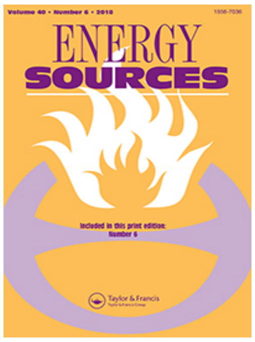

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Optimizing energy recovery level of a Dutch waste incineration facility

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ABSTRACT

Energy recovery level indicated as an R1 factor has become increasingly important for the municipal solid waste incineration (MSWI) facilities in the EU. This study focuses on potential improvement of energy recovery through different heat products. It quantifies the extent to which heat extraction with various quality and quantity heat products may influence the energy recovery level. It is concluded that the R1 status of a planned facility (reference case) is estimated as 0.71. The optimized energy recovery level 1.14 can be achieved by delivering hot water through low-pressure steam extraction plus a heat exchanger. The highest R1 factor in the high-pressure steam scenario is 0.81. This study serves as the first step in facilitating the decision-making process of an MSWI facility to prioritize the heat extraction options.

KEYWORDS

Energy recovery optimization; heat extraction; municipal solid waste incineration; R1 factor; waste to energy

Introduction

The revised EU Waste Framework Directive 2008/98/EC (WFD) came into force in December 2008. Special attention has been given to energy recovery in the new WFD. An R1 factor is elaborated and serves as a performance indicator of energy recovery for a plant dedicated to the municipal solid waste incineration (MSWI).

Current studies on the R1 factor contributes to better understand R1 evaluation methodology (Grosso, Motta, and Rigamonti 2010; Ozansoy 2016; Wetterlund and Söderström 2010) and also, to strength knowledge of how to improve the energy recovery level. Identifying the influential factors of the energy recovery level was the major objective of the previous studies (Pavlas et al. 2011; Reimann 2012; Tan et al. 2015). One of the general conclusions was that the pattern of energy products, the size and the location of the facility are three major factors influencing the R1 status. The highest energy recovery level is achieved by the facilities producing both electricity and heat. This result is in line with the conclusions from the studies aiming at identifying the optimal energy efficiency (not the optimal R1 status) of the municipal waste incineration facilities (Luoranen and Horttanainen 2008; Tsai and Kuo 2010; Vochozka et al. 2016).

Adjusting energy products between electricity and heat is an important approach in pursuing a higher energy recovery level. However, the literature on quantifying the extent to which such adjustment can affect the energy recovery level, especially with different types of heat production, is lacking. This study regards this issue as the research objective and aims to facilitate the decision-making process of MSWI facilities in improving energy recovery level and selecting heat production.

With these research objectives in mind, two investigations are carried out in sequence. Firstly, the W2E computer tool has been chosen to simulate the energy recovery process. Secondly, two scenarios have been developed to represent different ways of heat extraction.

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A Dutch MSWI facility was designed in 2010 to expand the capacity of an operating facility. The capacity and technical designs are the same as the operating. It was, however, not constructed due to financial reasons. The non-existent plant is chosen in this study to avoid using data of the operating facility treating technical information as confidential.

Methodology

Energy recovery level-R1 factor

An MSWI facility can be regarded as recovery operation only when its R1 status is equal to or above (The European Parliament and of the Council 2008):

- 0.60 for installations in operation and permitted in accordance with applicable Community legislation before 1 January 2009;
- 0.65 for installations permitted after 31 December 2008.

Using the R1 formula (The European Parliament and of the Council 2008, 3–30):

$$R1 = \frac{Ep - (Ef + Ei)}{0.97 \times (Ew + Ef)}$$

In which:

Ep means annual energy produced as heat or electricity (GJ/year);

Ef means annual energy input to the system from fuels contributing to the production of steam (GJ/year);

Ew means annual energy contained in the treated waste calculated using the net calorific value of the waste (GJ/year);

Ei means annual energy imported excluding Ew and Ef (GJ/year);

0.97 is a factor accounting for energy losses due to bottom ash and radiation.

Waste to energy (W2E) modeling

The computer tool named Waste to Energy (W2E) has been chosen to model the processes of waste incineration and energy recovery because of its applicability and availability. W2E is a computer tool dedicating to the facilities in the field of waste and biomass utilization for the purpose of energy production (Pavlas 2017).

The tool has been applied to reveal the most efficient way of thermal treatment of sludge produced in a particular wastewater treatment plant (Touš et al. 2009); to simulate an operating MSWI plant with annual processing capacity of one million tons (Kropác et al. 2011), and to test the operation features of the secondary combustion chamber installed in an existing MSWI plant (Jegla et al. 2010). More information about the W2E computer tool can be found in the document (Pavlas 2017).

