Analysis to intensify the energy utilization in incineration plant
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Miroslava Dudeková[a], Jiří Klemeš[b], Petr Stehlík[a]

[a]*Institute of Process and Environmental Engineering UPEI-VUT, Brno University of Technology, Technická 2, 616 69 Brno, Czech Republic, Tel +420 541 142 308, dudekova@fme.vutbr.cz*
[b]*Centre for Process Integration, CEAS, The University of Manchester, PO Box 88, Manchester M60 1QD, UK, Tel: +44 161 3064389, j.klemes@manchester.ac.uk*

Abstract

Thermal processing of waste represents not only waste disposal including reducing its volume but also waste to energy (WTE) process. Most up to date municipal solid waste (MSW) incinerators are delivering WTE. Results of energy utilization analysis in one of the type of MSW incinerator are presented in this paper. The aim of the analysis was to identify the potential energy saving within the plant. *Plant efficiency factor* and *Energy utilization rate* are considered as the criteria used for assessment of plant performance from the view of energy utilization. Simulations based on industrial data acquired by monitoring system were carried out and obtained results are analyzed. It was found out that the potential energy savings are available in the area of low-potential heat. The possible improvements were proposed and consulted with the plant operators.

Keywords: intensification of energy utilisation, heat integration, incineration, waste to energy

1. Introduction

Thermal treatment of waste (municipal, hazardous, biological) is used as an integral part of integrated waste management throughout Europe because it is a safe and clean technology superior to landfill and is compatible with high levels of recycling. Using municipal solid waste (MSW) to produce energy (waste to energy system – WTE) is not only an important waste treatment option but it also cuts down the use of fossil fuels and hence can help to meet renewable energy targets. Thermal treatment processes recover the energy in MSW incineration plants and convert it into heat and power (electricity, steam, gas etc). Thus thermal processing of MSW can be considered as certain form of recycling energy. It is necessary to analyze all feasible ways how to utilize this energy as much as possible.

The work focuses on one of the up-to-date MSW incinerator which belongs to WTE category. The energy released during thermal oxidation of waste is utilized for generation of high pressure process steam and subsequently for co-generation.

The incineration plant was built in 1999 and processes 96,000 t/y of municipal waste. There is one processing line with the capacity 12 t/h which produces 2.5 MW of electricity and 24 MW of thermal energy per hour. Important feature of the plant is a CHP arrangement – a connection with the heating station which produces steam for district hearting. The incineration plant supplies to the heating plant steam and electricity and the heating plant provides to the incineration plant DEMI water and returns condensate from the steam.

2. Municipal solid waste incineration plant

The incineration of the waste takes place in furnace comprising moving grate and combustion chamber. The primary air is drawn from the waste pit, preheated and injected through the grate and the waste layer into the combustion chamber. The generated flue gas (70,000 Nm^3/h) flows from the furnace to the Heat Recovery Steam Generator (HRSG). The heat content of flue gas is utilized here for production of superheated steam. HRSG can be divided into 3 parts: economizer, boiler and superheaters. The flue gas leaves HRSG at temperature around 200 °C and goes through the electrostatic precipitator to remove solid particles. Consequently, part of flue gas is recycled (about 1/7 of the generated amount) and is returned to the combustion chamber as secondary air. The rest moves on to the block of flue gas cleaning which consists of dioxin filter and wet scrubbing. After removing such compounds like dioxins, acid gases and heavy metals to the level set by valid regulation cleaned flue gas is released to the atmosphere.

Superheated steam generated in the HRSG at amount of 35 t/h is led to the backpressure turbine which is used for electric power generation. Part of the electricity is supplied to all plant internal installations. The surplus production is fed into the heating station. After leaving the turbine the boiler-feed-water (BFW) is injected to the steam to control the temperature. Then the majority of the steam is exported (31 t/h) and the rest is used in the incineration plant. The main consumer of steam in the incineration plant is preheating of primary air and heating of BFW. The sum of the condensate from the incineration plant, DEMI water and returned condensate from the heating station form the BFW supplied to the boiler.

The process flow diagram of described incineration plant is shown in Figure 1.

