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Industrial and Hazardous Waste Combustion and Energy Production

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About 8.1 % of waste incinerated in the EU was categorized as hazardous in 2008. The paper aims to assess whether the plants for combustion of industrial and hazardous waste can serve as facilities for energy production. The assessment was performed using a simulation model created in an in-house developed software W2E (Waste-to-Energy).
Internal energy consumption under different operational regimes, various lower heating values, temperatures in combustion chambers, air excess and specific flue-gas treatment systems was taken into account; their influence on the available energy production (in the form of heat and/or electricity) and its export was discussed.
It is highlighted, that two-stage combustion of industrial and hazardous waste may be associated with significant supplementary fuel consumption. The energy introduced into the combustion chamber by this fuel, usually natural gas, reduces overall positive impact.
Attainable specific production of heat and electricity and specific primary energy savings criteria were evaluated for several technological concepts of combustor design. Obtained results indicate that combustion of industrial and hazardous waste can reach "energy recovery" status under only specific operational regimes. These conditions are discussed in more details.

1. Introduction

Industrial and Hazardous Waste (IHW) is a material with a range of problematic features, e. g. toxicity, carcinogenicity, high flammability, infectivity, etc. Landfilling of this material represents particular damage of the environment. Units for combustion of IHW are preferred. An up-to-date IHW incinerator with heat recovery and efficient flue gas cleaning system is a safe and clean technology (European IPPC Bureau, 2005). It is used as an integral part of waste management across Europe. These utilities are usually able to treat waste in any state (solid, liquid, gaseous). They are built for wide range of waste throughputs. There are 19 IHW incinerators with capacities of 270 to 15000 t/y in the Czech Republic.
Pyrolysis technologies are also applied for treating of IHW. Understoichiometric amounts of oxygen are used for the furnace. Partial oxidation products combustion is usable to achieve necessary temperatures. However, these technologies are not within the scope of the article.
Unit with heat released by IHW incineration 3 MW and waste throughput 5 kt/y was chosen as a model case. The aim was to specify whether and under what conditions the processes of IHW combustion could serve as a device for energy production.

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1.1 Legislation

Hazardous waste is a waste that exhibits one or more hazardous characteristics stated in Appendix III of the 2008/98/EC Directive according to EU legislation.

Environmental regulations are very strict in this area. Used equipment has to be in accordance to the Best Available Technologies stated in Waste Incineration Reference Document (European IPPC Bureau, 2005).

2000/76/EC directive on the incineration of waste imposes strict operating conditions and technical requirements on waste incineration plants. According to this directive, if hazardous wastes with a content of more than 1 % of halogenated organic substances (expressed as chlorine) are incinerated, the temperature has to be above 1100 °C for at least two seconds after the last injection of combustion air. Temperature 850 °C is sufficient in other cases. This directive also stated air emission limit values and other requirements on the plant output flows.

1.2 Two-stage waste combustion

IHW incinerator technology arrangement corresponds to other incineration plants – it consists of thermal part (where the waste combustion and after-burning processes take place), heat recovery with steam production and flue-gas cleaning system (Figure 1). Technological layout may have a variety of modifications according to local requirements. Combustion air and feed water preheating, produced steam utilization, or the flue-gas temperatures in various parts of the plant may vary.

For IHW incineration two-stage combustion is usually used to ensure the quality of combustion processes in the thermal part. Rotary kiln is the most common equipment used in the first combustion stage. Afterburning processes in secondary combustion chamber represent the second combustion stage. Ash melting point determines operational regime and design of rotary kiln. One should avoid problematic temperature area 900 to 1000 °C, in which the ash melts. The incineration process in rotary kiln is usually designed for temperatures under the ash melting point. This fact in combination with legislative requirements (1100 °C for two seconds after the last injection of combustion air) is connected with significant additional fuel consumption. This consumption turns the process from energy recovery to disposal and it is analyzed in more details in the paper.