Scenarios development and modeling

Two scenarios are developed to represent two possible ways of large amount heat extraction. One is to extract high-pressure pressure steam (HPS) from the connection between the boilers and the turbine. Another is to produce hot water by using heat from a low-pressure steam (LPS) bleeder by means of a heat exchanger (HE). In the scenario of HPS extraction, the steam is suitable for the industrial use due to its high pressure and temperature. In the LPS+HE scenario, the heat production is hot water and more suitable for residential use. Figure 1 illustrates two ways of heat extraction in a simple way. The technical assumptions are listed in Table 1.

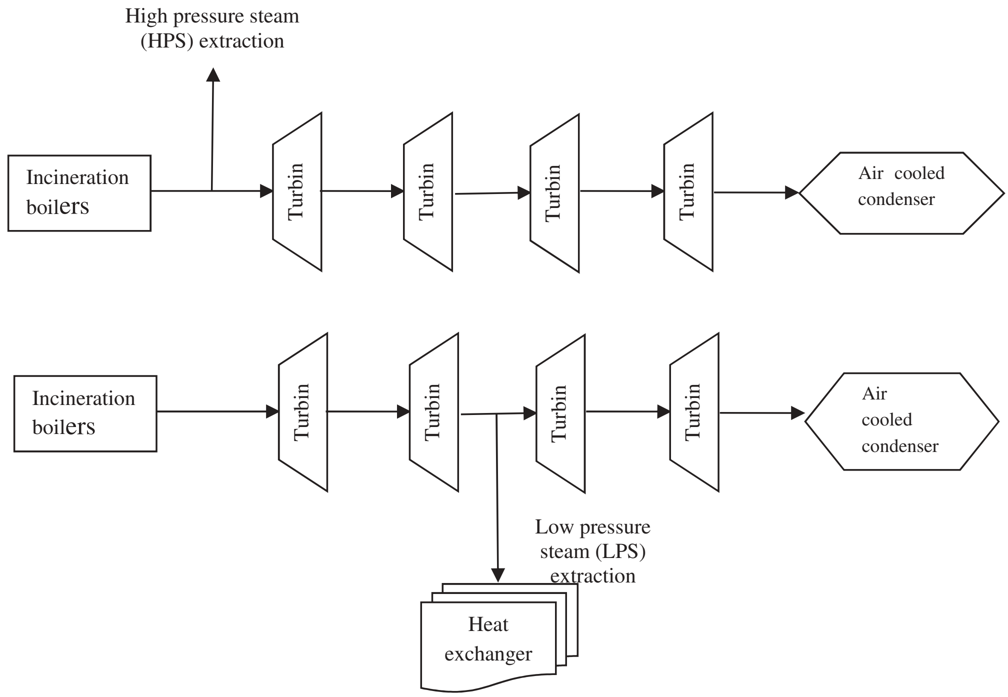

Figure 1. A simple illustration of heat extraction in two developed scenarios.

In these two scenarios, a series of sub-scenarios has been calculated to represent the turbine load from the minimum to the maximum value. Sub-scenarios are developed at 20 ton/h mass low rate intervals. The sub-scenario without any heat extraction is defined as the reference case.

Results and discussions

The HPS scenario

The results of the electricity generation, gross and net heat production and the R1 result of each sub-scenario are calculated and presented in Table 2. The minimum turbine load in the MSWI facility is determined by the minimum flow through the final stages as about 6.2 MW. The maximum turbine load of the designed facility is about 48 MW, corresponding to the condition that both boilers are in the operation without any HPS extraction. Figure 2 is the

Table 1. The technical parameters of two scenarios.

	HPS scenario			
	HPS extraction		Return flow from the third party	
Pressure (bar)	42		3	
Temperature (°C)	400		130	
Enthalpy (kJ/kg)	3210.9		546.4	
	LPS+HE scenario			
	LPS extraction		Hot water	
	Heat exchanger inflow	Heat exchanger outflow	Heat exchanger inflow	Heat exchanger outflow
Pressure (bar)	2	2	3	3
Temperature (°C)	120.2	113.3	90	120
Enthalpy (kJ/kg)	2663.7	475.4	377.1	503.9

Table 2. The electricity generation, gross and net heat production and R1 result in the HPS scenario.