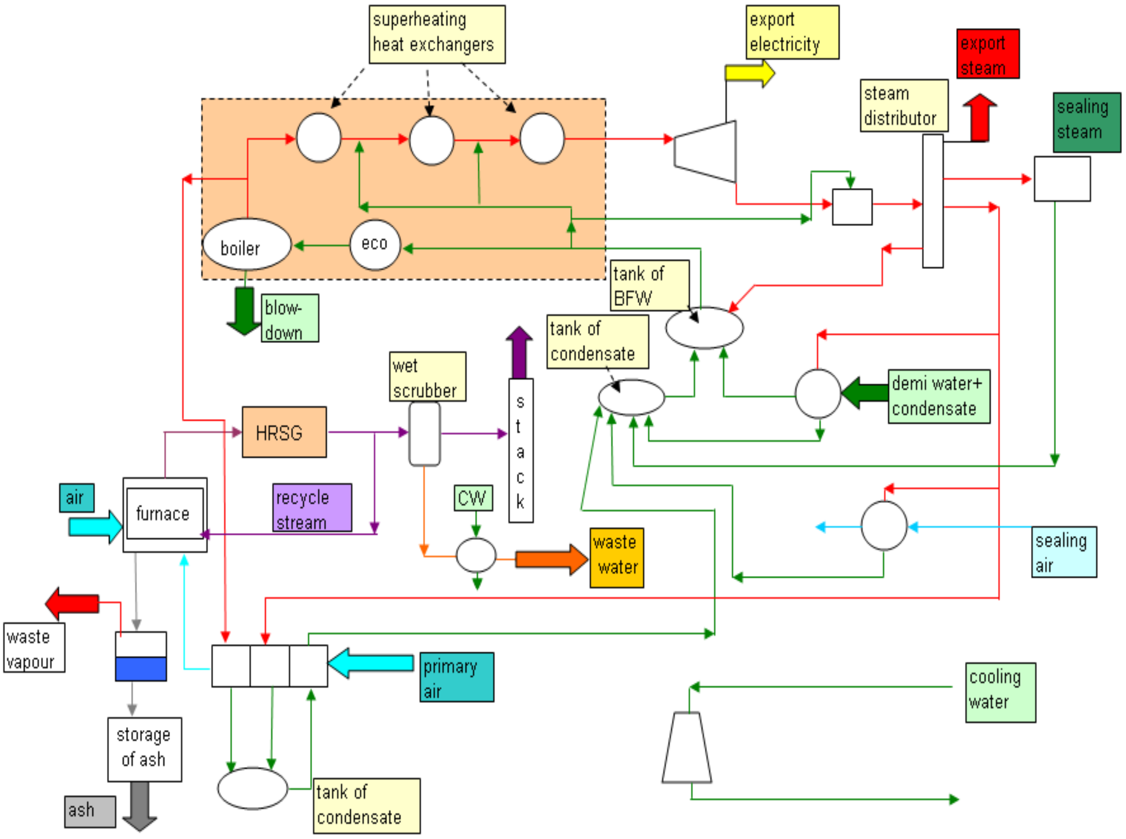


Figure 1: Process flow diagram

3. Energy efficiency analysis

The analyses have been based on calculations using the industrial data from the incineration plant monitoring system. As a first step the individual process streams, heat flows and utilities were identified. Extracted data were used for mathematical model creation. Newly developed WTE software (2007) for simulation of waste to energy systems was used for this purpose.

WTE software is for the design and complex assessment (in economic and environmental view) of systems in the field of utilization of energy from biomass and wastes with the aim of maximum heat recovery and energy utilization. The core of the system comprises balance nodes of basic operations (like mixing of streams, combustion of gaseous fuels, combustion of solid matter, heat exchange, etc.) supplemented by simple thermodynamic models of heat engines (steam turbine, gas turbine, etc.). This allows a relatively simple adding new units and involving potential changes in computational algorithm (e.g. recycle streams, investigation of parametric sensitivity and partial changes). The whole system is therefore open for building up the balance models of common as well as untraditional devices.

The model of investigated incineration plant created in the WTE software is presented in Figure 2.

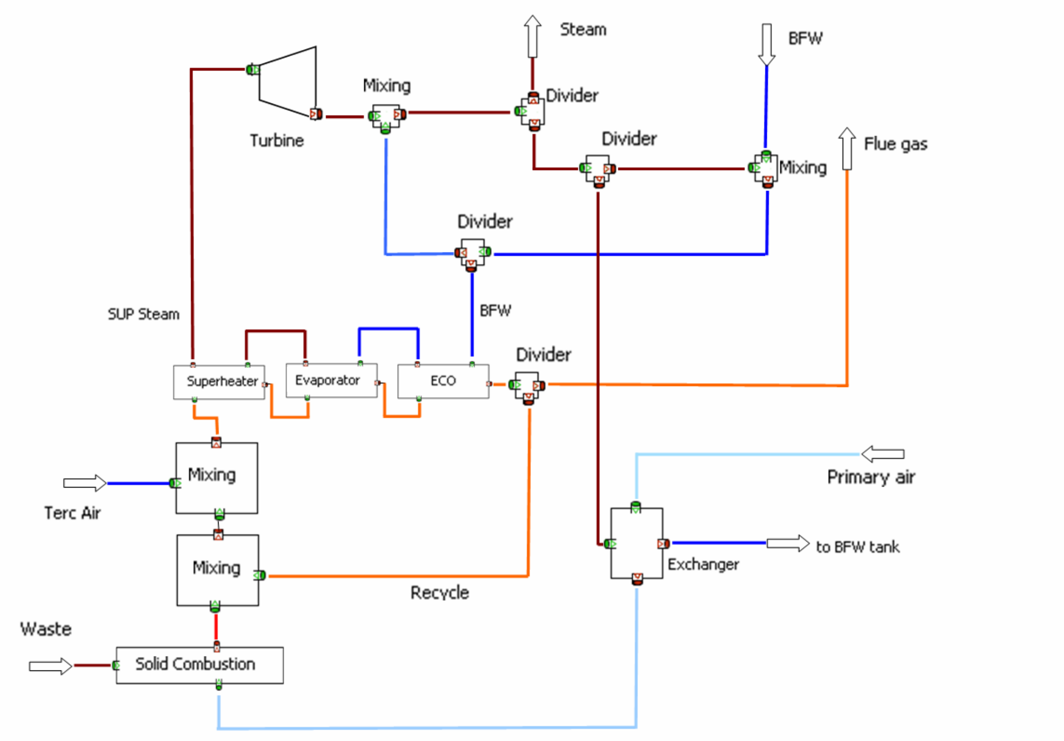


Figure 2: Model in WTE software

4. The effectiveness of energy utilization

The effectiveness of energy utilization in the analyzed incineration plant was evaluated by two criteria proposed by The Confederation of European Waste-to-Energy Plants (CEWEP, 2004): *Energy utilization rate* and *Plant efficiency factor*.

The first of the stated criterion *Energy Utilization Rate* defines what part of the total energy released during incineration process is utilized. The second stated factor *Plant Efficiency Factor* defines the ratio between energy produced by incinerating the waste and energy consumed by the process itself. Waste treatment in waste incineration plants is qualified as recovery if the plant energy efficiency factor allows delivering energy to third parties, because in this case the energy produced by incinerating the waste is higher than the plant's own demand. In that case the value of Pl_{ef} is higher than 1. Hereby the incineration plant operates as an energy source. The definition of both factors as well as the needed value for waste-to-energy plants are presented in Table 1.

