, in the three planned incinerators another 400 thousand tonnes, and in other energy waste recovery plants, 350 thousand tonnes of mixed municipal waste. To the year 2025, about 1,850 thousand tonnes of mixed municipal waste still remains, which we will not be able to put on landfills (landfilling of municipal waste in the Czech Republic will be over since 2024).

The waste energy recovery saves e.g. an equivalent of the brown coal volume, which would otherwise have to be extracted and consumed in power plants and heating plants. It should also be pointed out that no matter how well cleaned flue gases from power plant processes are, their quality is incomparable with that of treated flue gases from waste energy recovery processes.

Incineration and energy recovery from municipal waste in the Czech Republic

Plants Based on Grate Boilers

In the post-war history a large municipal waste incinerator was put into operation in Brno (now SAKO Brno, plc) as the first in the former Czechoslovakia. The incinerator was built in the years 1984–1989. Originally, the incinerator had three ČKD Dukla boilers with cylindrical grates. The total capacity of the incinerator was 240 thousand tonnes of waste per year. Since 1998 the incinerator has also produced electricity using the equipment with an output of 400 kWe.

In the years 2008–2011, the incinerator underwent large renovation and modernization (for around EUR 72 million), when two new lines for waste incineration were built. Each line includes a steam boiler with a rated output of 45 TPH of steam. The maximum incineration power of the grate of each boiler is 16 tonnes per hour, the minimum one is then 8 tonnes per hour. The total incinerator capacity is 248,000 tonnes of waste per year for the heating value of waste of 8-9.6 MJ/kg. The municipal waste incinerator SAKO Brno, a.s. was officially reopened on 7th September 2011 [1]. The renovated plant of the Brno incinerator can satisfy up to 30% of steam consumption in the city of Brno.

Each boiler is equipped with an internal incineration reverse grate by Martin GmbH, developed specifically for the incineration from municipal solid waste; the boiler itself is of water-tube kind with natural circulation, three-pass design with two drums. The modern operation of the Brno incinerator meets stricter emission limits than required by current legislation on air quality protection.

The treatment of flue gas, resulting from the incineration of waste, has the following steps:

The flue gas generated during the incineration of waste is fed to the top of an absorber at the outlet from the boiler at a temperature of 195°C. The flue gas treatment is based on a semi-wet type system, and along with technical and operational measures also addresses issues of heavy metals, dioxins and other persistent organic pollutants. The CNIM-LAB semi-wet type system consists in injecting fine-atomized aqueous lime slurry into the flue gas stream at a temperature of 195°C. The result is a series of chemical reactions taking place during gradual evaporation of water between the parallel flow of hot gaseous acidic components of flue gas and alkaline sorbent which is a lime slurry aerosol. The result is a very fine powder which is separated from the flue gas on fabric filters. Into the flue-gas duct of each line before absorbers, the activated carbon is forced down under pressure, to the surface of which the heavy metals and dioxins are mainly bound which were not removed by the previous reactions.

If necessary to capture the increased concentrations of acidic components of the flue gas, in addition to the semi-wet type system, the dry type flue gas treatment system can be run, during which a dry hydrate of lime is fed into the flue-gas duct before the fabric filter to increase the efficiency of the neutralization reaction. The flue gas, including fly ash, reaction products of neutralization and residua of unreacted reagents are led through the flue-gas duct on the fabric filter. Prior to entry into the chimney with a height of 125 m, the cleaned flue gas is subjected to a continuous analysis.

The construction of a new incinerator for disposal from municipal solid waste in Prague was considered already in the late 70ies. The construction itself was commenced in September 1988. The Plant for energy recovery from municipal waste (ZEVO) Malešice was put into operation in the fall of the year 1998. There were four steam boilers by ČKD DUKLA in the incinerator, with a capacity of 15 tonnes of waste per hour each. The total capacity of the incinerator is 310 thousand tonnes of waste per year. This capacity is used from two thirds only. In 2010, a new co-generation unit was put into operation, allowing increased production of energy from waste. The incinerator delivers about 1,000 TJ of thermal energy annually to Pražská teplárenská plc, and produces about 90,000 MWh of electricity per year. The output of the installed turbines is 17.6 MWe.