Mass flow rate of HPS (ton/h)	Turbine load (MW)	Electricity generation (TJ)	Gross heat production (TJ)	Return flow energy (TJ)	Net heat production (TJ)	R1 result
0	47.8	1,336.8	0	0	0	0.71
20	43.5	1,258.8	521.8	87.4	434.4	0.74
40	38.3	1,102.4	1,043.6	174.8	868.8	0.75
60	33.1	943.5	1,565.5	262.3	1,303.2	0.77
80	27.8	788.6	2,087.3	349.7	1,737.6	0.78
100	22.6	633.7	2,609.1	437.1	2,172.0	0.80
120	17.4	481.2	3,130.9	524.5	2,606.4	0.81
140	**12.2**	**344.4**	**3,652.8**	**612.0**	**3,040.8**	**0.83**
160	7.0	208.5	4,174.6	699.4	3,475.2	0.82
167	6.2	179.3	4,229.2	708.5	3,520.6	0.81

Sankey Diagram of the energy balance in the sub-scenario of the maximum amount of HPS extraction.

The R1 results in all sub-scenarios surpass the threshold of R1 factor (0.60) regulated in the latest EU WFD. The lowest R1 result is 0.71 in the reference case. The R1 result firstly increases along the growth of the heat production and then drops to 0.81 after it reaches the highest value 0.83. The corresponding turbine load of the optimized R1 result is 12.2 MW with the electricity generation of 344.4 TJ. It is close to the internal electricity demand of the facility. The results reveal two pieces of important information. Adjusting the energy production from electricity to HPS brings a positive effect on the energy recovery level. An optimized energy recovery level can be achieved by maximizing the heat production in the condition of the internal electricity demand can be fulfilled by its own generation.

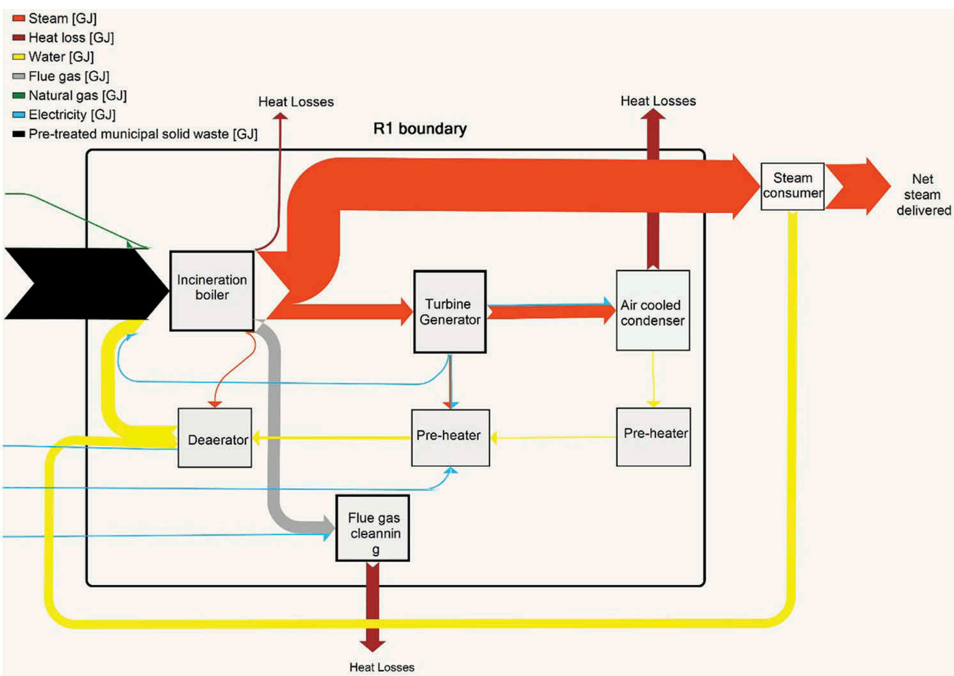

Figure 2. The Sankey Diagram of the energy balance in the HPS scenario with the maximum amount of HPS extraction.