Criteria	Equation	Waste-to-Energy
Energy utilization rate	$\eta_e = \dfrac{Q_{prod} - (E_f + I_{imp})}{f_B \cdot \left(E_w + E_f\right)}$	$\eta_e > 0.5$
Plant efficiency factor	$Pl_{ef} = \dfrac{Q_{prod} - (E_f + I_{imp})}{E_f + I_{imp} + I_{circ}}$	$Pl_{ef} > 1$

Table 1: Definition of criteria

The meaning of particular symbols is shown in Figure 3:

E_f	Imported energy to the combustion process (e.g. supplementary fuel)
E_W	Energy released by waste combustion processes
f_B	Factor for energy losses by bottom ash and radiation
I_{circ}	Energy circulated (thermal and electrical), which is necessary for the process (energy for driving fans and pumps, for pre-heating of combustion air, pre-heating of feed water, etc.)
I_{imp}	Imported energy not used for heat production
Q_{exp}	Total amount of exported energy (thermal and electrical)
Q_{prod}	Total amount of produced energy (thermal and electrical)

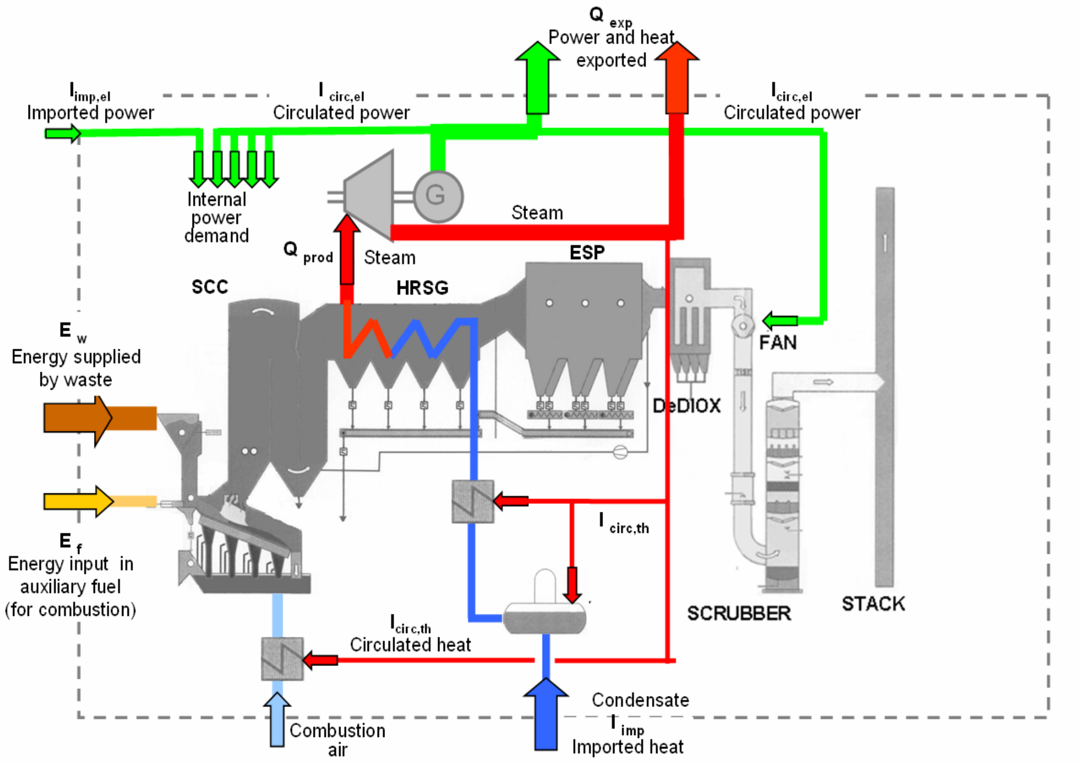


Figure 3: Main energy streams in the municipal solid waste incineration

All figures substituted into relation of both criteria should be equivalents. It means that individual energy forms have to be taken into account and comparison of different units of measurements (MWh, MWh_e, MWh_{th}) is necessary. Therefore conversion factors as equivalents are needed assuming an overall European average of 38 % conversions efficiency for electrical generation and 91 % for heat generation (CEWEP, 2004). Only by this way different kind of energy can be evaluated and summarized to a comparable energy mix. Therefore there are two columns with figures in the Table 2 in which applied data as well as results of evaluation are introduced. The first column shows the actual values obtained from the annual statement of the plant. In the second column are the values after multiply by the conversion factors for individual type of energy. These figures were used for criteria's evaluation.

The small numbers of imported energy (I_{imp} and E_f are negligible) point out, that this plant is almost independent on the external energy supplies. Auxiliary energy is consumed only under non-standard conditions like regular shut-down or short time break down. The evaluated values of *Energy utilization rate* and *Plant efficiency factor* highly exceed the minimum value expected for waste-to-energy plants (see Table 1). It can be said, that the attained operating parameters of production and energy recovery provide high value of both criteria and hereby this plant can be characterized as very effective waste-to-energy plant.