ZEVO Malešice has four identical lines, two of which were in operation previously and two of them were shut down, but in winter three of them worked if there was a high enough demand for heat. It is now moved to 3 + 1 after the adaptation with the co-generation [2].

About 6 years ago, the flue gas treatment system in ZEVO Malešice was reconstructed. Now the plant disposes of a top multi-stage flue gas treatment system. The flue gas is first fed to a spray dryer for pre-treatment of dust particles, acidic components and heavy metals. The effect of the first stage is also the fact that water is evaporated from a washing suspension so that the waste leaves the system in the solid phase only. The flue gas continues passing to an electrostatic precipitator where particles are removed (the second treatment stage). Behind the electrostatic precipitator, a new combined catalyst (SCR – selective catalytic reactor) is integrated, where the degradation of nitrogen oxides and oxidative decomposition of dioxins and furans take place (DeNOx and DeDiox catalytic reactor). The flue gas is thus deprived of nitrogen oxides, dioxins and furans, and is pre-treated in terms of acidic components, and particles are removed. Further it proceeds into the two-stage wet flue gas treatment system. There is a so-called pre-scrubber placed here, which dissociates chlorides, iodides, bromides and fluorides, and in the next stage the absorption SO_2 and SO_3 takes place as well. Thus, it is a five-stage flue gas treatment system. As regards the achieved emission levels, it is clear that all emission values are below ten per cent of the allowed limits, only CO reaches 30% and NOx 70% of the level of emission limits [2].

Modern municipal waste incinerator in the Czech Republic is also situated in Liberec (TERMIZO plc). The construction was commenced in 1997; the trial operation started in 1999 and was completed in 2000 by final building acceptance. The incinerator has a capacity of 96,000 tonnes of waste per year, has one incineration line with a moving grate of the Von Roll system with a capacity of 12 tonnes per hour. The made preheated water steam is supplied to a local heating system.

The most modern plant for energy recovery from municipal waste (ZEVO) in Chotíkov near Pilsen also operates in a cogeneration mode (Figure 1). Up to 95,000 tonnes of municipal waste [3] per year is used for energy recovery. The plant has one incineration line with a moving grate of the Von Roll system. The thermal output of plant is 31,7 MW, electric output of turbine is 10,5 MWe. The made preheated water is supplied to a local heating system (City Pilsen). The plant disposes of a top multi-stage flue gas treatment system [3,4], where besides other things the degradation of nitrogen oxides and oxidative decomposition of dioxins and furans also take place (DeNOx and DeDiox catalytic reactor). The plant was put into trial operation on 12th August 2016.

Currently the construction of other incinerators for energy recovery from municipal waste is considered, which would partly address the issue of waste management at regional levels. In all the cases the usage of conventional grate boilers is considered.

The Highlands Region (Kraj Vysočina) in the Czech Republic prepares the project Integrated waste management system in the Highlands Region whose part is a municipal waste incinerator as well.

Other prepared projects:

- The company United Energy plc is preparing the construction of plants for energy recovery from waste at the premises of the Komořany heating plant with an annual capacity of 100 to 150 thousand tonnes of waste.
- Further construction of the municipal solid waste (MSW) incinerator being considered is located at the premises of the Opatovice power plant. Its capacity should be about 100,000 tonnes of incinerated waste and

