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Balances of contaminants in flue gas from municipal waste incineration plant

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Due to current increased interest in the environment protection, the issue of waste treatment has to be solved. Those wastes that cannot be immediately materially used can be treated in many different ways, from landfilling up to thermal decomposition processes. Although landfilling can seem as the most favourable way at the first sight, it is connected with accumulation, pollution of the surroundings and the ground water, prevalence of infections etc. The thermal decomposition processes are necessary not only because of detoxification, but also because of prevention of excessive load of the environment. At the same time, the wastes are becoming a secondary energy source.
Yet, the thermal ways also have their difficulties, namely emissions to the air, residual wastes and water pollution. The emissions to the air represent pollutants in the flue gas that are produced during the incineration process and have harmful or even toxic properties. The residual wastes are products that are produced by incineration, namely cinder, ash and fly ash.
The incineration plants have a number of technologic equipment serving to flue gas cleaning that use various physical chemical technologic procedures and devices to reach the required cleaning effect (BAT, 2006). To capture gaseous compounds with acidic nature (SO_2, HCl and HF) the methods of dry, half-dry and wet cleaning of flue gas are used.
The results of technical measurement that should have gained data needed from particular key technologies in the incineration plant to create an overall balance of solid pollutants, particularly heavy metals are be presented in this paper.

1. Introduction

A technical measurement that had to gain the data needed from particular key technologies in the incineration plant to create an overall balance of solid pollutants, particularly heavy metals, was carried out in the municipal waste incineration plant. For this purpose, the particular measure points were chosen so that the efficiency of elimination the given compounds in particular devices of the technologic line on the heat utilization and flue gas cleaning rout could be determined.
During thermal elimination of both municipal and hazardous wastes, a number of pollutants is produced. The pollutants are contained in the processed waste; they leave the incineration process in the elementary form, or they are present in the incineration products in the form of oxides, sulphates, and carbonates etc. or they are constituted during processes that take place during incineration. A great part of metals and their oxidizing compounds are in the shape of solid residuals separated in discharger chamber. A particular part of the heavy metals compounds is in the shape of fly ash or steam carried away by the flue gas steam.

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The composition of the fly ash carried away by the flue gas depends on the type of the processed waste. The heavy metals monitored in this study are As, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Sb, Tl, V, Zn. From Figure 1 it is obvious that in the monitored spectrum of metals more than 42 % was Pb. Both the Czech (Czech Government Regulation, 2002) and the EU (Directive, 2000) legislation require evaluation of content of this element. The flue gas contain approximately 0.44 % of weight of mercury that is though considered a hazardous contaminant form the healthcare point of view. The measures ensuring environment protection strictly require minimization of emissions of all these elements.