IHW incinerators can also produce heat and power. The heat released by waste combustion is recovered in boilers (Heat Recovery Steam Generator – HRSG). Produced steam can be used to generate electricity and/or for heating purposes. The flue-gas heat can be used directly in the process, e.g. for preheating of the combustion air. Heating of circulating hot water for local heat supply is also possible.

Flue-gas from HRSG continues to the highly efficient system of mechanical and chemical flue-gas cleaning. Various emission reduction measures are applicable for strict emission limits fulfilment.

1.3 Software W2E

The waste incineration in current equipment combines a group of energic and chemical processes. There is a variety of software tools applicable in these fields. An overview of process integration, optimization and modelling software tools can be found in (Lam et al., 2010, 2011). The W2E (Waste-to-Energy) software was used for simulation of IHW incinerator processes in this paper. The software was created in-house as a support tool in the research sector (Touš et al., 2009) and it is available online (Waste to Energy (W2E) Software, 2012).

2. Case study – computational model of IHW incinerator

Plant considered as typical representative of up-to-date technology with waste throughput of 5 kt/y was assessed. Superheated steam production for flue-gas heat recovery and two typical layouts of superheated steam utilization system were chosen for analyzing of energy production. The energy consumption of the plant was also considered.

Complex computational model was created in W2E software. Theoretical approach (energy and mass balances, thermodynamic processes) and experience from real incineration plants operation was combined in the simulation. In this way material and energy flows in main technological nodes and other important values for process analyzing were computed.

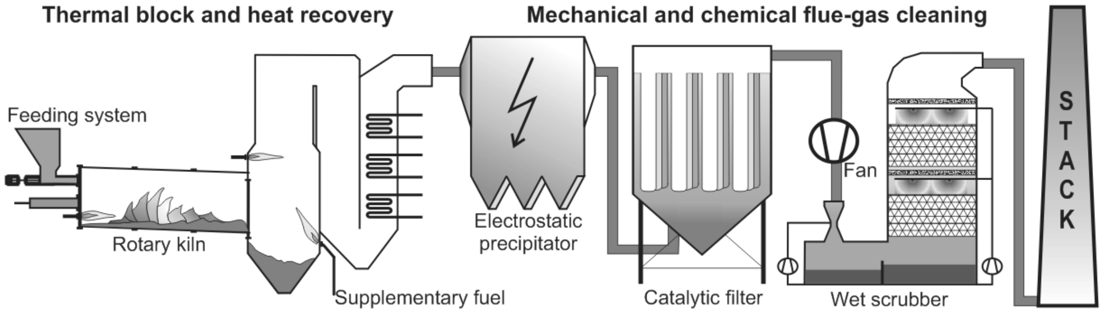

Figure 1: Basic technological layout of IHW incinerators

2.1 Model building procedure

The model building procedure is presented in simplified scheme on Figure 2. It corresponds to the above described technology. There are these main computational nodes in the model:

- Rotary kiln where stoechiometric combustion takes place. This is the first combustion stage.
- Secondary combustion chamber. Flue gas parameters are changed here due the after-combustion processes and auxiliary fuel (natural gas) combustion.
- Heat recovery steam generator (HRSG) for the production of superheated steam.
- Air preheater for heating of air for natural gas combustion in secondary combustion chamber.

Feed water pump consumption, heat losses, infiltration of atmospheric air, minimal operation of stabilization burner in rotary kiln and other additional parameters are also considered.

Two possible layouts of superheated steam utilization were analyzed. The first system uses cogeneration (combined heat and power), which enables high efficient and flexible use of energy contained in the waste. The second case is layout with condensing turbine for maximal electricity generation.

2.2 Model input data

IHW calorific value is variable for different materials. Waste chemical composition with lower heating value 15 GJ/t was chosen for the simulation. Different fuel composition with the same calorific value leads to the similar results. Waste throughput 720 kg/h and plant allowing 7000 h/a were considered, these values denote the heat released by IHW incineration 3 MW and waste throughput 5 kt/y.

