Beckmann, M.; Horeni, M.; Metschke, J.; Krüger, J.; Papa, G.; Englmaier, L.; Busch, M.: Possibilities of Process Optimization in Municipal Solid Waste Incineration Plants by an Online Balancing Program. In: Proceedings of the International Conference on Incineration and Thermal Treatment Technologies - IT3, 09.05.-13.05.2005, Galveston (USA)

Possibilities of Process Optimization in Municipal Solid Waste Incineration Plants by an Online Balancing Program

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Abstract

In municipal solid waste incineration plants (MSWI) there are varying waste compositions at the feeding system of the plant and changing energy output (district heating and steam). Consequently, different process conditions arise.

The optimization of these plants requires - according to the actual operating condition - detailed material, mass and energy balances, as well as further information about operational behaviour (e. g. corrosion). The newest MSWI plants are equipped with measuring process control systems delivering enough process data to allow online balancing for the different single units and, consequently, also for the overall process.

Such a detailed description of the actual state of MSWI-plants is not yet available. However, with such a tool of online balancing (also referred to as feed forward control) the operational staff will initially be able to optimize the overall process manually.

Objectives of this manual optimization are, for instance, the increase of overall energy efficiency, the saving of additional materials, longer operating period and, consequently, the improvement of economic operation and results.

In this paper the development of an online balance program, its connection to the process control system of the MSWI-plant Schwandorf in Bavaria/Germany, and the valuation of the obtained results are described. At first the fundamental basics of the balancing (method) are explained.

The illustration of the current operational state with the help of an online balance program in the waste incineration plants Schwandorf, Burgkirchen and Coburg is done in the project “EU 24 – Effectiveness of Waste Incineration Plants; Technical, Ecological and Economic Optimization.” This project, with the further project partners of the three plants in Schwandorf, Burgkirchen and Coburg, as well as the plant engineering/construction company in Munich (Martin GmbH für Energie- und Umwelttechnik München), is being supported by the State of Bavaria Department of Health, Environment and Consumer Protection as part of EU infrastructure funding for regional development (EFRE).

Fundamental aspects of balancing and evaluation

As is usual in process engineering, implementing an online balancing of MSWI-plants first requires defining the balance boundaries for the single contributing units in a multi-unit process. In Fig. 1 the outer balance unit is the plant itself with the main input streams: waste, air, energy, water, and operation material, and the main output streams: flue gas, residues, energy for utilization and losses.

Detailed balancing requires dividing the entire plant into a number of single balance units for aggregates, apparatuses, etc. ([1]). After that, these single balances can be combined to form the paramount balances, which in this paper will be termed as modules, for example for 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, flue gas treatment, etc. (Fig. 1).