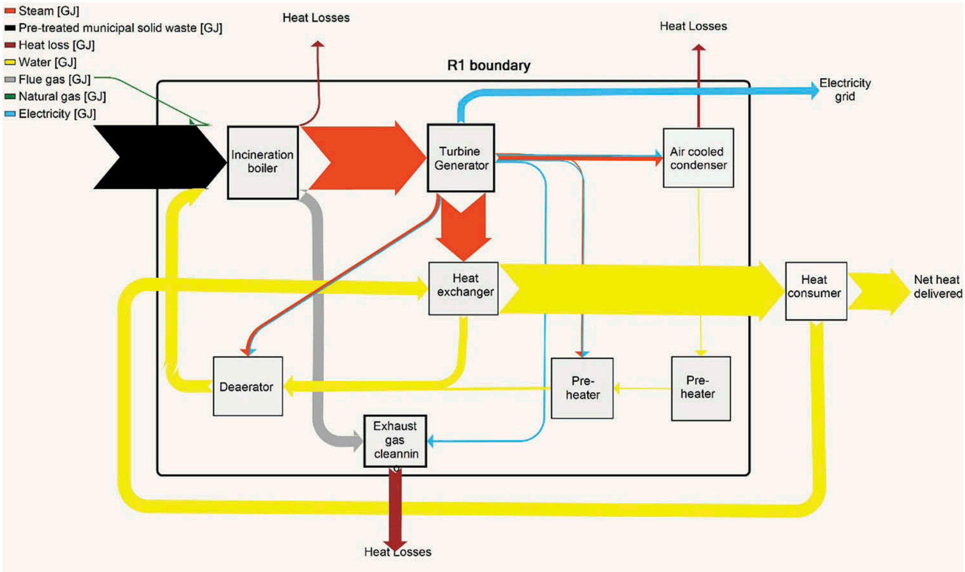

Figure 3. The Sankey Diagram of the energy balance in the LPS+HE scenario with the maximum amount of LPS extraction.

The LPS+HE scenario

The results of the simulation are listed in Table 3. The maximum amount of LPS extraction is about 179 ton/h. It means to maintain the minimum amount of the LPS through the turbine for cooling the blades of the final stage. Figure 3 visualizes the energy balance of the scenario LPS+HE with the maximum amount of the LPS extraction.

The R1 results of all sub-scenarios are higher than the threshold of the R1 factor and also the R1 status in the reference case (0.71). The overall trend is that the R1 result steadily increases along with the growth of the heat production without any turning point. The optimized R1 result is 1.14 and it happens in the sub-scenario of the maximum amount of LPS extraction. The optimized energy recovery level achieved with the turbine load 29 MW by which the electricity generation can still satisfy the internal electricity demand.

Again, adjusting the energy production from electricity to hot water affects the energy recovery level in a positive way. The same mass flow rate of LPS extraction leads to a much higher R1 status than HPS extraction does.

A survey on the R1 status of EU MSWI facilities has concluded that the average R1 status in all 314 EU plants was 0.69 in 2010 (Reimann 2012). The average R1 status in 188 Central Europe plants

Table 3. The electricity generation, net heat production and R1 results in the LPS+HE scenario.

Mass flow rate of LPS (ton/h)	Turbine load (MW)	Electricity generation (TJ)	Net heat production (TJ)	R1 result
0	48	1,336.8	0	0.71
20	43	1,267.2	345.6	0.76
40	40	1,203.8	691.2	0.80
60	38	1,143.4	1,036.8	0.84
80	37	1,088.6	1,382.3	0.89
100	35	1,033.9	1,727.9	0.93
120	33	985.0	2,073.5	0.98
140	31	936.0	2,419.1	1.03
160	30	887.0	2,764.7	1.08
179	**29**	**861.1**	**3,110.3**	**1.14**

and in 71 Northern Europe plants was 0.62 and 0.97, respectively. The R1 status of the planned facility (reference case) is 0.71 which is slightly higher than the average of the EU plants. The optimized R1 status by HPS extraction is 0.83 which cannot compete with the average of that in the plants of Northern Europe. The optimized R1 status by LPS extraction is 1.14 and it is much higher than the average of the plants in Northern Europe.

Conclusion

The R1 status is regulated in the revised EU WFD 2008/98/EC is legally binding to all Member States. It is a performance indicator for the level of energy recovery for the municipal solid waste incineration plants in the EU. The previous studies have proved that adjusting the electricity and heat production is an important approach to achieve a higher energy recovery level. This study takes one step further to quantify the extent to which switching to heat production with different types of products may improve the energy recovery level.

It has been concluded that a higher optimized energy recovery level can be achieved by the way of low-pressure steam extraction plus a heat exchanger than the way of directly extracting high-pressure steam. The optimized R1 status in the HPS scenario is 0.83 while in the LPS+HE scenario is 1.14. They are both higher than the R1 status of the planned facility without any heat extraction (0.71). This research may serve as the first step to facilitate the decision-making process of an MSWI facility on seeking a higher R1 status by providing the potential and limitation of the R1 improvement with two alternative energy productions. It also highlights the importance of being a heat supplier for an MSWI facility in a district heating system to obtain the mutual benefit of a higher R1 status and a more sustainable heat supply system.

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