Flue-gas temperatures in rotary kiln were set in the range from 600 to 1150 °C by changing overstoichiometric air rate (so-called cooling air). In the next step, auxiliary fuel (natural gas) consumption was adjusted to maintain flue-gas temperature at 1150 °C (i.e. over the legislation level) at the outlet of the secondary combustion chamber. Flue gas temperature at the output of the boiler was fixed at 250 °C and air for the auxiliary fuel combustion was preheated to 200 °C.

Produced steam is at 4 MPa and 400 °C. 50 % of steam at 700 kPa is exported for heating purposes after back-pressure turbine if cogeneration was analyzed, the rest expands in condensing turbine (Figure 3). In the second case, the whole steam production expands to 20 kPa in the condensing layout of the steam utilization.

3. Results of simulation

The results are presented in specific values related to ton of combusted IHW. Temperature mode 800 to 900 °C in rotary kiln (below the ash melting point) and 1150 °C in the secondary combustion chamber (above 1100 °C stated by legislation) was considered as common operational regime in thermal part. This temperature mode is highlighted by dotted circle in following graphs.

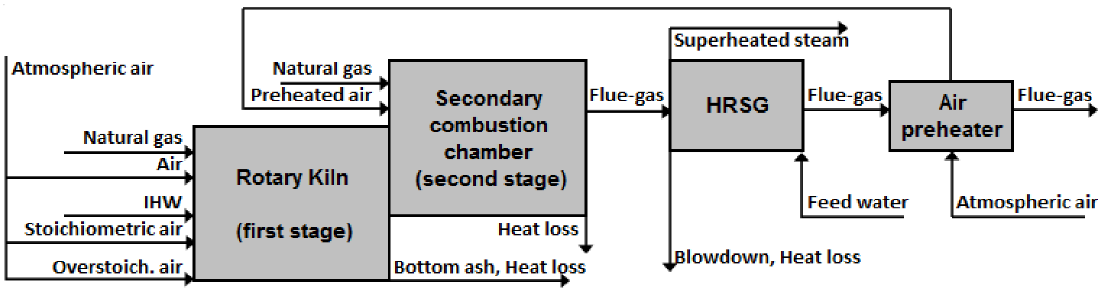

Figure 2: Simplified scheme of model computation procedure

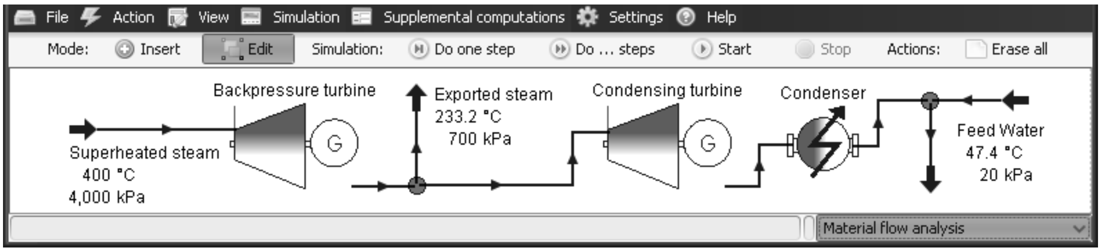

Figure 3: Cogeneration mode of superheated steam utilization system – model in W2E software

3.1 Potential for energy production and auxiliary fuel consumption

First of all, superheated steam production was analyzed. The steam contains calorific potential usable for power and heat production. As shown in Figure 4, the production increases in proportion to the temperature difference between rotary kiln (600 to 1150 °C) and secondary combustion chamber (1150 °C). This is due to higher consumption of auxiliary fuel (natural gas) for heating of flue gas above the legislative level 1100 °C. Figure 5 indicates the contribution of waste and auxiliary fuel to steam production. It is obvious, that the auxiliary fuel energy input corresponds to the heat released by IHW incineration in the common temperature mode. The auxiliary fuel input exceeds the IHW energy input in cases of lower temperature in the rotary kiln.

