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Energy Efficient Processing of Waste

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Discussion about utilization of waste for energy production (waste-to-energy, WTE) has moved on to next development phase. Waste fired power plants are discussed and researched. Present results of simulation prove that increase of net electrical efficiency above 20 % for units processing 100 kt/y is problematic and tightly bound with increased investments. Lower cogeneration production leads to ineffective utilization of energy, which is documented in present paper with help of primary energy savings criterion. Once sole electricity production is compelled by limited local heat demand, application of non-conventional arrangements is highly beneficial to secure effective energy utilization. In the paper a system where municipal solid waste incinerator is integrated with combined gas-steam cycle is evaluated in the same manner.

1. Introduction

Heat utilization makes up one of the most important aspects related to design and operations of WTE systems. Efficient utilization of released heat is conditioned by numerous aspects including properties of combusted waste, technology applied, local conditions, and current energy prices and last but not least limited financial resources of investors.

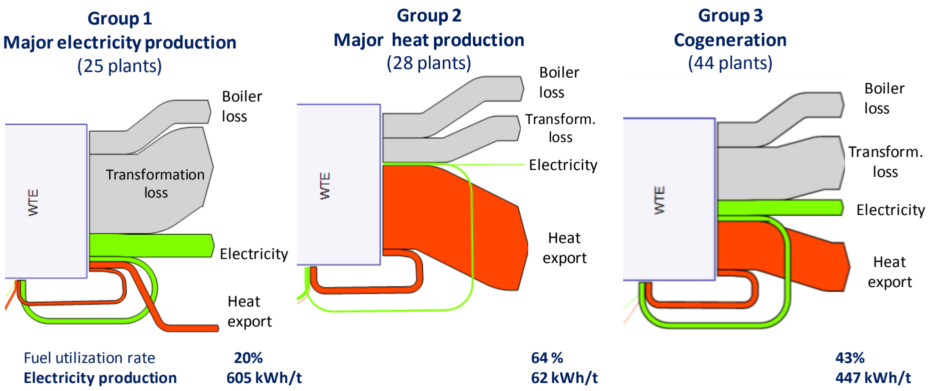

Figure 1: Classification of facilities and obtained efficiency (97 facilities associated in CEWEP, Reimann 2006)

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Reimann (2006) has published results of energy utilization efficiency at 97 European municipal solid waste (MSW) incinerators associated in CEWEP (Confederation of European Waste-to-Energy Plants) organization. Average net efficiency in facilities producing mostly electricity (see Figure 1, group 1) reaches approximately 20 %. Efficiency of facilities focused on heat production reaches 64 % (group 2). Considering cogeneration (group 3), overall efficiency may reach 43 %. These are lower if compared to efficiencies commonly achieved in conventional energy-producing facilities (power plants, heating plants, Graus and Worrell, 2009)).

2. Development trends

New generation of thermal processing has been emerging, i.e. waste fired power plants (WFPP). These facilities focus on electricity production. By taking advantage of high capacity they try to reach net electrical efficiency above 30 %. Heat supply is diminished and operations are not limited by heat demand. An example of such technology was presented by Berlo (2006). This solution is applicable in highly populated areas with large waste production.
Many regions (including Czech Republic) tend to favor electricity generation even for facilities with low processing capacity (100 – 150 kt/y) where the potential for increased efficiency is limited. Performance of such a plant is investigated by using simulation approach and consequences regarding the environment are pointed out.

3. Simulation approach and performance analysis

1.1 3.1 Simulation model of a unit with capacity 100 kt/y

Simulations presented in this paper were conducted using in-house built software tool *W2E – Waste to Energy*. Software is dedicated to perform mass and heat balances of technologies in the area of energy utilization of waste and biomass. It is based on Java platform (Tous et al., 2009). Model of a conventional up-to-date technology (grate combustion, waste heat boiler, backpressure or condensing turbine, NO_x reduction by SNCR, ESP, Catalytic filtration for dioxins/furans removal, wet scrubber) with annual capacity of 100 kt was created in this tool.

1.2 3.2 Boundary conditions of the calculation

Simulation model respects technological restrictions related to electricity production (limited live steam parameters to avoid increased corrosion risks, cooling system performance, etc.). The main features are as follows:

- Steam flowrate at the boiler outlet: 40 t/h
- Steam parameters as 4 MPa (g), 400 °C, respectively 6MPa (g), 620 °C
- Pressure at the turbine outlet (in the case of back-pressure turbine) and/or bleed pressure (for condensation turbine with extraction) of 1.1 MPa (g) for supply of heat into steam network; 0.3 MPa (g) for supply of heat into hot water network
- 8 kPa of pressure in turbine condensator
- 70% isentropic efficiency of the turbine.