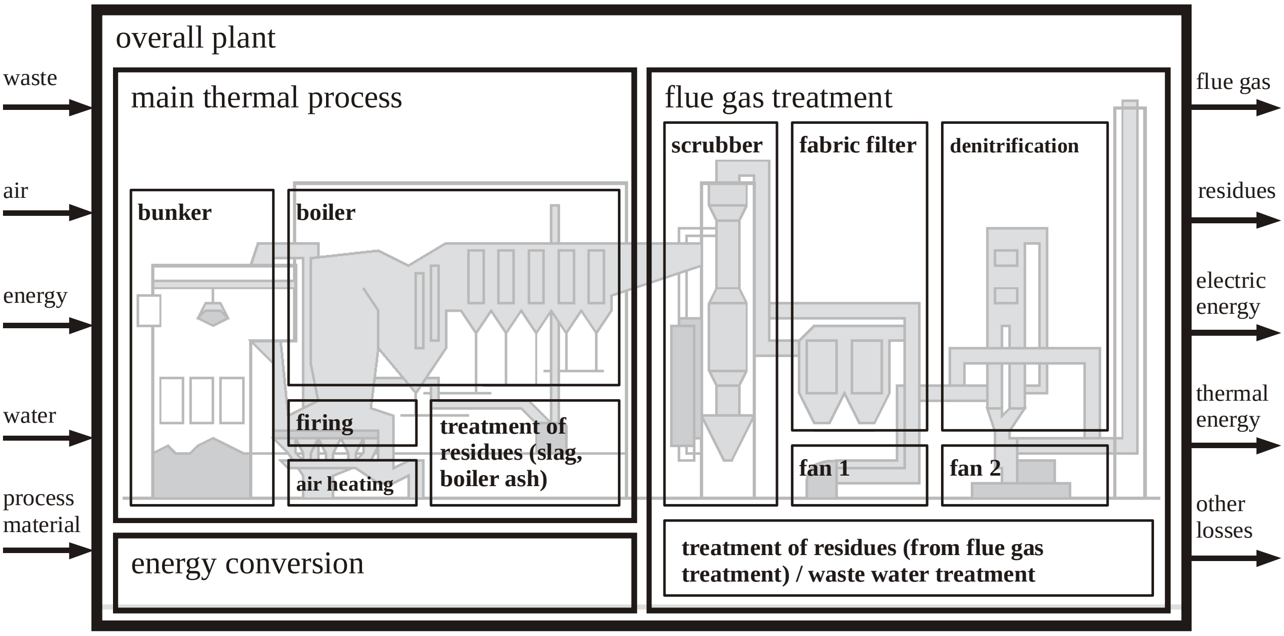

Fig. 1. Balance modules for the balancing of the MSWI-plant Schwandorf, showing only the major mass and energy flows.

For different MSWI-plants, a high degree of conformity in the subdivision process "main thermal process" on the level of modules (bunker, boiler) can be found. Consequently, good transferability of the online balance program from one plant to another with little effort is possible. This means in this paper that the balance modules for plant Schwandorf can be transferred and applied in the same manner or slightly diversified for the Burgkirchen and Coburg plants considered as part of this project, as well as for other plants.

In the subdivision process "flue gas treatment" balance modules depend on the plant configuration e.g., scrubber, fabric filter, deNOx-plant, etc. Additional balance modules may arise within waste water treatment and the disposition of residues from flue gas treatment (not illustrated in Fig. 1).

Within the subdivision process "energy conversion" for different MSWI-plants the variances between the steam cycle configuration and the existing energy output (electric energy, steam pressure levels, district heating) must be considered.

To make the online balance program available for most MSWI-plants, further completion and continuous supplementation of predefined balance modules are required for the individual process steps (thermal process, flue gas treatment)[1].

As is common in process engineering, the next process engineering step for the single balance units involves defining material, mass and energy balances taking into consideration all of the major in-

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[1] In regular modelling programs, e. g. for power plants, apparatuses are also predefined. They can be called from corresponding libraries to set up the steam cycle, for example.

put and output material, mass and energy streams. There is a requirement that the sum of all input mass and energy streams correspond with the sum of all of the output streams.

With the balance units defined above, the object of the evaluation can be performed. When the efficiencies are set up, they can then be formulated as a ratio of gain to effort with a certain balance unit connected to the input and the output energy streams. The calculation of specific materials consumption should be performed in the same manner [1].

Online balancing program for the plant Schwandorf

MSWI-plant Schwandorf – process units

With the method for balancing described in the preceding section, for the MSWI-plant Schwandorf the following process units with the accompanying balancing boundary lines can be defined (see also Fig. 1, e. g. [2] and [3])[2]:

Subdivision process "main thermal process"

- bunker: throughput about 400,000 t/a household waste, bulky waste and industrial waste, exhaustion of partial primary air, overall capacity of the plant 460,000 t/a with lower calorific value of approximately 10.5 MJ/kg,
- preheating of air: air preheating temperatures to approximately 130 °C, heating with low pressure steam 6 bar (incineration line 1-3) respectively middle pressure steam 26 bar (incineration line 4), distribution of preheated and non-preheated primary air to the first and last grate zones possible,
- firing: four incineration lines (incineration line 1-3 similar, incineration line 4 retrofitted 1992), single grates water-cooled (decoupling of heat for condensate preheating)
- boiler: steam production approximately 1,300,000 t/a with 72 bar and 410 °C (400,000 t/a waste).

Subdivision process "flue gas treatment"

- CDAS-reactor (conditioned dry absorption scrubber): SO_2 and HCl absorption with lime injection, dioxin and heavy metal absorption with activated carbon,
- fabric filter for particulate control ,
- deNOx-plant: NO_x reduction in selective catalytic reactor, reheating of flue gas with high pressure steam, three SCR units for 4 incineration lines.