Parameter	**Unit**	**Actual value**	**Value for evaluation**
Energy supplied by waste (E_w)	GJ/t	10.500	10.500
Imported energy :			
power	GJ/t	0.061	0.159
heat	GJ/t	0.053	0.058
total (I_{imp})	GJ/t	0.114	0.216
Imported energy :			
by supplementary fuel (E_f)	GJ/t	0.055	0.055
Total amount of produced energy (Q_{prod})	GJ/t	9.264	11.144
Exported energy:			
power	GJ/t	0.252	0.654
heat	GJ/t	7.048	7.753
total (Q_{exp})	GJ/t	7.300	8.408
Energy circulated :			
power	GJ/t	0.384	0.999
heat	GJ/t	1.579	1.737
total (I_{circ})	GJ/t	1.964	2.737
Plant Efficiency factor PI_{ef}	-	**3.61**	
Energy Utilization Rate η_e	%	**1.06**	

Table 2: Main annual parameters of plant and evaluated factors

5. Analysis of heat recovery system

By means of the model created in WTE software (2007) - see Figure 2- the analysis of the effect of the lay-out of heat recovery system was accomplished. The influence of the main parameters (e.g. outlet pressure of steam) has been studied as well.

Numerous simulations were carried out in WTE software. Small modifications were made in original model and the influence of these modifications on the size of reached primary energy savings (expressed by factor PI_{ef}) was studied. First tested modification consists in replacing backpressure turbine with a condensing turbine with one extraction. The change of the amount of bleeding is analyzed. The other variation, which effect was observed, comprises the change of pressure on the outlet of the backpressure turbine. The obtained results are presented in Figure 4.

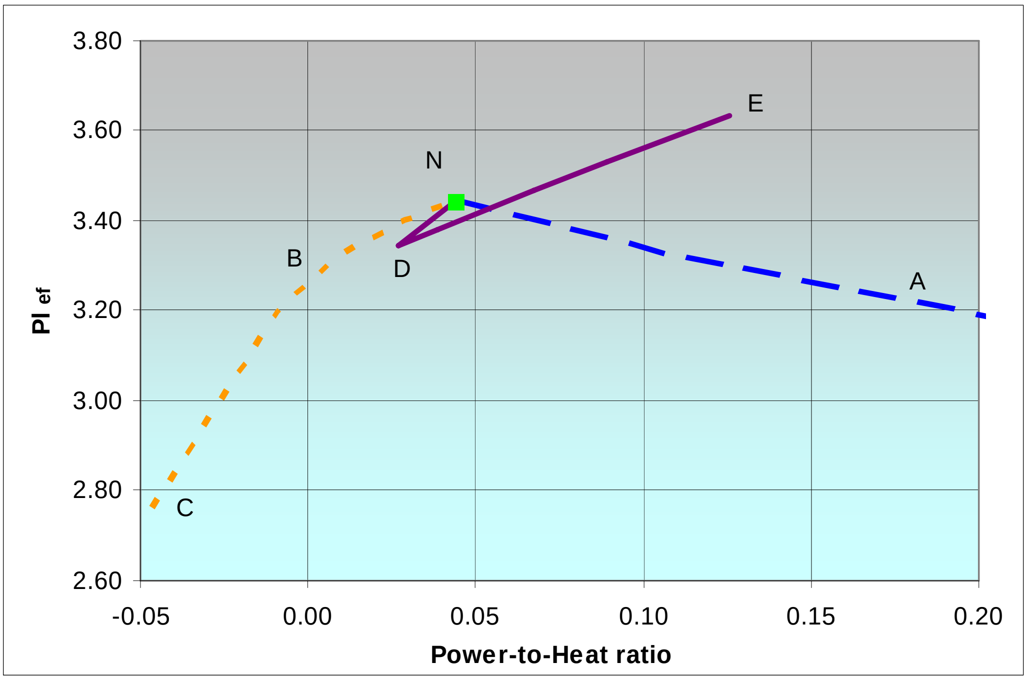


Figure 4: Influence of studied modifications on factor PI_{ef}

In the x-axis is displayed Power-to-Heat ratio which presented the ratio between the electricity and heat energy, the value of both was calculated as difference between exported value and imported value. The point N represents the results obtained from simulation of actual state on the plant. The blue dash line (N-A) illustrates the results from simulations with condensing turbine. As the flowrate of the bleeding rises, the PI_{ef} factor decreases.

The red dotted line (N-B-C) demonstrates the effect of outlet pressure increase. Since the heat drop over turbine falls, the power output falls too. The point B represents the state where no electricity is exported; whole generated amount is consumed by the in-site consumers. With the other increase of outlet pressure, the electricity has to be imported to cover the in-site demand. The point C represents the state, where no electricity is generated; the system generates only thermal energy.

And the scarlet (N-D-E) full line shows the influence of reduction of outlet pressure from backpressure turbine. Since part of the steam is currently used for cover the demand of in-site consumers this amount has to be led through the by-pass of turbine (to remain the higher parameters of steam). Therefore the scarlet line first decreases to point D. But from this point the effect of increased power production as a result of increased heat drop on the turbine dominates and the value of PI_{ef} factor increases.

On the basis of performed simulations and gained results it is possible to specify general recommendations for achieving maximum heat utilization in the municipal solid waste incinerator. Further mentioned formulations can be understood as a certain manual (instructions) which should be taken into account in design process of new up-to-date plants or in retrofit of existing waste-to-energy plants.

It is possible to determine a certain strategy of energy utilization for every unit. From the owner point of view the best strategy is that which ensures the maximal profit. From the global perspective the optimal strategy leads to primary energy saving. The most of the suggested options fulfil the both requirements. It means they have the positive influence on the plant economy and simultaneously they contribute to the environment protection. However in some cases and under certain circumstances (improper prices of energy) they could be misleading.

The fundamental rule for the effectively running plant with a high level of heat utilization arises from the principle of process self-sufficiency and can be formulated as follow:

To minimize the amount of imported energy and to maximize the amount of exported energy.