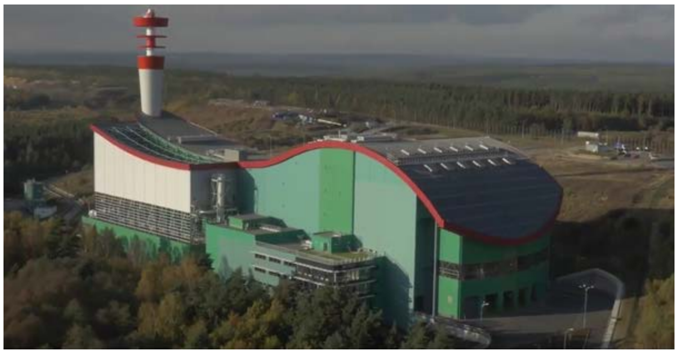

Fig. 1. Plant for energy recovery from municipal waste (ZEVO) in Chotíkov [photo ZEVO Chotíkov]
Rys. 1. Spalarnia odpadów komunalnych (ZEVO) w miejscowości Chotíkov

the heat should be used in the agglomeration of Pardubice and Hradec Králové.

Gasification of Waste

The essence of gasification is the conversion of carbonaceous materials at higher temperatures (above 800°C) into combustible gaseous substances under the supply of under-stoichiometric amount of air or other oxidising agent. The gasification is a strongly endothermic process. The advantage is that due to the high temperatures there are no problems with the formation of toxic dioxins, furans and polycyclic aromatic hydrocarbons. The reducing environment prevents the formation of nitrogen oxides [5].

The gasification is partial combustion of organic compounds forming gases which can be used as a raw material (using reform processes) or as a fuel. The gasification processes are suitable for the treatment of municipal waste, some hazardous waste and dried sewage sludge.

Very interesting structures are e.g. gasification units working in the plant for energy recovery from municipal waste of the company Kazusa Clean Systems Co., Ltd. The plant was built in Kisarazu City, in the Japanese Prefecture of Chiba, by the firm Nippon Steel Engineering Co., Ltd. [6].

In the gasification furnace, the temperature of up to 1,800°C is reached in the melting zone (here municipal waste is melted in the last phase), while the leaving slag is granulated in a water trough and then crushed. From the slag, metals are obtained by magnetic separation, and the rest is used in civil engineering.

The gas comes into the combustion chamber, where it is burned. Flue gases are fed to the waste heat boiler which produces superheated steam driving the turbine and the generator, producing electricity. Units are available with a capacity of 100 or 125 tonnes of municipal waste per day. The company Kazusa Clean Systems Co., Ltd. has 2 units in place for processing 100 tonnes of municipal waste per day and 2 units for processing 125 tonnes of municipal waste per day. The output of the generators is then 3,000 kWe and 5,000 kWe [6].

Flue gases are cleaned in a multistage process as is the case of the ZEVO Malešice plant and, also, as projected for the Plant for energy recovery from municipal waste Chotíkov (ZEVO Chotíkov), including the SCR - the DeNOx and DeDiox catalytic reactor.

Pyrolysis of Waste

Pyrolysis is the thermal decomposition of organic materials in the absence of oxygen-containing media (air, carbon dioxide, water vapour) which leads to the formation of gaseous, liquid and solid fractions. This process is an alternative to combustion.

The essence of this method is that organic compounds are less stable at higher temperatures. High molecular substances are decomposed to low molecular ones, which leads to their breakdown into volatile products and coke. Pyrolysis is carried out at the temperatures ranged from 150°C to 1,000°C.

Advantages of pyrolysis processes [7]: Easier and less capital-intensive plants, there is only a small fraction of gaseous products of incineration compared to the same amount of fuel.

Disadvantages of pyrolysis processes: Sometimes more expensive operation, sometimes a problem to remove the pyrolysis residue as for is not clean (pyrolysis coke), liquid hydrocarbons (difference between situation in the Czech Republic and other countries).

Pyrolysis can be used in addition to the thermal treatment of municipal waste and sewage sludge also to treatment of plastic waste and used tires.

Incineration has the advantage of taking profit of wastes energetic content, but produces pollutants like nitrous and sulphur oxides, dust, hydrocarbons, and dioxins, which have highly negative bearing on the environment. On the other hand, this combustion of wastes destroys completely an important resource, as wastes organic content are converted only into CO_2 and H_2O.