3.2 Available energy production

Values of specific energy production are presented in Figure 6. These are interesting especially when they are compared to the specific production of electricity at municipal waste incinerators (415 to 644 kWh/t, European IPPC Bureau, 2005). Large energy production in case of IHW combustion is achieved through the supply of auxiliary fuel, as shown in Figure 5. Specific electricity production after deducting the energy input introduced by the natural gas is only 630 to 690 kWh/t in condensing mode and 455 to 500 kWh/t in cogeneration mode.

3.3 In-house energy consumption

The plant uses several equipment with significant energy consumption; this is reflected in results of simulation. Various technological solutions are applicable for flue-gas cleaning. Layout with electrostatic precipitator, catalytic filter and wet scrubber (Figure 1) was analyzed in this paper.
The thermal part consumes at least 53 kWh/t (Hopjan, 2010) e.g. for rotary kiln driving. Depending on the temperature mode in thermal part (which determines the flue-gas flowrate), the feed water pump consumption was 7 to 23 kWh/t and the wet scrubber water pump consumption was 3.5 to 10 kWh/t.
Pressure loss of measures on flue-gas stream determines the flue-gas fan consumption. Pressure loss was estimated at 2 kPa in thermal part and HRSG, at 0.1 kPa for electrostatic precipitator, at 1.5 kPa for catalytic filtration and at 2.5 kPa for wet scrubbing. The fan power input was evaluated as a function of the overall pressure loss, fan efficiency and flue-gas flowrate. It is 25 to 70 kWh/t in dependence on the temperature mode. Depending on the temperature mode in thermal part, the overall energy consumption of the plant was estimated at 90 to 155 kWh/t.

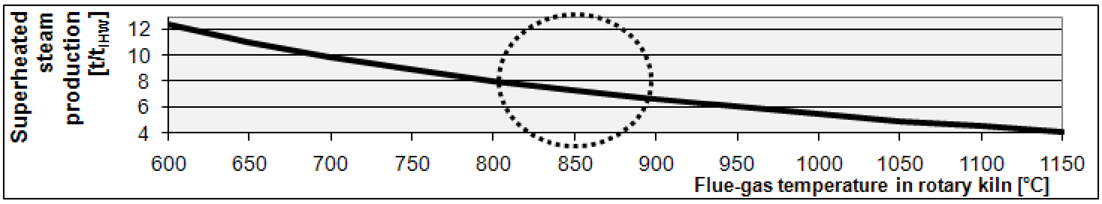

Figure 4: Superheated steam production under varying temperature modes in thermal part

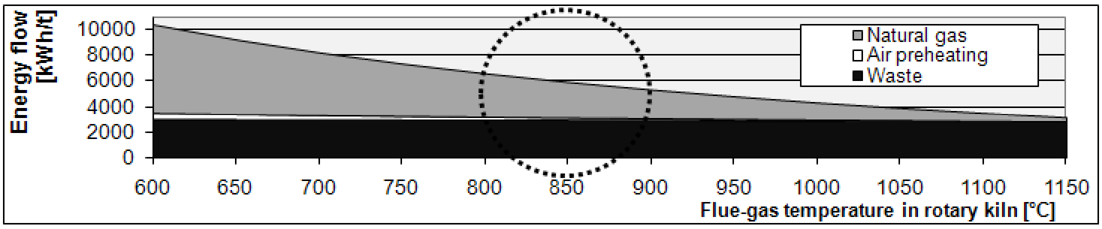

Figure 5: Participation of individual energy streams on the heat transfer in HRSG