Particular ways are described below:

1. Process optimization and selection of appropriate technology with the aim to reduce or completely eliminate the consumption of imported energy in the form of fossil fuels. This type of energy can be substituted by energy produced in heat recovery system only with difficulties due to low parameters of steam, etc. Predominantly it comprises supplementary fuel (E_f) - the consumption of this fuel in secondary chamber, the heating-up to very high temperature.

2. The identification the measures that lead to reduction of energy in the process itself. This consumption is covered by circulated energy (I_{circ}) and in some cases also by imported energy (I_{imp}). One of the ways is effective recovery of waste heat and low potential heat. Spread and for its simplicity also popular tool which enables to study the energy flows within the processes and to identify the ways of maximal waste heat recovery is Heat Integration (Smith, 2005 and Klemeš at al , 1997) based on the Pinch Analysis (Linnhoff and Hindmarsh, 1983).

3. The proposal of such parameters of heat recovery system that ensure the requirements for in-site consumption and simultaneously provide the possibility for the maximal export of energy.

4. The highest level of heat utilization is achieved in case of application the principle of co-generation, i.e. combined heat and electricity generation.

5. Co-generation in WTE plant is usually based on steam turbine. The best results are reached when the backpressure turbine is applied. However, this arrangement requires the external customers with full-year consumption of heat.

6. If there is no full-year demand of heat the operator of the plant has to look for another flexible solution. One of the options can be the condensing turbine with one or more extractions. Afterwards, the turbine works in so-called "backpressure" or "condensing" mode according to requirements of heat export.

7. Provided the structure of heat consumers enables it, it is profitable to perform the expansion on turbine to as low pressure as possible and to export the steam at the lowest parameters as possibly, in the extreme export hot water. Low parameters of the steam enable to increase the enthalpy drop over the turbine and thereby to reach the higher power output.

8. If the in-site consumption of thermal energy is also covered by steam from the turbine extraction it's necessary to check the parameters of low-pressure steam in respect to the heating-up of in-site streams (e.g. heating of primary air). If the required parameters for in-site consumers are higher than required parameters for export, it is profitable to consider the application of turbine with several extractions. Using by-pass of turbine for this purpose can negative influence the heat utilization.

9. If there is no consumer of heat, it's necessary to produce only electricity and waste heat from condenser is wasted. The efficiency of electricity generation is relatively low and can be increased by various measures (regeneration, staged expansion with steam re-heating, etc.).

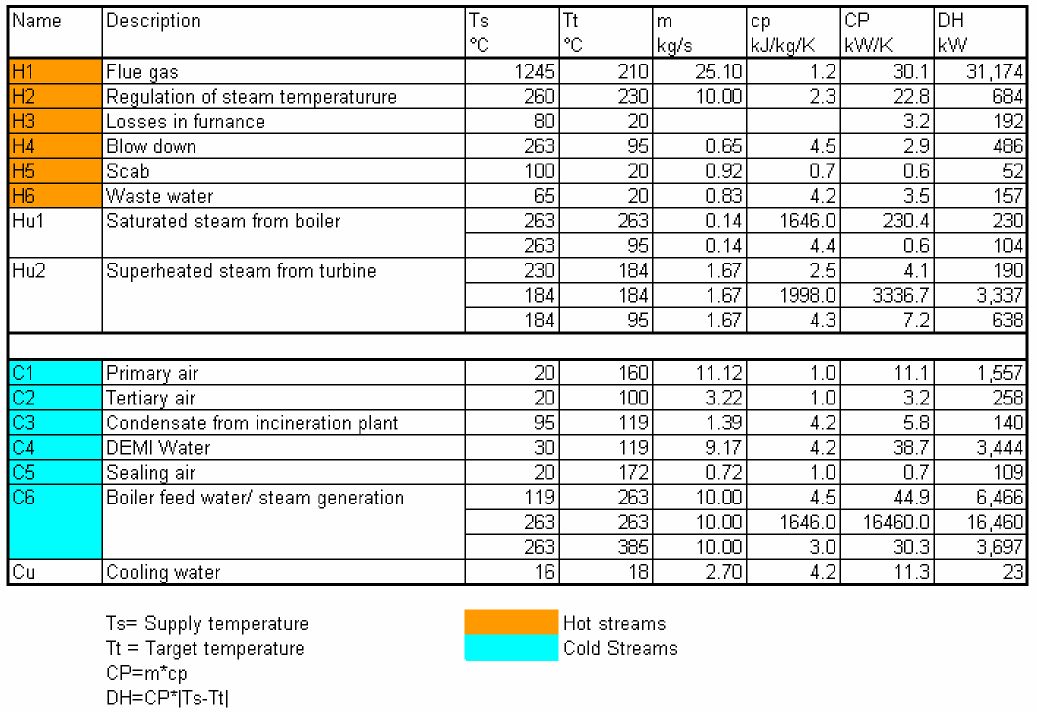
The feasibility of the concrete application depends on numerous factors included properties of incinerated waste, applied technology, local conditions, current prices of energies and last but not least limited financial sources of investors. Modern environmental friendly solution is usually connected with higher investment costs. Therefore it could be expected, that the real solution will arise as the result of the compromise.

6. Heat integration

In part 5 an alternative approach considering heat integration and utility system has been investigated by using SPRINT software for heat integration (2007). The Heat Integration technology was applied in this case. It is efficient methodology for process integration and is based on thermodynamic and economic principles – for the overview see (Smith, 2005) and has been extended to the Total Site Integration (Klemeš at al , 1997).

The first task in this case consisted in data extraction. Data obtained in the previous calculations of mass and heat balances of processes within the plant were used as initial sources. Data extraction is an important step, because when you take too much data, it is likely you obtain the same flowsheet as the original one. In some cases it is very difficult to decide which data exactly should have been extracted. Data extraction relates to the extraction of information required for the Heat Integration analysis from a given process heat and mass balance. This involves the identification of process heating and cooling duties. In the new simplified flowsheet are highlighted the heating and cooling demands without any reference to the existing exchangers.