Pyrolysis technology applied to these wastes may have an important role in future, as it may allow the conversion of these residues into economical valuable products, which can be used as fuels or as feedstock in petrochemical industry.

Tab. 1. Measured emission values – pyrolysis of municipal waste free of the biodegradable component and inert material. Pyrolysis plant PTR 1000 (manufacturer Hedviga Group plc, Czech Republic), certificates No. 03/13 and No. 06/13 of 18th February 2013 [11,12]

Tab. 1. Pomiary emisji – piroliza odpadów komunalnych bez frakcji biodegradowalnej i inertnej. Zakład pirolizy PTR 1000 (operator Hedviga Group plc, Czech Republic), certifikat No. 03/13 i No. 06/13 z 18 lutego [11,12]

Pollutants	Average mass concentration of pollutants	Emission limits	Remarks
NO_x	284 mg/Nm^3	500 mg/Nm^3	Emission limits for cogeneration units (Appendix 2 to Regulation 415/2012 Coll., as amended, Section II, Article 2, Table 2.2)
CO	800 mg/Nm^3	1300 mg/Nm^3	
PM (Solid pollutant)	1.05 mg/Nm^3	10 mg/Nm^3	Emission limits for incineration of waste (Appendix 4 to Regulation 415/2012 Coll., as amend-ed, Section I, Article 1, Table 1.1
HF	0.09 mg/Nm^3	1 mg/Nm^3	
HCl	0.17 mg/Nm^3	10 mg/Nm^3	
SO_2	135 mg/Nm^3	50 mg/Nm^3	
TOC	179 mg/Nm^3	10 mg/Nm^3	
PCDD/F (Σ TEQ)	0.00167 ng/Nm^3	0.1 ng/Nm^3	Emission limits for incineration of waste (Appendix 4 to Regulation 415/2012 Coll., Section I, Article 2.3)
Hg metals	0.00027 mg/Nm^3	0.05 mg/Nm^3	
Cd metals	0.00061 mg/Nm^3	Σ0.05 mg/Nm^3	
Tl metals	0.00046 mg/Nm^3		
PAH	0.000023 mg/Nm^3	1 mg/Nm^3	Emission limit (EU)

Using pyrolysis it is possible to dispose of municipal and other types of waste without the formation of hazardous emission products. This way, it is not possible to invest and build cost-intensive multi-stage flue gas treatment systems to collect hazardous pollutants.

For a long time, the pyrolysis and gasification of coal are considered to be very promising also in the field of energy recovery from waste. Although research in this area is quite wide and technological development is well advanced, neither of these technologies is still established in the waste area so that the future operator could get it complete, as we say "turnkey". This is currently a big problem, because there is nothing in this field in the Czech Republic the entrepreneurs could equipped with the intended operations for treatment of waste (municipal waste, tires) that they would like to operate as a plant for waste energy recovery.

It shows that promising are the batch pyrolysis facilities. In the neighbouring countries, e.g. Poland, a batch pyrolysis facility by the Chinese company Shangqiu Jinpeng Industrial Co., Ltd. [8] is well-established. This company offers both continuous and discontinuous (batch type) pyrolysis plant. The facilities can recycle and utilize waste plastics, waste rubber, tires, waste engine oil, and municipal waste. According to the actual situation in every country and district, it was developed by company Shangqiu Jinpeng Industrial Co., Ltd. series of machine for disposing scrap tyre and plastics that includes 4 tons, 6 tons, 8 and 10 tons (at most about 30 tons per batch) of different capacity. Unfortunately, emission values measured on this pyrolysis equipment by an accredited laboratory are not available.

Another plant is the one from the Hedviga Group plc (Czech Republic) with a trade name PTR (= engl. STD – slow thermal decomposition), which is able to use both waste rubber materials, tires and municipal waste, and a variety of other waste (sewage sludge, waste oil, plastics, biomass) [9]. Pyrolysis plant PTR 1000 (Hedviga Group plc) is connected with the cogeneration unit Cento T 160-200 (manufacturer Tedom plc, Czech Republic) [10].

