Environmental impact of emissions from incineration plants in comparison to typical heating systems

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Abstract In recent years, five modern municipal waste incineration plants have been built in Poland. Next ones are being constructed and at the same time building of several others is being considered. Despite positive experience with the operation of the existing installations, each project of building a new incinerator raises a lot of emotions and social protests. The main argument against construction of an incineration plant is the emission of pollutants. The work compares emissions from municipal waste incineration plants with those from typical heating plants: in the first part, for comparison large heating plants equipped with pulverized coal-fired boilers (OP-140), stoker-fired boilers (three OR-32 boilers) or gas blocks with heat output of about 100 MW have been selected, while the second part compares WR-10 and WR-25 stoker-fired boilers most popular in our heating industry with thermal treatment systems for municipal waste or refuse-derived-fuel (RDF) with similar heat output. Both absolute emission and impact - immission of pollutants in vicinity of the plant were analyzed.

1 Introduction

Among all waste generated in Poland the biggest problem is the municipal waste. Due to the complex and unstable composition its processing is a huge problem. According to the Central Statistical Office, the total amount of produced waste is about 10-12 million Mg a year [1]. Out of many municipal waste management methods the most effective is thermal treatment. In many EU countries incineration accounts for up to 60% of the methods used, but in Poland this level does not exceed 10% [2]. In recent years, five modern municipal waste incineration plants have been built (Białystok, Bydgoszcz, Konin, Kraków, Poznań), the next one in Szczecin will start at the end of this year. Adding to that the existing incineration plant in Warsaw, which has been operating since 2001, the capacity of Polish incineration plants is approximately 1 million Mg of waste per year [3].

The currently functioning model of waste management is based on the regional waste treatment facilities (so called Waste-to-Energy Plants - WtEs), which are mechanical-biological waste treatment installations (MBTs). In recent years, more than 150 such installations have been built with a capacity of nearly 11 million Mg, generating 2.5 to 3.5 million Mg of combustible fractions, called alternative fuels, refuse-derived-fuel - RDF or pre-RDF. It is important that since January 1, 2016, an alternative fuel fraction, due to its high calorific value, cannot be deposited [4]. This fraction can and should be incinerated in

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waste incineration plants and co-incineration plants, in cement plants or used in heat or power plants. In the last case, these installations, due the rigorous emission regulations, must be equipped in sophisticated flue gas treatment system and this is a serious financial problem [5].

Any new proposal to build an installation for thermal treatment of municipal waste and RDF fractions is subject to numerous protests. The most important argument against construction is the emission of pollutants. However, in accordance with the requirements of the Environmental Protection Act, the operation of the installation should not cause exceedance of emission standards that are very stringent in the case of waste incineration and environmental quality standards. Therefore the legislation guarantees a low environmental impact [6].

It was decided to analyze the absolute amount of pollutant emissions as well as the amount of pollutants emitted in vicinity of the waste incineration plants as compared to similar emissions from heating plants that are common in our country. In the analyzed heating plants (heat and power plants) there are both stoker-fired boilers as well as pulverized coal-fired boilers and relatively rarely used gas blocks. The first part of the work focused on the comparison of commonly used boilers fired with hard coal (pulverized coal-fired boilers OP-140, and stoker-fired boilers OR-32) and gas blocks with an installation for thermal treatment of municipal waste and RDF fraction of similar heat output. In the second part, calculations for WR-10 and WR-25 stoker-fired boilers are compared with the systems for thermal treatment of RDF or pre-RDF fractions.

2 Research methods

2.1 Assumptions for calculations

Two cases were investigated: the first is a comparison of the emissions of OP-140 pulverized coal-fired boilers (the smallest currently produced) commonly used in power plants, OR-32 stoker-fired boilers and gas blocks of similar total heat output, with the emissions from thermal waste treatment facility - (Waste-to-Energy - WtE) - a classical incineration plant and thermal waste treatment installation fired with alternative RDF fuel (WtE-RDF). For comparison, power plants operating in high-efficiency cogeneration - like in incineration plants, were selected. In the second case, a comparison was made between emissions from WR-10 and WR-25 stoker-fired boilers common in the Polish heating industry (respectively 30% and 10% of all heating boilers in Poland [7]) and the thermal Refuse Derived Fuel - RDF treatment installations with similar heat output. This is important because in the light of not yet implemented in the Polish law but the existing directive on medium combustion plants (MCPs) the present WR type boilers do not have any chance of meeting the requirements of this directive [8] and will have to be replaced by new installations [9].