Subdivision "process energy conversion"

- power supply (131,000 MWh/a), district heating (37,000 MWh/a), low and high pressure steam (282,000 MWh/a),
- power generation with three condensing turbines,
- different configurations within the steam cycle for condensate and feed water preheating.

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[2] Data for energy supply applies to 2003.

Due to the retrofitting of incineration line 4 in the year 1992, and its integration into existing plant engineering, there are a great number of configurations within the single apparatuses in the subdivision process "energy conversion". In this subdivision alone 30 balances are calculated within the online balance program (high, middle and low pressure lines, turbines, air condensator and cooling towers, preheating of condensate and feed water, pumps, etc.).

Inclusion and implementation of plant configuration in the online balance program for the plants Burgkirchen and Coburg occurs analogously.

Mass, material and energy balances for chosen subdivision processes

First, for the single modules respectively for the paramount subdivision processes, the calculation strategies for balancing, depending on the existing measuring points in the plant Schwandorf, were developed.

The general procedure for developing calculation strategies is shown in the following as example for the calculation of mass flow and lower calorific value of waste (waste enthalpy flow). The enthalpy flow of waste is of high importance for balancing of a waste incineration plant because enthalpy flow is a basic value for describing the operating state of firing and boiler on the one hand, and for calculating the efficiency ratio of the whole plant on the other

For the online balancing program for the plant Schwandorf, mass flow and lower calorific value of waste are calculated within the balance unit of the subdivision process "main thermal process".