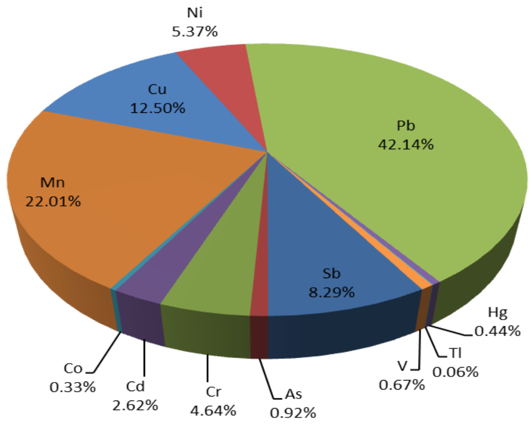


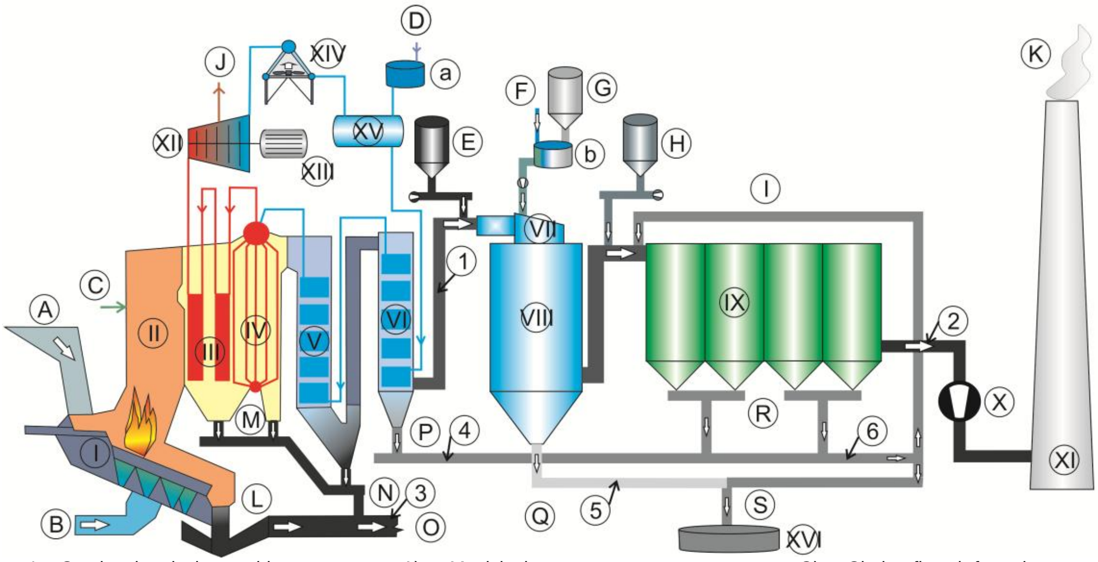
Figure 1: The share of particular elements in the fly ash drifted by flue gas from combustion chamber in the evaluated case

2. Operational Conditions of the Measurement

The measurement was carried out in a municipal waste incineration plant. A scheme of this plant is pictured in Figure 2. In the incineration plant the thermal disposal of mixed municipal waste (MMW) with average processing output of 13.7 t/h MMW (average value in first 5 months of 2011).

The heat content of the flue gas leaving the combustion chamber is in the utilization boiler used for production of steam with a pressure of 4.0 MPa and temperature of 400 °C and for the subsequent generation power in the bleeder steam turbine. This turbine enables a regulated offtake of steam at 220 °C and 1.0 MPa into the CHS system (central heat supply) in Brno agglomeration. The maximal electric output that the turbine can produce is 22.4 MW when combusting 28 t of waste/h and at calorific value of 8 – 13 MJ/kg. The steam boiler has a five-pass conception with two drums and a bundle of evaporators in the third pass and a two-stage economizer with the second stage placed outside of the boiler installation. In the utilization boiler, a significant share of the fly ash is separated. Other mechanical cleaning of flue gas from the drifts of fine fly ash takes place in economizers.

Flue gas cleaning is based on the principal of half-dry calcic method complemented by the possibility of dosing a dry calcic hydrate into the flue gas stream before the fabric filters. These methods ensure elimination of substances with acidic nature (e.g. HCl, HF, SO_2, SO_3) from the flue gas. The dry calcic hydrate is dosed only in case of increased concentration of acidic pollutants. The polychlorinated dibenzo-p-dioxins and furans (PCDD/F) and heavy metals are adsorbed on the surface of the active coal that is pressure-blasted into the flue gas stream in front of the reactor. The solid pollutants that leave the boiler and reaction products (active coal and lime cream or dry limestone) from the flue gas cleaning system are collected on fabric filters. On the load-bearing layers of the fabric filters, the last chemical reactions take place. A part of these products returns as a recycling product in front of the fabric filters to ensure maximal utilization of input materials. The final product of the flue gas cleaning is a mixture of fly ash and calcic products enriched with active coal.