As the results the Table 3 of cold and hot streams was compiled. This Table comprises the basic characteristics of the individual streams which are needed as input data into SPRINT. This data was processed by the SPRINT and a Problem Table and Composite Curves was drawn.



Name	Description	Ts °C	Tt °C	m kg/s	cp kJ/kg/K	CP kW/K	DH kW
H1	Flue gas	1245	210	25.10	1.2	30.1	31,174
H2	Regulation of steam temperaturure	260	230	10.00	2.3	22.8	684
H3	Losses in furnance	80	20			3.2	192
H4	Blow down	263	95	0.65	4.5	2.9	486
H5	Scab	100	20	0.92	0.7	0.6	52
H6	Waste water	65	20	0.83	4.2	3.5	157
Hu1	Saturated steam from boiler	263	263	0.14	1646.0	230.4	230
		263	95	0.14	4.4	0.6	104
Hu2	Superheated steam from turbine	230	184	1.67	2.5	4.1	190
		184	184	1.67	1998.0	3336.7	3,337
		184	95	1.67	4.3	7.2	638
C1	Primary air	20	160	11.12	1.0	11.1	1,557
C2	Tertiary air	20	100	3.22	1.0	3.2	258
C3	Condensate from incineration plant	95	119	1.39	4.2	5.8	140
C4	DEMI Water	30	119	9.17	4.2	38.7	3,444
C5	Sealing air	20	172	0.72	1.0	0.7	109
C6	Boiler feed water/ steam generation	119	263	10.00	4.5	44.9	6,466
		263	263	10.00	1646.0	16460.0	16,460
		263	385	10.00	3.0	30.3	3,697
Cu	Cooling water	16	18	2.70	4.2	11.3	23

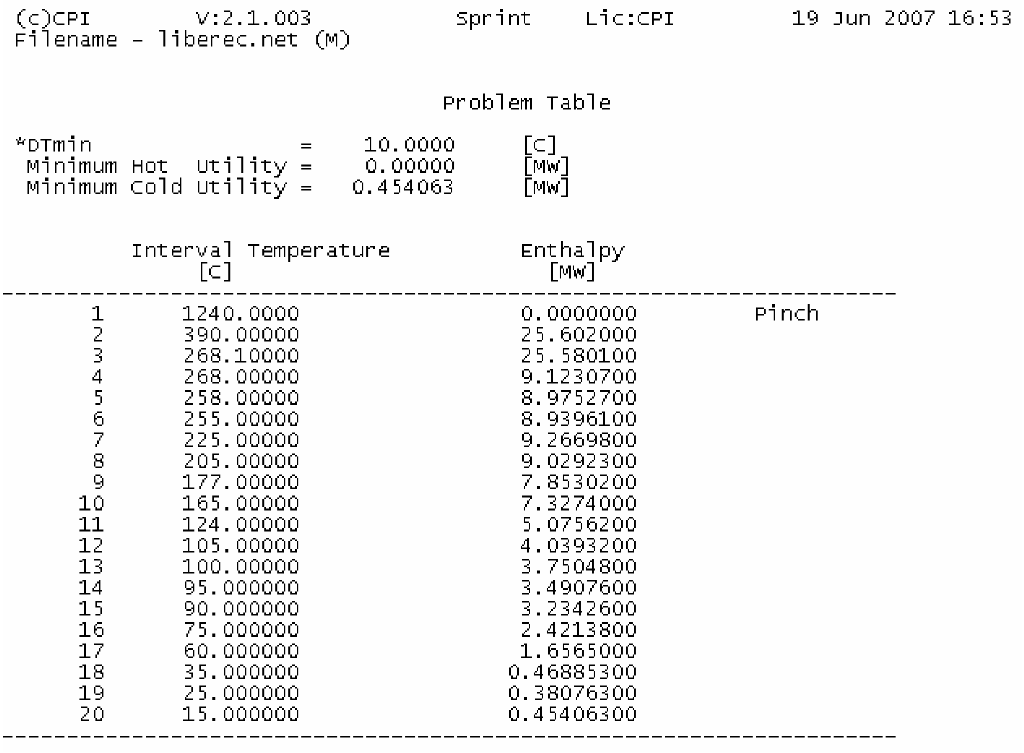
Ts= Supply temperature
Tt = Target temperature
CP=m*cp
DH=CP*|Ts-Tt|

🟧 Hot streams
🟦 Cold Streams

Table 3: Basic characteristics of cold and hot streams

By means of the Problem Table can be pinpointed where the Pinch Point is located ((Linnhoff and Hindmarsh, 1983). Also minimum value of external heating and cooling requirements are calculated in this Table. From gained Problem Table (Table 4) can be seen that processes in incineration plant are different from the common chemical plants. Because of large amount of generated steam, there are no requirements for hot utilities.

The Figure 5 presents the Composite Curves (CC) of the whole process. From the picture is obvious, that utilisation of the heat content of individual stream is very good. Another positive fact is the big temperature difference between hot and cold streams. This implies big driving force for the heat exchange. Because of big scale of the temperature axis it has been provide a zoomed part of the CC from the Figure 5 (in the low temperature field). It is shown in Figure 6. For better clarification every part of the CC is labelled with name of the stream it belongs to. There are still some parts of the streams and their temperatures in the Hot Composite Curve which can not be clearly seen. For this reason another zoomed selection for the narrower range of temperature has been provided and is shown in Figure 7. Individual temperatures are also labelled in this Figure. Both zoomed selections indicate that the most of possible energy saving could be made in low potential heat area which bring some problems for finding a proper use of this energy.