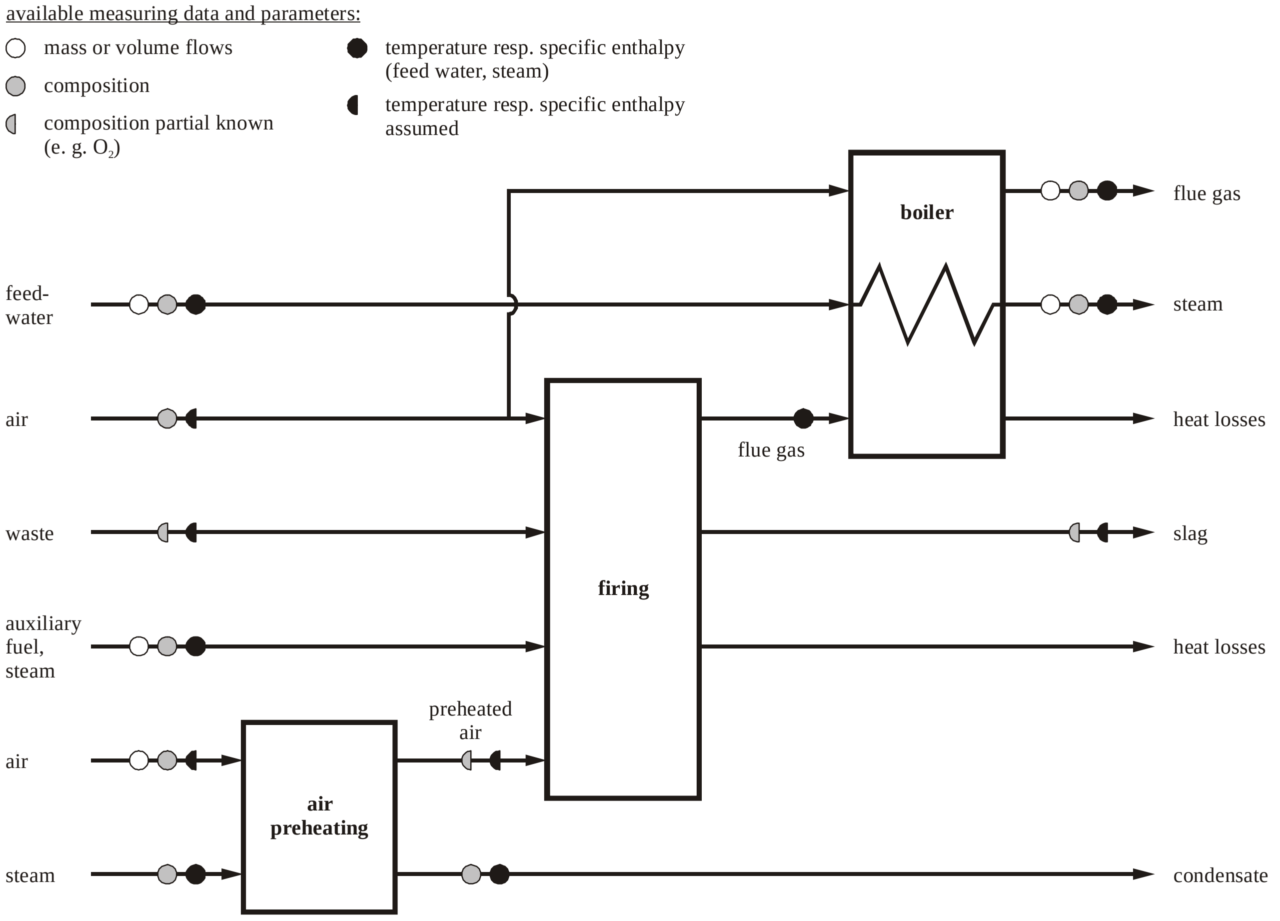

Fig. 2. Available measuring data and parameters (adequately precise assumptions) at plant Schwandorf for calculating the modules air preheating, firing and boiler, showing only important mass

Fig. 2 shows for the three balancing modules of the main thermal process, - air preheating, firing and boiler -, the mass and energy flows and the available measuring data as well as parameters (e. g. composition of air).

For a single process unit shown in Fig. 2, based only on measured data at the input and the output of the process unit or at the input and the output of the single modules belonging to the process unit, an initial closing of the balancing may not necessarily result. A corresponding calculation algorithm must be developed to link the single modules with one another.

Fig. 3 illustrates the steps for calculating the mass flow of waste actually located on the grate from the known flue gas mass flow and composition after the boiler (which are calculated before as part of the subdivision process "flue gas treatment").

