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Investigation of Process Optimization Measures in MSWI Plants with an Online-Balancing Program

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Abstract

In Germany municipal solid waste is treated in more than 60 incineration plants (MSWI plants) with an overall capacity to treat over 16 million tons per year. A number of operational measures are under development to improve waste thermal treatment processes including the reduction of pollutant emissions, the improvement of ash quality, the increase of efficiency, and the reduction of corrosion. Although much work has been done in this area there still exists a high potential for additional process optimization.

In order to investigate the effects of different optimization measures, detailed information is required about the operational behavior of the process as it relates to the actual operating conditions. As such, an Online-Balancing program has been developed that relates the actual operational conditions of a MSWI plant with real time calculated values using detailed mass and energy balances for the different process units of the plant. These process units include the primary and secondary thermal treatment processes (incineration process), water steam cycle (boiler), flue gas treatment, energy conversion, and treatment of residues by using data from the existing process control sys-tem. The Online-Balancing program when connected to the plant's existing control system allows the engineers and operational staff of the MSWI plant to see immediate feedback on various calculated process efficiency data. This data allows the MSWI staff to adjust certain operational parameters in order to achieve greater efficiency and performance from the plant. The Online-Balancing program has been tested on several municipal solid waste incineration plants in Bavaria with reasonably good predictability. This paper will review the methodology used by balancing MSWI plants and then present case studies of several plants used to validate the model. Opportunities for process optimization at each of these tested sites will also be presented.

Keywords: MSWI-plant, Online-Balancing, process optimization, energy efficiency

INTRODUCTION

The optimization of municipal solid waste incineration plants (MSWI) requires detailed information and data about the actual operating conditions. This information can be obtained from the plant's existing process control system. Modern process control systems utilize computers to collect and store process data as well as to control the actual process conditions. These control systems can report the actual measured process values in the plant as well as the time behaviour of these values. Process data includes air and flue gas flow rates, flue gas component concentrations (CO_2, CO, O_2, N_2, H_2O, etc.), mass rate of steam generated as well as steam temperature and pressure. In the newer MSWI plants the process control systems can provide sufficient information to allow mass and energy balances to be modelled for each of the process units and consequently for the overall process.

The following information is of special interest for optimization of MSWI plants:

- Mass flow (kg/hr), composition (weight percent) and calorific value (kJ/kg) of the waste and fuels fired in the combustion process
- Flow rates of combustion air and estimated infiltration air into the combustion systems
- Air flow rates used in the flue gas treatment system (compressed air, pulse air, or air used to convey solids)
- Combustion air preheating temperatures
- Total, electric and thermal efficiency ratios for the overall process
- Boiler and turbine efficiency
- Heat needed for condensate and feed water preheating, etc.

With this data the operational staff would have sufficient information to perform real time process optimization calculations and to implement process modifications of plant operations in order to increase the system efficiencies. Furthermore, it is envisioned that some of the manual process changes could be programmed into the existing control system to automate the optimization process.

Existing MSWI plants are not equipped with possibilities to model mass and energy balances "online". However, with such a tool of Online-Balancing[1] operational staffs are able to manually adjust the operational parameters in order to optimize the overall process.

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[1] In the following the real time calculation of mass and energy will be termed as Online-Balancing. The computer model applied for these calculations will be termed as Online-Balancing program.

Examples of opportunities for manual optimization include:

- Increase of overall energy efficiency of the system
- Reduction in reagents and additives used in the flue gas treatment system
- Increase availability of the system (decreased downtime)
- Reduced operating costs.

Therefore the Online-Balancing program displays to the user both the actual as well as the calculated operational data from detailed mass, material and energy balances in all essential process units and associated

The Online-Balancing program was developed at the Schwandorf, Burgkirchen and Coburg MSWI plants in a project called "EU 24 – Effectiveness of Waste Incineration Plants; Technical, Ecological and Economic Optimization" [1]. This project was a collaboration of various companies and personnel including the three MSWI plants in Schwandorf, Burgkirchen and Coburg and Martin GmbH für Energie- und Umwelttechnik München (a plant engineering/construction company in Munich). The project was supported by the State of Bavaria Department of Health, Environment and Consumer Protection as part of an EU infrastructure funding for regional development (EFRE) program.

BASIC PRINCIPLES OF BALANCING

As is usual in process engineering, implementing a model for mass, material and energy balances for an MSWI plant first requires that the boundaries be established for each unit operation (for aggregates, apparatuses, etc. [2]) in the MSWI plant process. Figure 1 shows a schematic of a typical MSWI plant with the main input streams being the waste, air, energy, water and operation material, and the main output streams being the flue gas, residues, energy for utilization and (heat) losses. Single unit operations can be combined to form the paramount balance units which in this paper will be termed as (calculation) modules, for example for the bunker, firing, boiler, scrubber, etc. The combination of modules leads to single process units and the paramount process subdivisions such as the main thermal process (incineration process), energy conversion system, flue gas treatment system, etc. (Figure 1).