I. Combustion device – grid
II. Combustion chamber
III. Steam superheater
IV. Steam boiler
V. Economizer 1
VI. Economizer 2
VII. Rotary atomizer
VIII. Absorption reactor
IX. Fabric filter
X. Fan
XI. Stack
XII. Steam turbine
XIII. Generator
XIV. Air condenser
XV. Feed tank
XVI. End-product bin

A) Municipal waste
B) Combustion air
C) Urea (deNO$_x$)
D) Demineralized water
E) Active coal
F) Water
G) Calcium oxide (burned lime)
H) Calcium hydrate $Ca(OH)_2$
I) Recirculation of the powdery reaction product
J) Heat into the central heat supply system
K) Cleaned flue gas
L) Cinder
M) Fly ash from the steam boiler
N) Fly ash from the economizer 1
O) Cinder, fly ash from the steam boiler and economizer 1
P) Fly ash from the economizer 2
Q) Reaction product from the absorption reactor
R) Reaction product from the fabric filter
S) Reaction product for storing

a) Demineralized water tank
b) Lime slurry tank

1- 6 measure points

Figure 2: Description of flows a measure points in the incineration plant

On Figure 2 the particular entering and leaving streams are described and also the direction of the streams' flow is pictured. The measure points for monitoring distribution of heavy metals are marked with numbers 1 – 6.

Unfortunately, it is not possible (from the construction point of view) to measure pollutants in flue gas in all the needed places. Authorized measure group carried out measuring in particular points and the results of the measuring are stated in technical protocol (Březina, 2012). The range of measurement in particular measure points is presented in Table 1.

Table 1: Collection points with description of particular types of measurement

Collection point	Description of the point	Sample	Measured quantities
1	In front of the absorber	Flue gas	O_2, SO_2, NO_x, CO, SP, HM, HCl, HF
2	Behind the filter	Flue gas	O_2, SO_2, NO_x, CO, SP, HM, HCl, HF
3	Cinder and fly ash from the first stage of the economizer	Cinder, fly ash	HM
4	Fly ash from the second stage of the economizer	Fly ash	HM
5	product from the absorption reactor	reaction product	HM
6	Fly ash from the second economizer and residual product from the filtration device	Fly ash, reaction product	HM

On the basis of the incineration plant structure and the possibility of sampling was the incineration plant divided to two computation circuits, as pictured on figure 3.

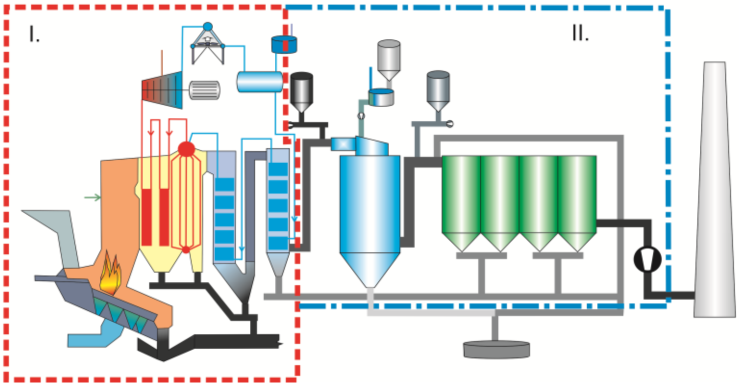


Figure 3: Division of the incineration plant to computation circuits

In the first circuit, the mass flows of the entering waste and leaving flue gas, cinder with fly ash and the fly ash from the second economizer are balanced. Determination of the heavy metals (HM) in mixed municipal waste was computed on the basis of material balance of this nod. For the purposes of computation, the processing output was considered 13.7 t/h of the municipal mixed waste and production of 3217 kg/h of dry cinder and fly ash. The amount of fly ash from the second stage was determined on the basis of the second circuit balance.

In the second circuit, the solid pollutants (SP) mass flows in the flue gas leaving the boiler, fly ash from the second stage of economizer, reaction agents (lime cream, active coal and dry calcic hydrate), cleaned flue gas, reaction product from the absorber and the final product that consists of fly ash from the second stage of economizer and the reaction product from the filter are balanced. A 80 % recycling into the flue gas stream in front of the filter is considered in case of the final product. The significant amount of the stored final product was gained again from the incineration plant operation and was determined to 434 kg/h. Based on the operational estimation was determined that the reactant from the absorber makes only 1 % of the overall amount of the final product. From the operational records of the incineration plant data about the amount of the lime dosed in the lime cream, active coal and the dry sodium hydrate were taken.