Results - Emission Values of Flue Gases from Pyrolysis Plant

The purpose of the measurement of emissions was to use accredited and authorised emissions measurement methods and procedures to determine output concentrations and mass flows for contaminants specified below in waste gas at the output of cogeneration unit Tedom Cento T 180 during combustion of pyrolysis (synthetic) gas produced at the PTR unit.

The PTR 1000 facility has been designed for pyrolysis of municipal waste free of the biodegradable component and inert material, rubber pulp from recycled tires, and other materials. Fuel dosage is discontinuous, i.e. batch-based. In addition to other products, pyrolysis gas is produced from the fuel inside the reactor. The gas is then cooled down, purified and captured in a gas pressure reservoir. The stored gas is brought to a vacuum reservoir through a reducing valve, where from it is taken further and combusted in the cogeneration unit Tedom Cento T 180 kWe. The waste gas (combustion products) is discharged into the surrounding air through a damper and a flue with an output above the roof of the hall. Cogeneration unit is equipped with a catalyst at the waste gas output.

The measurement was performed as authorised measurement for the purposes of Act No. 201/2012 Coll. on air protection, in the scope of Decree No. 415/2012 Coll. of the Ministry of the Environment.

The measurement was performed in the scope below [11]:

- Air-conditioning parameters were determined,
- Concentrations of solid contaminating substances were determined,
- Concentrations of oxygen and carbon dioxide (O_2, CO_2) were determined,
- Concentrations of gaseous contaminating substances were determined,
- Results were evaluated and the report was prepared.

The Energy Research Centre at VSB – Technical University of Ostrava measured emissions (certificates of accredited tests No. 03/13 and No. 06/13 of 18th February 2013 – pyrolysis of municipal waste free of the biodegradable component and inert material [11]) in the premises of company Hedviga Group plc in the Czech Republic on 23rd January 2013 using facility PTR 1000 combined with a cogeneration unit Tedom Cento T 180. Table 1 gives an extract of the taken emission values for the cogeneration unit (pyrolysis of municipal waste free of the biodegradable component and inert material).

Discussion

The values in Table 1 imply that the overwhelming majority of the taken emission values of pollutants comply with the set specific limits. In accordance with Article 2.3, Section I, Appendix 4 to Regulation 415/2012 Coll. (Czech Republic), the specific emission limits (for PCDD/F, Hg, Cd, and Tl) are fully complies with; in case of Cd, Tl, Hg and PCDD/F they are two orders of magnitude lower. In line with Article 2, Section II, Appendix 2 to the Regulation (i.e. the EL for NOx and CO), the emission limits fall behind 1.6 times (CO) to 1.8 times (NOx). The remaining pollutant limits for which the Appendix 4, Article 1.6 of Act 201/2012 Coll., on the protection of air, prescribes continuous measurements of emissions (the EL for PM, TOC, chlorine as HCl, fluorine as HF, and SO_2) are met in the majority of cases with reserve for the emissions limits for thermal processing of waste according to Section I, Article 1, Table 1.1 of Appendix 4 to Regulation 415/2012 Coll. For example, the measured emissions of HCl are 58.8 times lower than the set emission limit, the emissions of HF are 11.1 times lower than the EL, and the emissions of PM are 9.5 times lower than the EL. The emission limit (meant for the thermal processing of waste) will be exceeded for SO_2 and TOC [13].

Considering the above mentioned facts the facility under assessment may be used in practice as higher emissions values were measured only in SO_2 and in TOC (pyrolysis of municipal waste free of the biodegradable component and inert material). For such substances it is the relevant regional authority that may stipulate higher specific emission limits in a source operation permit. This solution is viable as it is not the case of waste incineration plants, but stationary sources thermally processing waste, other than waste incinerators, cement kilns and stationary combustion sources (in line with Article 2.3, Section I, Appendix 4 to Regulation 415/2012 Coll.), where mostly emissions of PCDD/F, Hg, Cd, and Tl, are observed. In the given case, the emissions are fully complied with and they range in very low values (see Table 1). In other pollutants the set specific limits of general emission limits, the values of which are high, need not be used.