Once the boundaries of each module were defined the next process engineering step is to define the mass, material and energy balances for each of the modules taking into consideration each of the input and output streams. Simply stated, the sum of all input mass and energy streams to a module must equal the sum of all output mass and energy streams from the module.

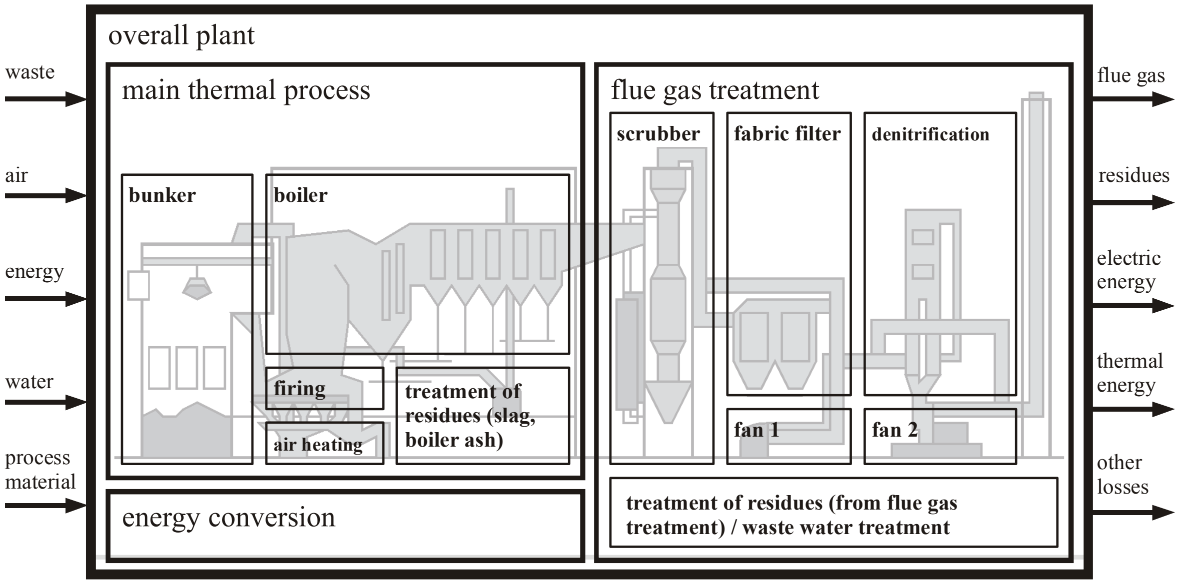

Figure 1. Balance modules for modelling a typical MSWI plant

Some streams are difficult if not impossible to measure in real time and as such these streams will require an alternative calculation strategy. For example, the mass flow and composition of the actual solid waste feed to the incinerator is difficult to measure. This is calculated backward by the Online-Balancing program in the subdivision process "air preheating, firing and boiler" from the measured values within the subdivision process "flue gas treatment".

In modern MSWI plants the connection of the Online-Balancing program can be realized directly via a dedicated OPC-Server[2]. Where possible, the program uses measured data when performing the heat and mass balance real time calculations. This measured data is imported into the program and validated before use in the model as follows:

1) Reads and records the measured data from process transmitters via the OPC-Server,
2) Converts the measured digital or analogue signals and correcting the values to the calibration of the measuring device (if necessary),
3) Checks that the measured value is valid and the transmitter is not in a failed state. This is accomplished by checking if the value is within an individually defined ratio (upper and lower limit) and
4) Checks that primary operational parameters are at steady state (The model can be used to verify that the MSWI plant primary operational parameters are at steady state in accordance with German guideline VDI 3986 [3], [4]).

[2] OPC...OLE (Object Linking and Embedding) for Process Control. An OPC-Server is a hardware device driver enabling OPC capable standard software (OPC-Clients) to communicate with external devices without additional programming work.

Furthermore, the measured values can be checked that they do not contradict with other (in over determined balancing equations) measured data and – when indicated – these data can be mathematically corrected in accordance with German guideline VDI 2048 [5] within the model.

OPPORTUNITIES FOR PROCESS CONTROL AND OPTIMIZATION

One key process parameter is the calorific value of the waste which is of special interest for the process control in MSWI plants. Measuring the caloric value of the waste in real time is impossible at this time. However, this value can be real time calculated within Online-Balancing Program with relatively high certainty by performing an energy balance of the boiler and/or by using regression formulas based on the calculated composition of waste. Variations in calorific value obviously impact the efficiency ratio of the boiler and overall plant efficiency ([2], [6]) but it also impacts the feed rate of waste to the system. In the following example of the MSWI plant in Schwandorf (Figure 2) the factors that have the greatest impact on energy efficiency and throughput of the system are discussed.