3.4 Primary energy savings evaluation

Another parameter that should be considered is Primary energy savings criterion. Absolute Primary Energy Saving values according to the 2004/8/EC Directive cannot be compared directly when technologies are not at identical capacity. Criterion defining specific primary energy saving were expressed (Pavlas et. al., 2011). Criterion which relates absolute Primary Energy Savings value (exported energy reduced by auxiliary fuel energy supply and imported energy) to total process energy input (energy supplied by waste, auxiliary fuel and imported energy) was used in the assessment. It describes the utilization rate of process energy input (renewable and primary). The process can be classified as highly efficient if the criterion exceeds 0.6 value. This criterion is usable for comparing of different fuel combustion processes. Different forms of energy production are considered, electricity and heat production are influenced by production efficiencies in reference plants. The procedure is similar to the R1 formula assessment for energy recovery classification of municipal solid waste incinerators. Primary energy savings are low; they are in negative values in some cases (more primary energy is consumed than produced). The values decrease in proportion to the increasing auxiliary fuel consumption (Figure 7).

4. Conclusions

Computational model of typical IHW incineration plant technology was compiled in in-house developed software W2E. Available heat and electricity production have been concretized and specific primary energy savings criteria were evaluated for several alternatives of the plant technological layout. For the most common technological layout and condensing mode of superheated steam utilization 1250 to 1520 kWh/t of electricity production was determined, which is much higher than production of municipal waste incinerators. Nevertheless, this value is highly influenced by the auxiliary (fossil) fuel combustion and the process is co-combustion with very low to negative impact to fossil energy conservation.
This was demonstrated by the specific primary energy savings criterion. This criterion indicates that IHW incinerator can achieve the satisfactory value only under operational regimes without auxiliary fuel combustion. However, these regimes (combustion above ash melting point, lower combustion temperatures if the content of halogenated organic substances is less than 1 %) cannot be regarded as common and reliable due the present state of technology and other operational problems.
The technology can reach "energy recovery" status only in specific operational regimes. The primary purpose of IHW incinerators is problematic materials disposal. Energy production can only reduce operating costs and external energy consumption.

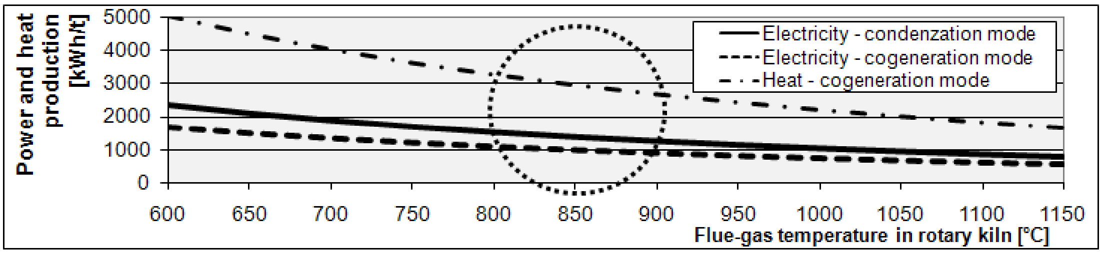

Figure 6: Electricity and heat production under different operational regimes

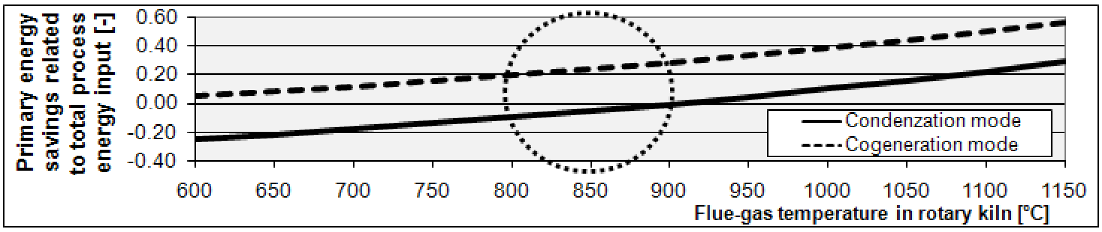

Figure 7: Specific primary energy savings criterion under different operational regimes

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