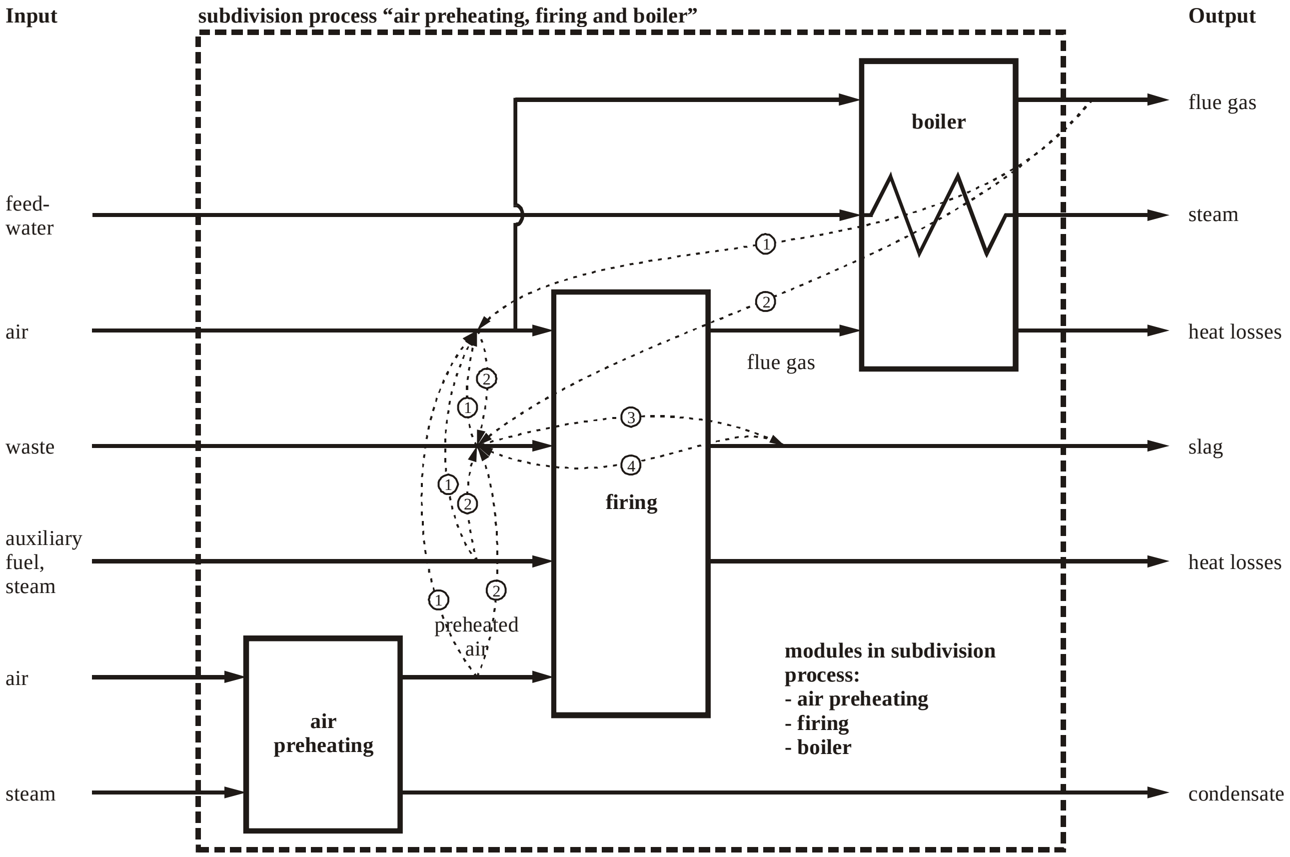

Fig. 3. Balancing of subdivision process "air preheating, firing and boiler" – in the plant Schwandorf / calculation steps 1 to 4 (illustration of important mass and energy flows.)

In step 1 (Fig. 3), with the overall mass flow based on flue gas (exiting the boiler) and based on mass flows (flowing to combustion and into the boiler and then going into flue gas) the overall mass flow air to combustion and boiler is calculated. In addition to the mass balance, a material balance for the nitrogen in flue gas (assumed as inert) is conducted by approximation of a mass fraction nitrogen in waste ≤ 1 ma.-%.

In step 2, once again via the mass balance connected to combustion and boiler, the mass flow of the reacting part of waste on grate is calculated. By assuming an ash fraction of waste and flue dust content, step 3 is the determination of the mass flow of slag and flue dust.

Next the overall mass flow of waste is calculated in step 4.

In step 5 (Fig. 4), the preheating of air is balanced to obtain the enthalpy flow transferred to the heated air supplied into the combustion.