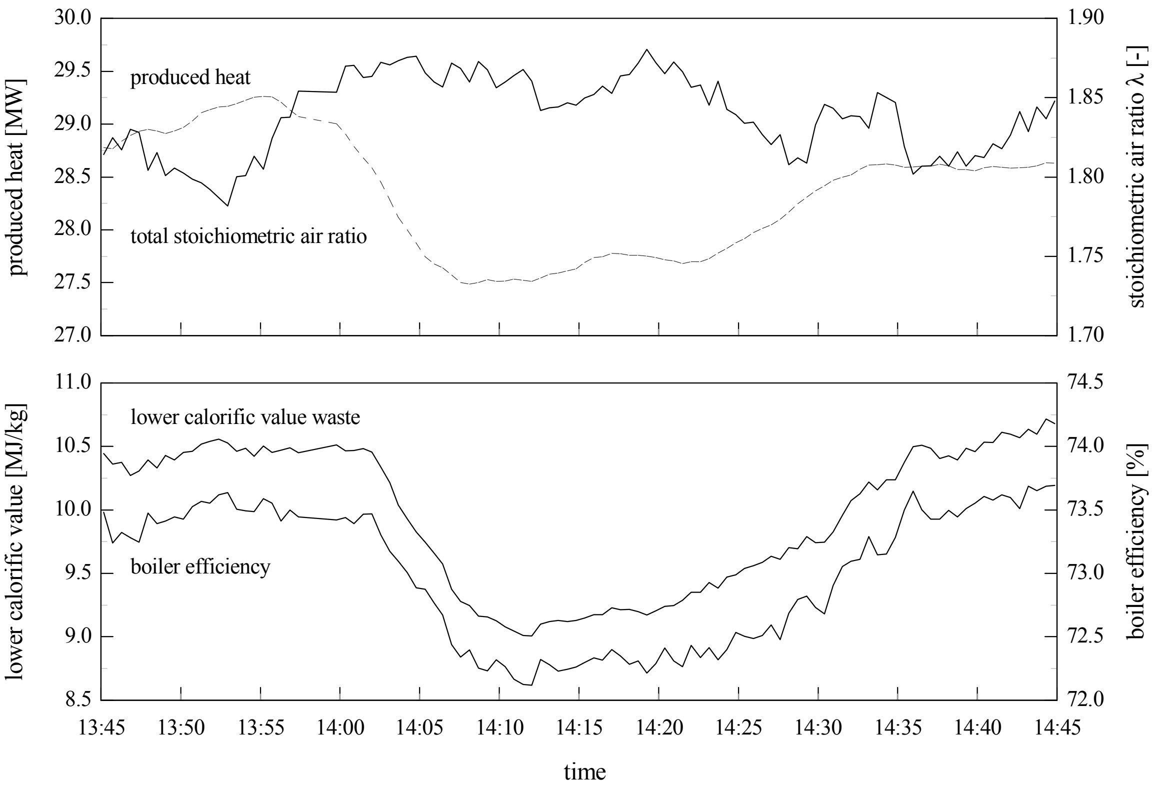

Figure 2. Lower calorific value of waste, boiler efficiency, total stoichiometric air ratio and produced heat (steam and water from grate cooling).

Figure 2 shows the rapid decrease in calorific heating value from approximately $h_{u,1}$ = 10.5 MJ/kg (in the following termed as state "1", 14:00 hours) down to $h_{u,2}$ = 9.0 MJ/kg (state "2", 14:12 hours). The produced heat (approximately 98 % steam and 2 % water from grate cooling) decreased in the same time period from over 29 MW down to 27.5 MW. The boiler efficiency ratio decreased in approximately 1.5 percent. The reason for the decrease in efficiency ratio is due to an increase in energy exiting the boiler with the flue gas since there was a corresponding increase in specific flue gas flow rate at this time (and therewith specific higher losses, related to the incoming energy). Also the ratio of mass flow rates in state "1" and "2" $\dot{m}_2 / \dot{m}_1$ increased over proportional compared to the ratio of lower calorific values $h_{u,1} / h_{u,2}$ (for $h_{u,1} > h_{u,2}$). "The throughput in state "2" is 15 % higher then in state "1".

The overall plant has a lower energy efficiency due to the low waste heating values and the higher flue gas flow rate. The higher flue gas flow rate results in increased energy consumption by the exhaust fans and the higher energy consumption for reheating the flue gas before the denitrification plant (Figure 1).