In the first part of the calculations, a nominal heat output of the boiler equal to 105 MW_t was assumed. This value results from the capacity of one of the smallest pulverized coal-fired boilers produced and used in Poland, i.e. OP-140. This variant was compared with a stoker-fired boiler also fired with hard coal - in this case the assumed heat output can be provided by three OR-32 boilers. It was assumed that the analyzed boiler should be a steam boiler so that by analogy to the waste incinerator it would work in cogeneration. As a third variant to compare, a gas boiler also of output 105 MW_t was selected. Total capacity of the boiler in the case of waste incineration plant also remained at the same level. At the assumed heating value of mixed municipal waste at an average level of about 7.5 MJ/kg, this means the incineration plant capacity of 440,000 Mg/year, i.e. twice as large as the largest Polish incineration plant for mixed municipal waste in Cracow with a capacity of 220,000 mg/year. In addition, the RDF incineration plant has been analyzed, assuming that it will incinerate approximately 235,000 Mg of RDF per year with a net calorific value of 14 MJ/kg and will have a nominal heat output of 105 MW_t.

The basic characteristics of the installation for the five variants analyzed are presented in Table 1.

Table 1. Basic characteristics of the installation for five variants analyzed in first comparison.

Boiler	Unit	OP-140	3 x OR-32	Gas block	WtE	WtE-RDF
Heat output	MW_t	105.0	105.0	105.0	105.1	105.0
Efficiency	%	90	85	92	86	86
Flue gas temperature	°C	130	140	160	120	120
Fuel net calorific value	MJ/kg *) MJ/m^3	21.0	23.0	34.5*)	7.5	14.0

The second part analyzes pollutant emissions from some of the WR-10 and WR-25 stoker-fired boilers most frequently used in the Polish heating industry. Heat output of the WR-25 boiler is about 30 MW_t and, as in the previous case, the efficiency of the RDF thermal treatment system has been adjusted to the same level. With an assumed net calorific value of RDF equal to about 14.0 MJ/kg, this means a capacity of 67,500 Mg/year. In the case of the WR-10 boiler, the nominal heat output is about 12 MW_t which, at the calorific value of RDF, results in capacity of about 27,000 Mg/year. The calorific value of coal in both cases was assumed to be 21 MJ/kg. The characteristics of individual boilers are shown in Table 2.

Table 2. Basic installation characteristics of WR-10 and WR-25 boilers compared to the corresponding WtE-RDF plants in second comparison.

Boiler	Unit	WR-25	WtE-RDF	WR-10	WtE-RDF
Heat output	MW_t	30.0	30.1	12.0	10.0
Efficiency	%	84	86	82	86
Flue gas temperature	°C	130	4120	130	120
Fuel net calorific value	MJ/kg	21.0	14.0	21.0	14.0

2.2 Maximum and average annual fuel consumption

Then, based on the data in Table 1 and 2 (for both variants), the maximum instantaneous fuel consumption and the average annual fuel consumption was calculated. Next, using the Recknagel relationships [10] the maximum flue gas flow rate was calculated for the operating conditions of the system and converted into assumed conditions (temperature: 273 K, pressure: 1013 hPa, dry gas, assumed oxygen content in the exhaust gas: 3% for the gas block, 6% for coal-fired boilers and 11% for waste incineration plants in both variants).

Results of these calculations are given in Tables 3 and 4. The values of excess air ratio (oxygen concentration in the flue gas) and the flue gas humidity were based on the data obtained from potential installation suppliers.

Table 3. The most important operating parameters of the system for five variants analyzed.

Boiler	Unit	OP-140	3 x OR-32	Gas block	WtE	WtE-RDF
Maximum fuel consumption	Mg/h *) m^3/h	20.0	19.3	11 909*)	58.7	31.4
Annual fuel consumption	Mg/year *) m^3/year	150 000	145 013	89 319 47 1*)	440 003	235 500
Excess air ratio	-	1.3	1.6	1.1	2.3	2.3
Oxygen concen-tration in flue gas	%	4.51	7.50	1.74	10.10	10.95
Flue gas humidity	%	7.5	5.5	6	16	16
Flue gas flow rate	m^3/h	229 409	296 945	198 448	526 976	436 391
	m^3_u/h	158 042	166 937	125 825	335 303	252 744

Table 4. The most important operating parameters for WR-10 and WR-25 boilers as compared to the corresponding WtE-RDF.

Boiler	Unit	WR-25	WtE-RDF	WR-10	WtE-RDF
Maximum fuel consumption	Mg/h	6.1	9.0	2.5	3.6
Annual fuel consumption	Mg/year	45 918	67 500	18 815	27 000
Excess air ratio	-	1.3	2.3	1.3	2.3
Oxygen concentration in flue gas	%	4.51	10.95	4.51	10.95
Flue gas humidity	%	7.5	17	7.5	17
Flue gas flow rate	m^3/h	70 227	125 080	28 776	50 032
	m^3_u/h	48 380	48 295	29 736	28 977

2.3 Calculation of maximum emission

For the two analyzed cases, a maximum variant was assumed for the calculations, which means that it was assumed that for the maximum instantaneous fuel consumption there was a maximum flue gas flow rate and maximum emission limit values, i.e. not exceeding emission standards (emission standards given in Table 5 according to the Ordinance of the Minister of the Environment on emission standards for certain types of installations, sources of fuel combustion and incineration or co-incineration equipment [11] which adopted the regulations of IED [12]. A total of 7,500 hours of operation per year identical for all analyzed variants was assumed.