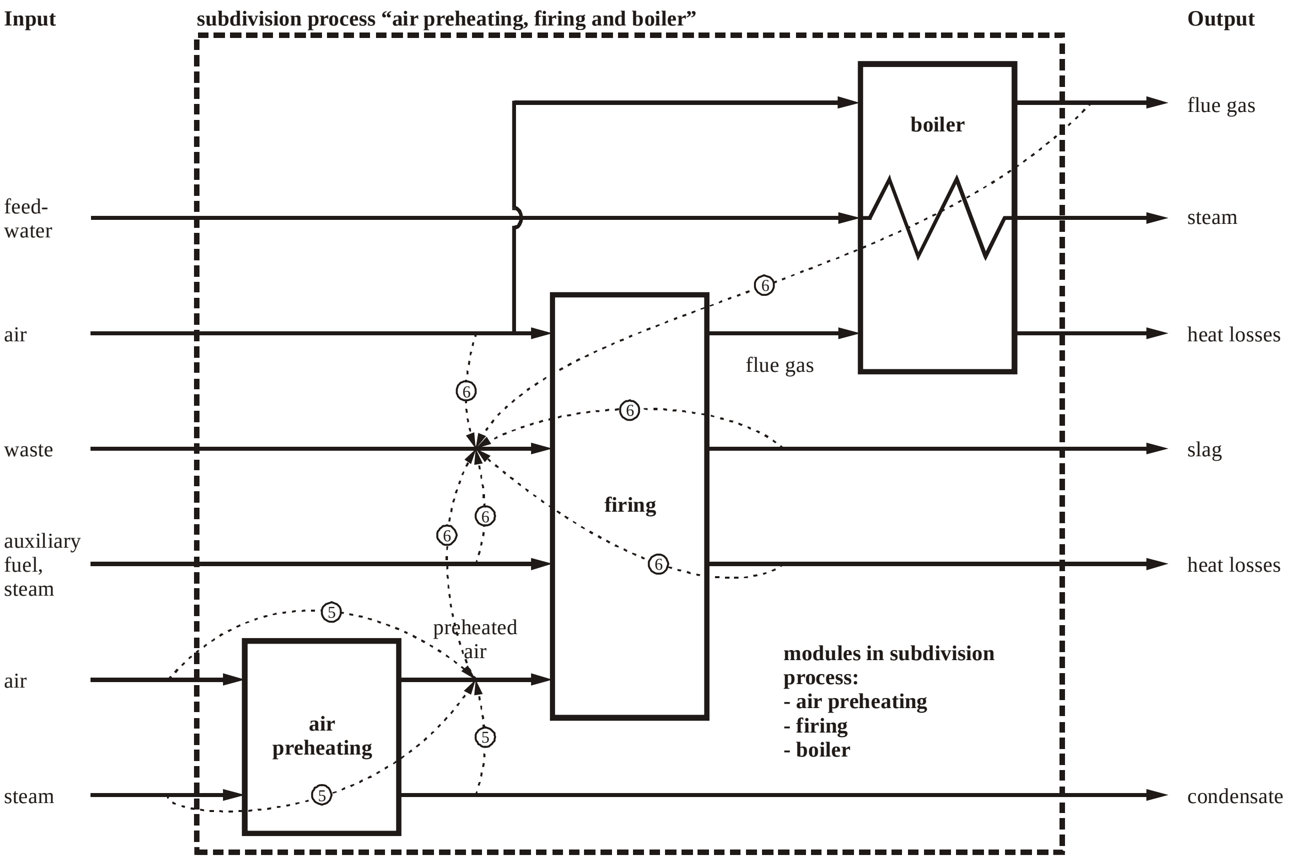

Fig. 4. *Balancing of the process unit "air preheating, combustion, boiler" in the waste incineration plant in Schwandorf. Calculation steps 5 and 6 (illustration of important mass and energy flows.)*

In step 6, the lower calorific value of waste actually incinerated on the grate can be calculated.

In the same way calculation strategies were developed for all other modules of the specific process units based on available measuring data and known parameters and in the online balance program [2].

Connection of the online balance program to the process control system of the plant

In the MSWI plant Schwandorf, the connection of the program is realized directly via an especially installed OPC-Server[3]. Consequently, the actually measured values are available for balancing via a databank without bypasses.

For balancing, emphasis is placed on using only suitable and validated measured values are used for calculations. This validation is carried out within the online balance program by the following steps:

1) Reading/recording the measured data signals via the OPC-Server connection,
2) Converting the measured signal corresponding to the calibration of measuring device if necessary,

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

3) Checking the measured value if the value is within an individually defined ratio (upper and lower limit) and
4) Checking the measured value - if the value is defined as indicator parameter (see below) - to see if it can be allocated to a practically stationary state.

Furthermore, balancing necessitates that the plant be in a practically stationary state at the time of observation. Non-stationary processes (e.g. heating or cooling of heat exchange surfaces, filling or discharging of vessels) are not taken into account as part of the online balancing program.

The probability of getting a stationary state for all used measured values (in this case 285 measured values) at any particular moment and thus in accordance with the criteria of acceptance tests for steam power plants [4]) is very low. Therefore, one must take into consideration that not all measurable values are significant for calculation results.

As part of the online balancing program a division occurs in form of

- measured values representative for dynamic operation conditions and relevant for calculation results – in the following so-called “indicator parameters” and
- measured values where this is not the case.

For the indicator parameters, a check as to the of fulfilment of practically stationary operational state in accordance with German guideline VDI 3986 [4] can be done using the higher chosen tolerance criteria noted in a later section of this paper. This approach examines the relevance of other measured values, which are not classified as indicator parameters, by subjecting them to a statistical variance analysis according to German guideline VDI 2048 [5] (checking of confidence intervals). In doing so the variances are not a test or check criteria for the stationary state but can be calculated for additional evaluation purposes.

The calculation of the actual operation state only occurs when a stationary state can be found for all indication parameters as described before.

Results of balancing, evaluation

Results of balancing

Plant data recording systems show the actual values measured in the plant and the time behaviour of these values. These are, e.g., air and flue gas flow volumes, flue gas concentrations, amount of produced steam, and steam parameters. With the above-described online balancing program the mass, material and energy balances in all essential process units and associated efficiency ratios and specific characteristic values such as process material usage, specific steam amounts, etc., are calculated in addition to the shown data.