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(c)CPI        V:2.1.003          Sprint    Lic:CPI         19 Jun 2007 16:53
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                                 Problem Table

*DTmin                   =     10.0000      [C]
 Minimum Hot  Utility =     0.00000      [MW]
 Minimum Cold Utility =    0.454063      [MW]

          Interval Temperature          Enthalpy
                 [C]                      [MW]
-------------------------------------------------------------------
       1      1240.0000                 0.0000000          Pinch
       2      390.00000                 25.602000
       3      268.10000                 25.580100
       4      268.00000                 9.1230700
       5      258.00000                 8.9752700
       6      255.00000                 8.9396100
       7      225.00000                 9.2669800
       8      205.00000                 9.0292300
       9      177.00000                 7.8530200
      10      165.00000                 7.3274000
      11      124.00000                 5.0756200
      12      105.00000                 4.0393200
      13      100.00000                 3.7504800
      14      95.000000                 3.4907600
      15      90.000000                 3.2342600
      16      75.000000                 2.4213800
      17      60.000000                 1.6565000
      18      35.000000                 0.46885300
      19      25.000000                 0.38076300
      20      15.000000                 0.45406300
-------------------------------------------------------------------
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Table 4: The Problem Table

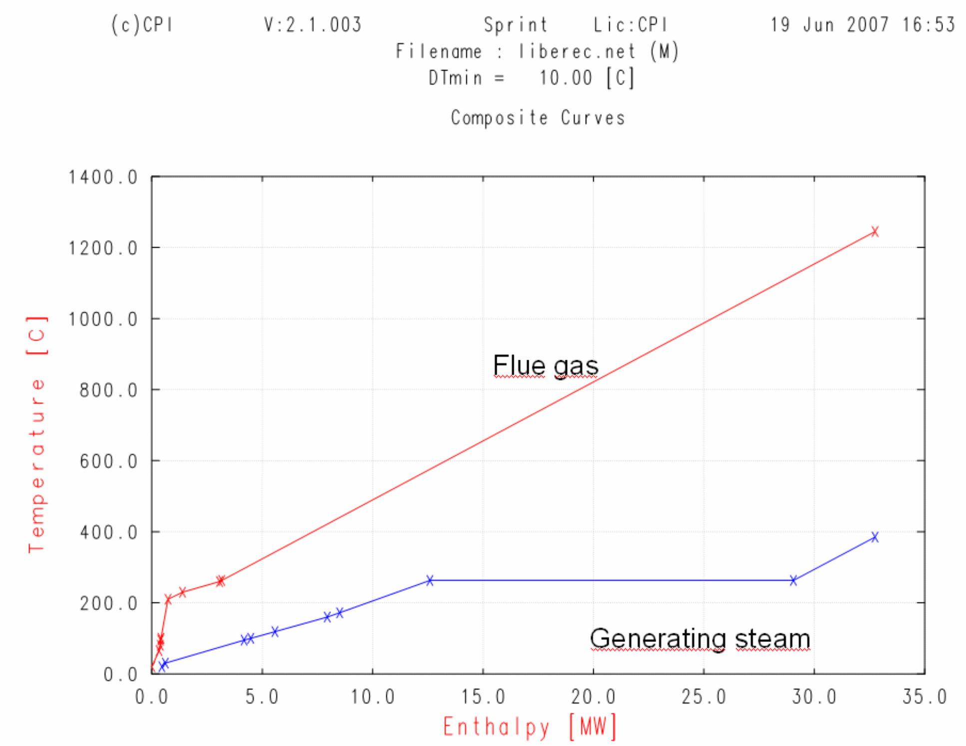

Figure 5: The Composite Curve

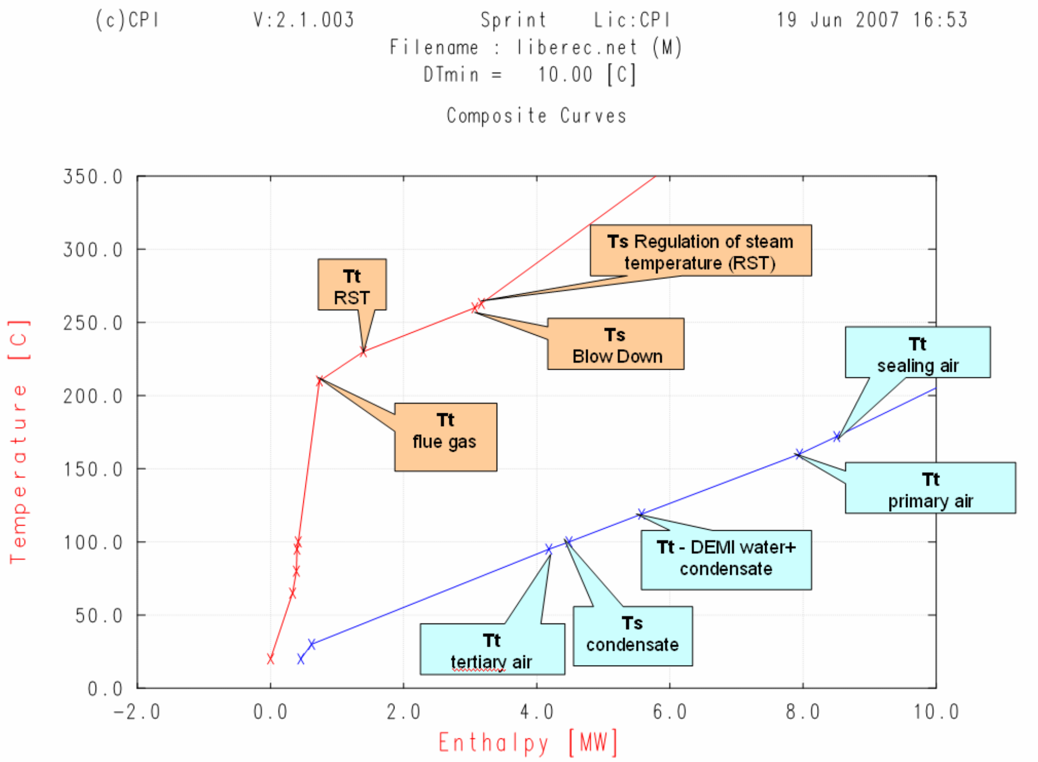

Figure 6: A zoomed part of Composite Curves for the lower temperatures

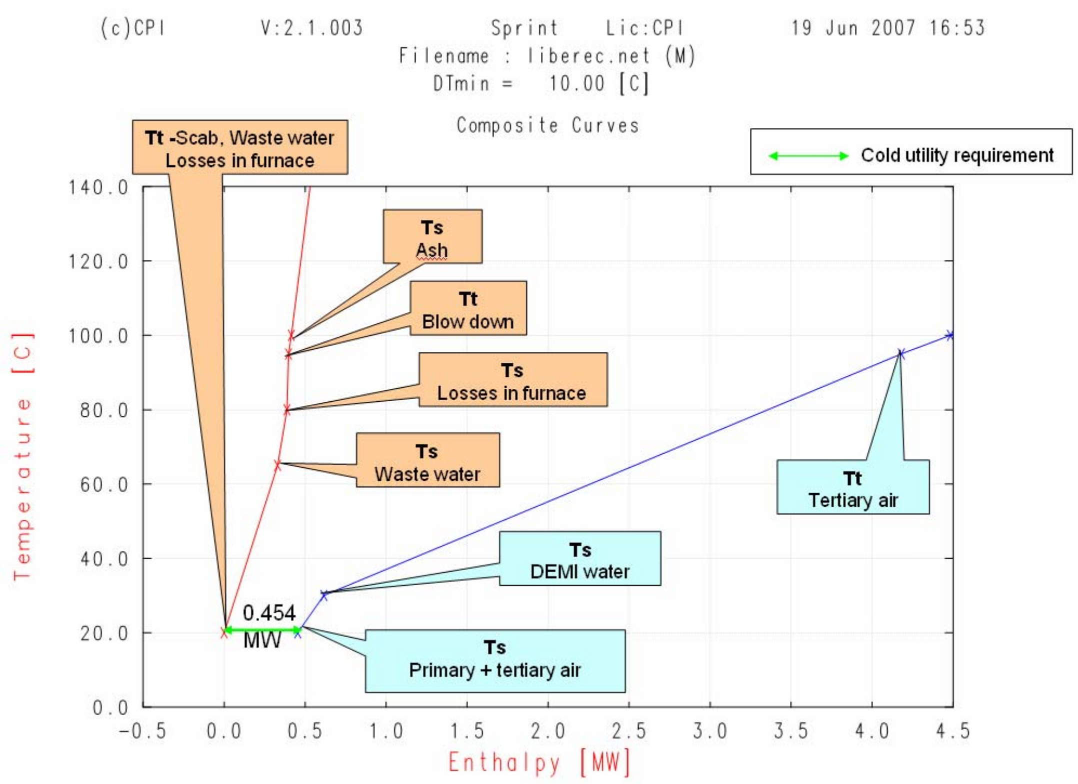

Figure 7: Another zoomed part of the Composite Curves for the lowest temperatures

There were identified following losses of the plant:

- Scab — ash
  — iron
- Filtration cake (from fly ash cleaning and from waste water cleaning)
- Waste water
- Flue gas (60 000 Nm^3/h, T= 60 °C, P= 95 kPa)
- Heat losses from furnace
- Heat losses from absorption column
- Waste steam from water seal for ash from furnace
- Losses in small cooling tower

Also the prospects for potential saved energy were found:

- Heating of sealing air