Table 5. Applicable emission standards for the analyzed variants.

Boiler	Unit	OP-140	3 x OR-32	Gas block	WtE	WtE-RDF	WR-10	WR-25
SO_2	mg/m^3_u	250	1300	35	50	50	1300	1300
NO_x	mg/m^3_u	200	400	200	200	200	400	400
TSP (Total suspended particles)	mg/m^3_u	25	100	5	10	10	100	100

For these assumed maximum values, in the next part of the calculations, the maximum emission of the three main pollutants from the combustion process, i.e. sulfur dioxide (SO_2), nitrogen oxides (NO_x) converted to nitrogen dioxide, and both instantaneous and annual particulate matter emissions were estimated. Results of these calculations are compiled for the first and second analyzed case, for all variants, in Tables 6 and 7, respectively.

Table 6. Maximum and annual emissions for five variants of the first case.

Boiler	Unit	OP-140	3 x OR-32	Gas block	WtE	WtE-RDF
SO_2	kg/h	39.51	217.02	5.28	16.77	12.64
NO_x	kg/h	31.61	66.77	30.20	67.06	50.55
TSP	kg/h	3.95	16.69	0.75	3.35	2.53
SO_2	kg/year	296 328	1 627 633	39 635	125 739	94 779
NO_x	kg/year	237 063	500 810	226 485	502 955	379 116
TSP	kg/year	29 633	125 203	5 662	25 148	18 956

Table 7. Maximum and annual emissions for WR-10 and WR-25 boilers compared to the corresponding WtE-RDF.

Boiler	Unit	WR-25	WtE-RDF	WR-10	WtE-RDF
SO_2	kg/h	62.89	2.41	38.66	1.45
NO_x	kg/h	19.35	9.66	11.89	5.80
TSP	kg/h	4.84	0.48	2.97	0.29
SO_2	kg/year	471 706	18 111	289 927	10 866
NO_x	kg/year	145 140	72 443	89 208	43 466
TSP	kg/year	36 285	3 622	22 302	2 173

2.4 Calculations of pollutant immissions

According to the Environmental Protection Act in force in Poland, the emission of pollutants from the installation should not only meet the emission standards (if any), but also the emissions should not exceed environmental quality standards (i.e. in this case the permissible concentrations of pollutants in the atmospheric air - reference values). Therefore, in addition to the comparison of the emissions from the thermal waste treatment system with the emissions from heating installations pollutant immisions from the analyzed installations were also compared.

In the first part pollutant immissions from the OP-140 pulverized coal-fired boilers, three OR-32 stoker-fired boilers and gas block of a similar total heat output (about 105 MW_t) were compared with immissions from the thermal waste treatment facility (WtE) - a classical incineration plant and thermal waste treatment facility fired with alternative RDF fuel (WtE-RDF).

The second part analyzes immissions of pollutants from one of the WR-10 and WR-25 stoker-fired boilers in comparison with the thermal RDF treatment facility of similar heat output.

Calculations of immission pollutants were made using the Polish methodology given in the regulation of the Minister of Environment on reference values for some substances in the air, based on Pasquill atmospheric diffusion model [13,14]. Emissions of sulfur dioxide, nitrogen oxides and particulate matter given in Tables 6 and 7 as well as flue gas parameters given in Tables 3 and 4 were taken for calculations.

In order to maintain identical conditions of pollutant diffusion in the atmosphere, the emitter height was assumed to be 60 m and its diameter was chosen to be about 20 m/s. This gave a diameter of 1.9 m for the gas block, 2.0 m for the OP-140 boiler, 2.3 m for three OR-32 boilers, 2.8 m for the RDF incinerator and 3.1 m for the mixed municipal waste incineration plant. In the second case an emitter of 50 m was adopted. As in the previous example, the diameter of the emitter was different: for the WR-10 boiler it was 1.2 m, and for the corresponding RDF boiler with heat output of about 12 MW_t - 1.6 m, while for the WR-25 boiler - 1.8 m and 2.4 m for the corresponding RDF boiler with heat output of about 30 MW_t. That gave the same outlet velocity for both cases compared - about 7.7 m/s for the WR-25 boiler and about 7 m/s for the WR-10. Results of the modeling of spread of pollutants in the form of calculated concentrations in one-hour and average annual immissions are presented in Tables 8 to 11.