The following is of special interest:

- Efficiency ratios for the overall process (total, electric, thermal) and for single balance units (boiler efficiency, turbines, condensate preheating, etc.),
- Mass flow, composition and lower calorific value of waste located on the grate,
- Input of process and infiltrated air in the combustion and boiler as well as in apparatuses of flue gas treatment,
- Air volume flow and air heating temperatures before combustion, etc.

With these data, the operational staff has additional information for optimization of plant operations. Furthermore, a direct integration of this information as additional control variables into existing control concepts of the plant (e. g. lower calorific value of waste into combustion control system) is possible.

Concerning the above-mentioned data calculated by the online balancing program, at first the plant efficiency ratios (total, thermal, electric) are discussed below. For calculation the efficiency ratio the sum of net energy relates to the sum of incoming energies.

Concerning the incoming energy flows, one can roughly differentiate between energy from waste (approximately 80 % of total incoming energy), auxiliary energy (electric, approximately 5 %), condensate from steam supply (approximately 5 %), and return flow of district heating water (approximately 10 %). In the plant Schwandorf, net energy is produced thermally (low and high pressure steam, district heating and other consumer) at approximately 45 % of total energy input and electric energy (approximately 15 %).

The plant efficiency ratios discussed in the following are connected to Fig. 1 and defined as:

$$\eta_{P,total} = \frac{Gain}{Effort} = \frac{\sum \dot{E}_{NetEnergy}}{\sum \dot{E}_{Input}} = \frac{\sum \dot{E}_{NetEnergy,electric} + \sum \dot{E}_{NetEnergy,thermal}}{\sum \dot{E}_{Input}} \quad (1),$$

$$\eta_{P,electric} = \frac{Gain}{Effort} = \frac{\sum \dot{E}_{NetEnergy,electric}}{\sum \dot{E}_{Input}} \quad (2),$$

and

$$\eta_{P,thermal} = \frac{Gain}{Effort} = \frac{\sum \dot{E}_{NetEnergy,thermal}}{\sum \dot{E}_{Input}} \quad (3).$$

Fig. 5 is exemplary for a period of 1.5 hours that the plant efficiency ratios for the MSWI plant in Schwandorf calculated with the online balancing program. The generated gradient shows that

- the total plant efficiency ratio is at approximately 60%,
- the total plant efficiency ratio varies within the relatively short period of 1.5 hours by approximately 3.5 %, and
- the fluctuations from an energy / power economical viewpoint show a relevant magnitude (value).

With regard to plant optimization questions concerning the reasons of fluctuation arise. For discussing these questions it is necessary to focus on the relationships between the actual efficiency ratio and the associated operational state of the plant. The operational state can be characterized by a number of measured values as well as by values calculated with the online balancing program.

The online balancing program was initiated in mid-January 2005. Thus, the initial results are given here. Further analyses using these results are still forthcoming. But, the fluctuation of the total plant efficiency ratio as well as thermal and electric plant efficiency ratio can be discussed based on this single set of results and calculated values, which were also calculated with the online balancing program, such as mass flow and lower calorific value and net energy total, thermal and electrical.

This evaluation is done here exemplary with the time period 13:00 to 13:10 hours during which an operational disturbance occurred in incineration line 1. In the considered period incineration line 2 and 3 were almost constant. That means that variations in plant efficiency ratios are connected to variations in operation of incineration line 1. Incineration line 4 was out of order during this period.

The initial observation is that during the period from 13:00 to 13:10 hours the thermal plant efficiency ratio increased only slightly (from 50 % to 51 %) and the electric plant efficiency ratio also only decreased slightly (from 12.5 % to 11.5 %). During this period the total plant efficiency ratio is almost constant.

The total net energy decreases in the period 13:00 to 13:10 hours significantly (Fig. 5). This significant reduction of total net energy is caused by an also significantly reduced waste energy flow and, consequently, resulting in a reduced steam enthalpy flow (see below). In the given period specifically less electric energy was produced (requirement: high pressure steam). The impact on the total plant efficiency ratio is a reduction of the production of electric energy and a corresponding reduction of the absolute energy conversion. In the example discussed here, there is no shifting from electric to thermal energy.