- Heating of DEMI water and condensate coming from heating plant
- Heating of primary air
- Heating of boiler-feed water

The main aim should be to reduce the consumption of the steam inside the plant. This would increase the amount of steam which could be export and sold to the heating station and improve overall economic of the plant. It was found out, that there is a waste steam generated in water seal for ash from furnace, which has not been utilized so far. The heat content of the blown down from the boiler has not been utilized as well. The blow down could be expanded to the outlet pressure of steam from the turbine. The generated steam as well as hot water could be utilized. This steam is suitable for heating the returning condensate from the incineration plant. Another possibility is to use the waste steam for heating up one part of DEMI water coming from the heating station at temperature 30°C. Both medium could replace the steam from the turbine used for heating of sealing air.

7. Conclusions

The aim of this work was to analyze the energy utilization in one of the up-to-date municipal solid waste incinerators with the capacity 12 t/h. Up-to-date incinerator plants are not units for waste disposal only. They are modern energy sources producing renewable energy as well, which can partly replace conventional energy sources combusting fossil fuels. The effectiveness of utilization energy in incineration plant was evaluated by two criteria proposed by The Confederation of European Waste-to-Energy Plants (CEWEP): *Energy utilization rate* and *Plant efficiency factor*. The industrial data from the incineration plant monitoring system were applied for the calculations. The obtained values are high above the recommended values for waste-to-energy plants and point out on very effective waste-to-energy plant. However a further analysis had been made using the model created in WTE software to study the influence of different factors on these criteria. From the simulation results were specified several general recommendations for achieving maximum heat utilization in the municipal solid waste incinerator. These results were further investigated by applying the heat integration with SPRINT software tool. Some further possible energy savings in the area of low potential heat have been found and will be investigated in the future work.

8. Acknowledgements

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