2.1 The Measurement Results

The incinerated waste contains inorganic incombustible substances that mostly enter into ash separate in discharger chamber and partly are drifted from the combustion area by flue gas in form of a fine fly ash. The ash stands for a main item in material balance, from the mass flows point of view. In a specific case, when waste containing ca. 25.5 % weight of inherent ash was incinerated, approximately 92 % weight of incombustible substances entered the cinder and ash flow separated in discharger chamber. The mass flow of solid substances drifted from the first economizer (239 kg/h) matched the observed concentration of SP in the flue gas (4322 mg/m^3_N). In the fly ash drifted by flue gas, the mass flow of heavy metals was ca. 24.3 % from the overall input amount of monitored metals. Almost 75 % of heavy metals were separated in cinder and in fly ash from the steam boiler. Unfortunately, these two flows cannot be expressed separately. Approximately 1.1 % weight of incombustible substances were intercepted in the second stage of economizer in the form of ash.

The content of some metals (Cd, Tl, Hg, etc.) is in solid residuals very low, which corresponds to operational knowledge that heavy metals enter almost quantitatively the flue gas flow drained from the combustion area. Whereas in cinder some heavy metals were almost not present, in the separated fly ash the amount of some substances (Sb, Cd, Hg etc.) increased more than ten times.

For the second computational circuit was the discovered content of heavy metals for the reactant flow from absorption reactor and the mixture of fly ash from the second stage of the economizer with reactant and fly ash from the fabric filter. The efficiency of the fabric filter to absorb fine fly ash contained in flue gas was 99.9 % and residual concentration of solid substances in cleaned flue gas was ca. 2.4 mg/m3N. The residual mass flow of solid substances in the flue gas leaving the fabric filter was approximately 0.16 kg/h.
The efficiency of elimination of most of the monitored heavy metals on the fabric filter varied between 97 – 99.9 %. An exception was mercury that was eliminated with the efficiency lower than 80 %. High efficiency of elimination of heavy metals is given by the used technology of half-dry calcic method supplemented with the possibility to dose dry hydrated lime and active coal into the flue gas flow in front of fabric filters. The half-dry method of flue gas cleaning eliminates sulphur oxide, the efficiency of elimination of SO_2 was 87 %; from the concentration of 144 mg/m^3_N behind the boiler the concentration of 18 mg/m^3_N was reached in the stack. During the whole measurement also the concentration of HCl and HF was monitored on the output of the boiler and on the entry of the stack, but because of low concentrations the complete efficiency of elimination of these substances cannot be proved.

3. Evaluation of the Results and Conclusion

In the municipal waste incineration plant an evaluation of heavy metals distribution that are monitored as pollutants in exhalations from the incineration plant (As, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Sb, Tl, V) was carried out. The particular flows of solid particles in form of cinder from the combustion chamber, fly ash from the utilization boiler and the fabric filter were monitored. The particular measure points for the analysis of flue gas composition were chosen considering the computation of the efficiency of chosen blocks of the incineration plant. Also, elimination of pollutants (SO_2, NO_x, HCl and HF) during the flue gas cleaning was evaluated. Detailed results of measured data and result of balances are stated in article (Jecha, 2012).
The results of transfer of particular heavy metals into the final products or into inter-streams are summarized in table 3. The results show that most of the heavy metals leave in form of cinder or fly ash from the boiler. However, there are also elements as mercury and cadmium that are in 85 % eliminated as late as in the flue gas cleaning area. It was confirmed that if mercury is present in the incinerated waste, filtration is not sufficient for the Hg emissions capture, because a major share of mercury goes in form of stream into the cleaning block (adsorption on active coal).