Conclusions

Currently, we get only about 3.6 million GJ of energy at the average calorific value of mixed municipal waste (MMW) of about 10 MJ/kg [14] and the actual annual burning about 360 thousand tonnes of MMW. According to well-known balances and overviews of the current waste management and following the strategy of development of waste management, it is stated that in 2020 it will be necessary to operate the plants for energy waste recovery with a total annual processing capacity of 3.2 million tonnes of MMW. With an average calorific value of mixed municipal waste, we obtain at least 32 million GJ of energy (potential energy) per year through the energy recovery of that amount of waste.

The capacity of three municipal waste incinerators in our country is about 600 thousand tonnes of waste (MMW) per year. The use of selected and modified municipal waste in cement plants through the gasification and in biogas stations is about 350 thousand tonnes per year.

Thus, from 2 million tonnes, 600 thousand tonnes can be processed in existing incinerators, in the three planned incinerators another 400 thousand tonnes, and in other energy waste recovery plants, 350 thousand tonnes of municipal waste. To the year 2025, about 1,850 thousand tonnes of mixed municipal waste still remains, which we will not be able to put on landfills.

It should be noted that the waste energy recovery saves e.g. an equivalent of the brown coal volume, which would otherwise have to be extracted and consumed in power plants and heating plants. It should also be pointed out that no matter how well cleaned flue gases from power plant processes are, their quality is incomparable with that of treated flue gases from waste energy recovery processes. The above facts should be taken into account in drafting the energy policy in the Czech Republic for the next period.

The above mentioned implies that it is desirable for the Czech Republic to support and develop the recovery of energy via thermal disposal of municipal and of other types of waste using all possible forms of disposal, i.e. incineration of waste in the conventional incinerators of waste in grate boilers equipped with advanced systems for collection of pollutants, using gasification and pyrolysis.

Using pyrolysis it is possible to dispose of municipal and other types of waste without the formation of hazardous products (see Table 1 above). This way, it is not possible to invest and build cost-intensive multi-stage flue gas treatment systems to collect hazardous pollutants, similarly to the combustion of municipal waste in conventional incinerators with grate boilers. Nevertheless, it is rather sad that during the implementation of new pyrolysis facilities for energy recovery from waste, investors in the Czech Republic face low willingness on the part of the relevant authorities within the permission granting procedures (EIA, land-use planning procedures, building permits) and cannot mostly implement their project plans.

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Odzysk energetyczny odpadów komunalnych

W artykule podsumowano możliwości odzysku energii z odpadów komunalnych i innych rodzajów odpadów. Opisano rozwój technologii spalania i odzysku energii z odpadów komunalnych w Czechosłowacji, a następnie w Czechach. Zwrócono uwagę na trzy obecnie eksploatowane instalacje do odzysku energii z odpadów komunalnych działające w Republice Czeskiej (ZEVO Malešice, SAKO Brno, TERMIZO Liberec i ZEVO Chotíkov). Przedstawiono charakterystykę planowanych instalacji do odzysku energii z odpadów komunalnych w Republice Czeskiej. Wszystkie zakłady działają zasadniczo w oparciu o kotły rusztowe z oczyszczaniem spalin na najwyższym poziomie technicznym. W artykule przedstawiono również inne technologie, które mogą być wykorzystane do odzysku energii z odpadów komunalnych – instalacje do zgazowania i pirolizy. Ostatnia część artkułu poświęcona jest analizie poziomu emisji gazów spalinowych z instalacji do pirolizy.

Słowa kluczowe: odpady komunalne, zużycie energii, spalarnie, oczyszczanie spalin, zgazowanie, pyroliza, emisja