1.3 3.3 Simulation results

Arrangement of back-pressure turbine and steam parameters of 4 MPa allow to reach specific electricity production (related to one ton of waste processed) of 200 to 270 kWh/t depending on value of back-pressure. Increase in pressure from 4 MPa to 6 MPa causes increase by 100 kWh/t. Arrangement with condensation turbine in full condensation mode leads to generation of 600 to 700 kWh/t and efficiency of power production reaches almost 20 %. With 6 MPa of steam parameters and low pressure of bleeding, 20% limit may be exceeded. However, increase in efficiency which is related to high steam pressure is linked with high potential of corrosion of superheater's bundles. Net efficiency of power production (export efficiency) may be calculated by subtracting internal power consumption (ca. 4 % of energy in waste, i.e. 100 kWh/t, Reimann 2006). Net efficiencies of electricity and heat production are given in Figure 2.

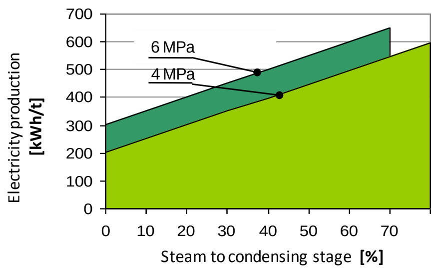


Figure 2:Specific electricity production

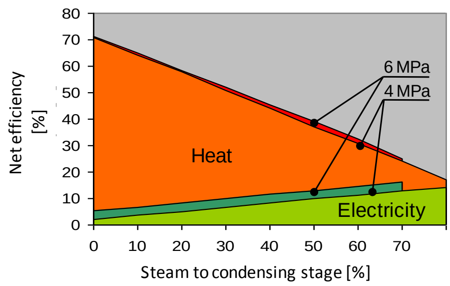


Figure 3:Export efficiencies

Results clearly show that net electrical efficiency in condensation mode under conventional steam parameters of 4 MPa does not exceed 20 %. Increase of efficiency over 20 % for units utilizing waste with processing capacity of 100 kt/year is problematic and is linked to implementation of financially demanding materials and measures.

1.4 3.4 Consequences of exceeding usage of condensing mode

Tendency to produce mainly electricity and minimize cogeneration results in lower overall efficiency of fuel utilization (see Figure 3). On the other hand, electricity is considered to be a more valuable form of energy. Efficiencies presented in Figure 3 are not a sufficient reason to claim that significant orientation towards electricity production with low overall efficiency still makes up a sustainable method of energy utilization, or whether we may start talking about energy wasting.

Criteria for performance evaluation. Directive 2008/98/EC defines an *Energy efficiency* criterion for evaluation of waste incinerators. Equation for its calculation is obvious from Table 1.

A new plant which is to be labeled as WTE has to reach minimum value of 0.65 of this criterion. Benefits of the incinerator taking into account other energy-producing plant may also be evaluated using *primary energy savings* criterion (*pes*, Table 1). This criterion was described in detail by Pavlas (2010). Figure 4 presents its meaning. We may then talk about WTE if the process saves primary energy, i.e. pes > 0

Table 1: Definition of Energy efficiency criterion

Reference	*Criterion*	*Equation*	*WTE*
Directive 98/2008/EC	Energy efficiency	$\eta_e = \dfrac{Q_{prod} - (E_f + I_{imp})}{0{,}97 \cdot (E_w + E_f)}$	$\eta_e > 0{,}6$ $\eta_e > 0{,}65^{*}$
Pavlas et al. 2009	Primary energy savings	$pes = \dfrac{Q_{exp} - (E_f + I_{imp})}{E_W + E_f + I_{imp}}$	$pes > 0$ $pes > 0{,}6^{**}$

* *For equipment put into operation after December 12, 2008*
** *0.6 value for highly efficient process of energy waste utilization*

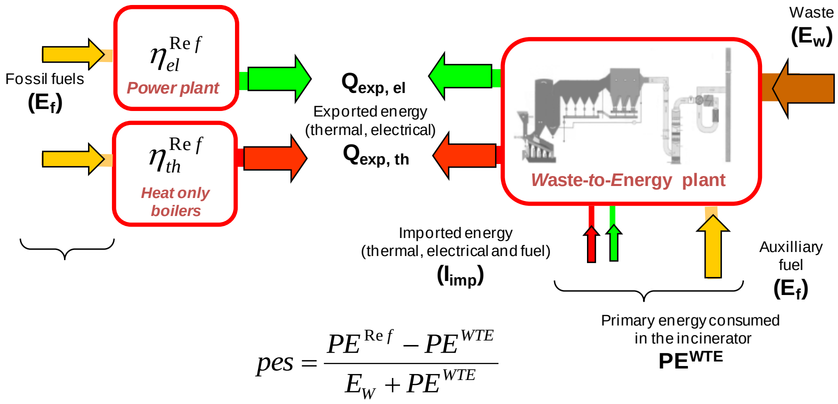
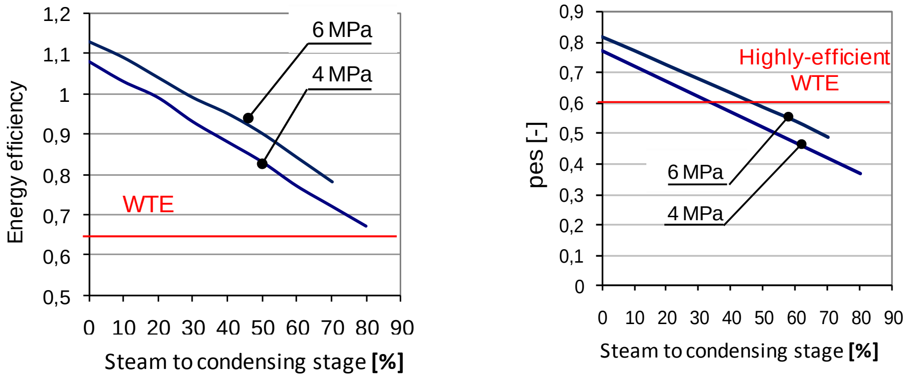