Table 3: Distribution of heavy metals into particular flows

Element	Transfer into cinder	Separated in II. Stage of economizer	Drift from II. Stage of economizer	Separated in abs. reactor	Separated in filter	Not captured (goes on into the stack)
			(% from the input amount)			
Antimony	35.84	3.84	60.32	0.11	60.19	0.03
Arsenic	58.18	2.82	39.00	0.08	38.80	0.12
Chromium	75.99	1.38	22.63	0.02	22.37	0.24
Cadmium	12.01	2.65	85.35	0.10	85.22	0.03
Cobalt	85.74	1.93	12.33	0.02	12.25	0.05
Manganese	86.51	1.74	11.75	0.02	11.70	0.03
Copper	86.72	0.80	12.49	0.02	12.06	0.40
Nickel	73.91	0.80	25.29	0.01	24.56	0.73
Lead	39.51	1.96	58.53	0.10	58.42	0.01
Mercury	14.23	0.45	85.31	0.66	67.12	17.53
Thallium	0.00	0.00	100.00	0.00	100.00	0.00
Vanadium	88.63	1.63	9.74	0.02	9.72	0.01
Heavy metals in total	74.88	1.59	23.54	0.04	23.32	0.18

The measured data are in good agreement with the values reported by Cernushi et al. (2002) and Jecha et al. (2008) that were collected in a municipal solid waste incineration plant. However. different conclusions concerning some substances were reached in the presented study. The deviations may be caused by different concentrations of monitored metals in the raw waste and by a different combustion regime.

In Figure 5 percentages of reaching current emission limits in the municipal waste incineration plant are pictured. The concentration of NO_x was closest to the emission limit. However. also in this case only 72 % of the emission limit was reached.

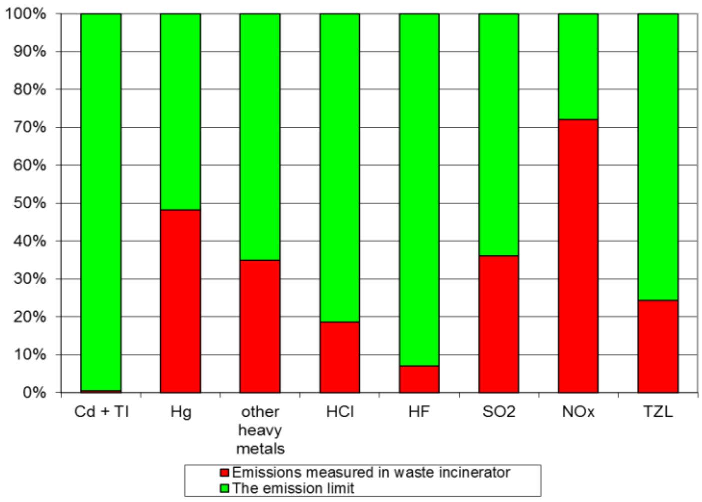


Figure 5: Comparison of concentrations of pollutants measured in the incineration plant with emission limits valid in the EU (Directive, 2000)

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References

Best Available Techniques - BAT. 2005, Seville: Edificio Expo. 638 s, Spain

Czech Government Regulation No. 354/2002

Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste, Official Journal of the European Communities, 28.12.2000

Brezina. J., 2012, Protocol on technical measurements: number: 2108/01. Technical services for air protection Brno, 19 p, Brno, Czech Republic

Jecha, D. Balance of pollutants in municipal waste incineration flue gas, In Odpadové fórum 2012, Praha, Czech Republic, 2012. p. 4 - 14. ISBN 978-80-85990-20-1.

Cernuschi S., Giuliano M., Grosso M,. Aloigi E., Miglio R., 2000, PCDD/F and trace metals mass balance in a MSW Incineration full scale plant. International Conference on Incineration & Thermal Treatment Technologies. Portland. Oregon. USA.

Jecha, D.; Dudekova, M.; Bebar, L.; Stehlik, P., 2008, Balances of contaminants in flue gas from industrial waste incineration plant, 18th International Congress of Chemical and process Engineering CHISA 2008. Praha, Process Engineering Publisher, 1492 - 1492.