In addition to the waste and auxiliary fuel there are a number of other streams entering the plant (condensate from steam supply, water from district heating, reagents, etc.). When assumed that these other streams have negligible enthalpies compared to the relatively large enthalpy of the waste. For the MSWI plant in Schwandorf the net plant efficiency ratio is approximately $\Delta\eta_{A,Netto} \approx -0.2\%$[3]. This small influence of fluctuation in calorific value on the overall efficiency is caused by an almost constant total stoichiometric air ratio $1.8 \leq \lambda_{Total} \leq 1.9$ in the firing (Figure 2) which results in almost similar specific flue gas volumes ($v_1 \approx v_2$). This results from the mode of combustion control in the incinerators (incineration lines 1 to 3) of the MSWI plant in Schwandorf, where the volume flow of primary combustion air remains constant and the combustion control system regulates the mass flow of waste based on maintaining an oxygen concentration in flue gas after the boiler.

[3] This result confirms to theoretical calculations [6].

The possible affect of integrating the calculated calorific value of waste into the combustion control system[4] is shown in Table 1. States “1” and “2” are the original operational states (14:00 and 14:12 hours in Figure 2). States “2a”, “2b” and “2c” represent optimized variations of state “2“ - in these states the overall air ratio was reduced from $\lambda_{Total} = 1.85$ to $\lambda_{Total} = 1.50$. Differences between the optimized states are the stoichiometric air ratio of the grate λ_{Grate} and the temperature of preheated primary air to the grate $\vartheta_{Air,Primary}$.

state		**“1“**	**“2“**	**“2a“**	**“2b“**	**“2c”**
		operational states		„optimized” states		
$h_{u,Balance}$	MJ/kg	9.0	10.5	10.5		
$\dot{Q}_{Boiler}$	MW	27.4	28.8	28.8		
$\dot{m}_{Waste}$	t/h	13.7	12.1	11.7	11.9	12.0
λ_{Total}	-	1.85	1.85	1.50		
λ_{Grate}	-	1.05	1.06	1.10	0.80	1.07
$\dot{V}_{Air,Primary}$	10³ m³/h	40.2	40.2	40.3	30.0	40,2
$\vartheta_{Air,Primary}$	°C	180	180	180		130
$\dot{Q}_{Air,Primary}$	MW	2.5	2.5	2.5	1.9	1,8
$\vartheta_{G,Balance}$	°C	1,010	1,070	1,240	1,220	1,220
$q_{Loss,G}$	%	16.8	15.8	13.3	13.6	13,6
η_{Boiler}	%	72.1	73.5	76.3	76.2	76.2

Table 1. Calculated affect of process optimization. explanation in the text.

The calculation results indicate that process optimization is possible by decreasing the total stoichiometric air ratio which will result in higher efficiency ratios for the boiler. In order to increase waste throughput the stoichiometric air ratio of the grate (state “2b”) must be decreased and/or the temperature of the preheated air (state “2c”) must be decreased. Since the stoichiometric air ratio of the grate is already low ($\lambda_{Grate} = 1.06$ in the operational state “2”) lowering the temperature seems to be more appropriate in order to increase waste throughput.

Boundary conditions and advantages of gasification in the primary combustion unit ($\lambda_{Grate} < 1$) and post-combustion in the secondary combustion unit of MSWI plants are described in detail in [2]. The additional steam saved in this process can be used to produce

[4] In existing combustion control systems the calorific value of waste is more estimated than calculated, based on measured values (oxygen content in flue gas, produced steam flow, temperatures at inner firing walls etc.).

more electric energy within the turbines (with a corresponding reduction of bleeder steam). Additional boundary conditions that must be considered in this type incineration system (combustion / post-combustion) include: percentage of combustible materials in the ash residues (slag), the shift in heat transfer into the radiation part of the boiler (increase of $\vartheta_{G,Balance}$ in Table 1) and related effects on emissions (CO and NO_X formation, see also [2] and [7]).

CONCLUSION

Additional testing and validation of the Online-Balancing program presented here is underway at the German MSWI plants in Schwandorf, Burgkirchen and Coburg [1]. The next step in the program development will be to test it at other MSWI plants. The user interface, calculation modules, and calculation strategies developed for the Schwandorf, Burgkirchen and Coburg MSWI plants will be used for this step. Consequently, the configuration and adaptation of the program for this plant will be much quicker. Due to the application of an easy-to-learn user interface, the program can be further adapted by operational staff without significant effort and also provide more details in specific balance units (e.g. water steam cycle, wastewater treatment, etc.). This is an advantage especially for those operational staff already using their own validation (evaluation) algorithms.

The next step in the development of the Online-Balancing program is to add simplified calculation methods for heat transfer in the boiler, kinetic in flue gas treatment, etc. in order to get a modelling and simulation program The program is then effective at evaluating the complex interrelating primary operating parameters for a variety of plant configurations with the focus being on optimizing the overall plant. All in all, the operational staff now has an enhanced tool which can be used to optimize plant operations on a real time basis using comprehensive knowledge of the operations regarding energy efficiency, waste throughput, corrosion, and operating costs.

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