Table 8. Maximum calculated one-hour concentrations in the immission within the range of an emitter for five variants analyzed.

Pollutant	Unit	OP-140	3 x OR-32	Gas block	WtE	WtE-RDF	Permissible value
SO_2	μg/m³	62.041	269.368	8.288	13.835	12.236	350
NO_x	μg/m³	49.636	82.876	47.404	55.324	48.933	200
PM10	μg/m³	3.101	10.358	0.589	1.382	1.225	280

Table 9. Maximum calculated average annual concentrations in the immission within the range of an emitter for five variants analyzed.

Pollutant	Unit	OP-140	3 x OR-32	Gas block	WtE	WtE-RDF	Permissible value
SO_2	μg/m³	1.924	8.492	0.257	0.437	0.392	20
NO_x	μg/m³	1.539	2.613	1.470	1.747	1.576	40
PM10	μg/m³	0.096	0.327	0.018	0.044	0.039	40
Dust precipitation	g/m² year	2.574	9.067	0.489	1.250	1.107	200

Table 10. Maximum calculated one-hour concentrations in the immissions within the range of an emitter for WR-10 and WR-25 boilers compared to the corresponding TWTF-RDF.

Pollutant	Unit	WR-25	WtE-RDF	WR-10	WtE-RDF	Permissible value
SO_2	μg/m³	354.119	20.738	319.180	12.655	350
NO_x	μg/m³	108.955	83.123	98.165	50.618	200
PM10	μg/m³	13.626	2.065	12.260	1.265	280

Table 11. Maximum calculated average annual concentrations in the immissions within the range of an emitter for WR-10 and WR-25 boilers compared to the corresponding TWTF-RDF.

Pollutant	Unit	WR-25	WtE-RDF	WR-10	WtE-RDF	Permissible value
SO_2	μg/m³	11.216	0.575	8.942	0.349	20
NO_x	μg/m³	3.482	3.304	2.750	1.398	40
PM10	μg/m³	0.435	0.057	0.343	0.035	40
Dust precipitation	g/m² year	13.276	1.595	9.650	0.972	200

At the same time, when analyzing the data in Tables 5 to 8, one can see that in most cases the pollutant emissions do not exceed air quality standards (permissible one-hour concentrations and permissible average annual concentrations) as required by article 144 of the Law on Environmental Protection [15].

As can be easily observed, most pollutants (both SO_2 and NO_x, as well as particulate matter) emitted to the atmosphere are generated by stoker-fired boilers. This is due to the relatively liberal emission standards for the existing sources of heat output below 50 MW_t. The smallest amount of pollutants is emitted to the air by gas blocks. A comparison of emissions of sulfur dioxide and particulate matter from waste incineration plants (both mixed and RDF) with the emissions from coal-fired heat plants (equipped with both pulverized coal- and stoker-fired boilers) is far better in favor of the waste incineration plants. Only in the case of emissions of nitrogen oxides, the emissions from the incineration plant are comparable to the emissions from the stoker-fired boilers. The other boiler rooms (with pulverized coal-fired boilers and gas block) are better. This is due to the relatively low calorific value of both mixed municipal waste (7.5 MJ/kg) and RDF (14 MJ/kg), and therefore the need to burn much more fuel which results in significant flue gas emissions with identical emission standards applicable to all installations, i.e. 200 mg/m^3_u.

3 Results

Pollutant emissions for both analyzed cases are compared in Tables 6 and 7. Similarly, the results of calculations of the spread of pollutants from the analyzed sources in the form of calculated pollutant concentrations in imission are summarized in Tables 8 to 11.

4 Conclusions

The calculations show that most of the pollutants are generated by coal-fired stoker-boilers and least by gas blocks, while the emission from pulverized coal-fired boilers is slightly lower than the emission from stoker-fired boilers, because other emission standards are decisive in this case. It is worth noting that emissions from the waste thermal treatment plant (both mixed and RDF) are slightly higher than those from the gas block. The comparison of emissions of pollutants from particular coal-fired boilers commonly used in Polish heating industry is far worse than that of incineration plants for municipal waste (mixed and RDF).

It is therefore safe to say that despite many protests and public reluctance to build a Municipal Waste Thermal Treatment Plant (Waste-to-Eneregy - WtE) or WtE-RDF facilities, they are a significantly smaller source of environmental pollution than the well-known and widely accepted coal-fired heating systems.

In conclusion, this work was aimed at comparing the impact of emissions from boilers commonly used in the heating sector with the municipal waste incineration plant (both mixed and RDF). From the presented results it can be clearly seen that thermal treatment of municipal waste and WtE-RDF has no significant environmental impact. This method is generally used as an indispensable part of the municipal waste management system, proven and functioning in the most industrialized countries not only of the European Union [2].

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