Figure 4: Graphical representation of Primary energy savings criterion



a) Energy efficiency *b) Primary energy savings*

Figure 5: Influence of usage of condensing regime on Criteria evaluation

Conducted calculations were completed with specification of both indicators (see Figure 5). Uptrend in electricity production (in Figure 5 expressed as increased ratio of stem going to condensing stage over overall steam generation in boiler) leads to fall of *Energy efficiency* criterion. Requirement for classification as WTE in all the analyzed cases is fully met. The requirements on WTE classification are set in such a way that the electricity production is limited in no way for up-to-date plants. Criterion *pes* drops along with usage of condensing mode (see Figure 5).

One of the advantages of using *pes* criterion is that it may be exercised in all types of power production processes and not only in municipal waste incinerators, which further allows to compare these plants. Results of such a comparison are stated in Pavlas et al. (2009). Based on previously published data, we suggest defining a new term “highly-efficient” energy production from waste. Similar mechanism is engaged in evaluation of cogeneration systems in accordance with Directive 2004/8/EC, where distinction of “cogeneration” and “highly-efficient cogeneration” is made. Value of 0.6 *pes* is to be practiced for differentiation between WTE and highly-efficient WTE. Excessive electricity production from waste leads to drop of *pes* below 0.6 and thus causes ineffective utilization of energy stored in waste.

1.5 3.5 Utilization of synergic effects

If local limited heat consumption compels sole electricity production, it is necessary to look for unconventional solutions. One of the many discussed technologies is an integration of municipal waste incinerator with combined steam-gas cycle. There are several arrangements available (Consonni and Silva, 2007). All the solutions have a common features:

- Need to reach higher parameters of steam at the turbine inlet (8 MPa and more)
- Avoid corrosion problems (recovery system of incinerator is not equipped with a superheater. Superheting takes part in waste heat boiler beyond the gas turbine.
- Application of common steam turbine with higher isentropic efficiency.

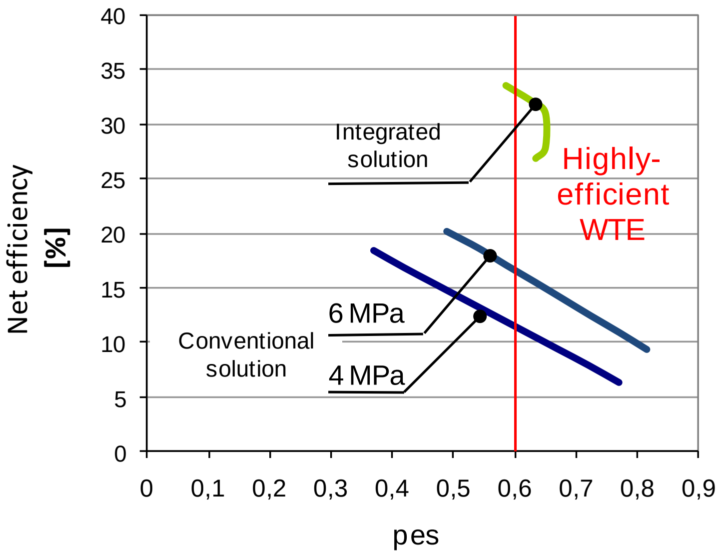


Figure 6:Efficiency of waste-based electricity production

Model of such integrated system was created and subjected to simulation including various share of installed capacity of gas turbine to incinerator itself. Evaluation of net electrical efficiency related to waste-based energy input followed (in accordance with K. Qiu and Hayden 2009) along with *pes* determination. Figure 6 presents the results. Despite the fact that this concept focuses only on electricity production, net electrical efficiency from waste may exceed 30 %. Process will be labeled as highly efficient waste-to-energy process as well.

4. Conclusion

Increase of net electrical efficiency above 20 % for units processing 100kt/year is problematic. Although electricity is considered to be a more valuable form of energy, trend to focus on sole electricity production accompanied by limited cogeneration production results in ineffective energy utilization from waste. Process thus cannot be labeled as highly-efficient. Only processes where primary energy savings (*pes*) exceed 0.6 may be classified as highly-efficient WTE processes. This value may be reached in technologies with limited electricity production and high share of supplied heat (cogeneration system). Limited local heat consumption may compel sole electricity production. Acceptable degree of utilization then may be reached via integration of municipal waste incinerator with combined steam-gas cycle. This concept focused solely on electricity production has been thoroughly discussed in the paper. Net efficiency of electricity production from waste may exceed 30 %.

Acknowledgements

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