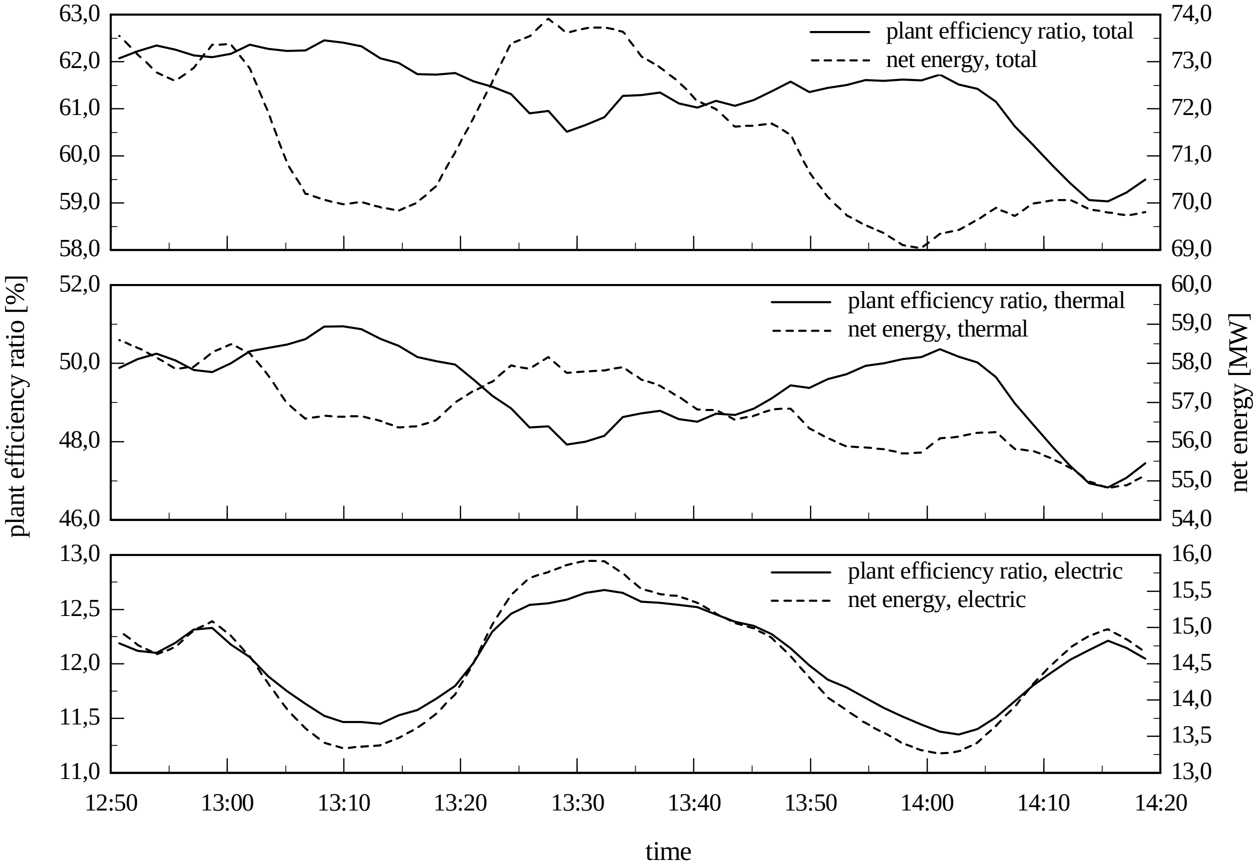

Fig. 5. Calculated plant efficiency ratios for the MSWI plant Schwandorf on January 11, 2005 from 12:50 to 14:20 hours in comparison to net energy.

Fig. 6 shows for incineration line 1 the gradient of mass flow and lower calorific value of the waste, oxygen concentration after boiler, and volume flow flue gas after the fabric filter. In the period from 13:00 to 13:10 hours the reason for the reduction of produced steam flow from approximately 42 t/h to 32 t/h is based on the reduction of the converted waste on grate connected to an almost constant lower calorific value. This means the total energy flow coming in with the waste decreases. The decrease of mass flow waste is caused here by an operational disturbance. This disturbance does not show up in the total efficiency ratio during the same period.

The following gradient in total efficiency ratio can no longer be solely evaluated based on the operational state of incineration line 1 because in the following time period there were also variations (fluctuations) in incineration line 2 and 3. Evaluation and interpretation consequently become more complex and needs further analysis.

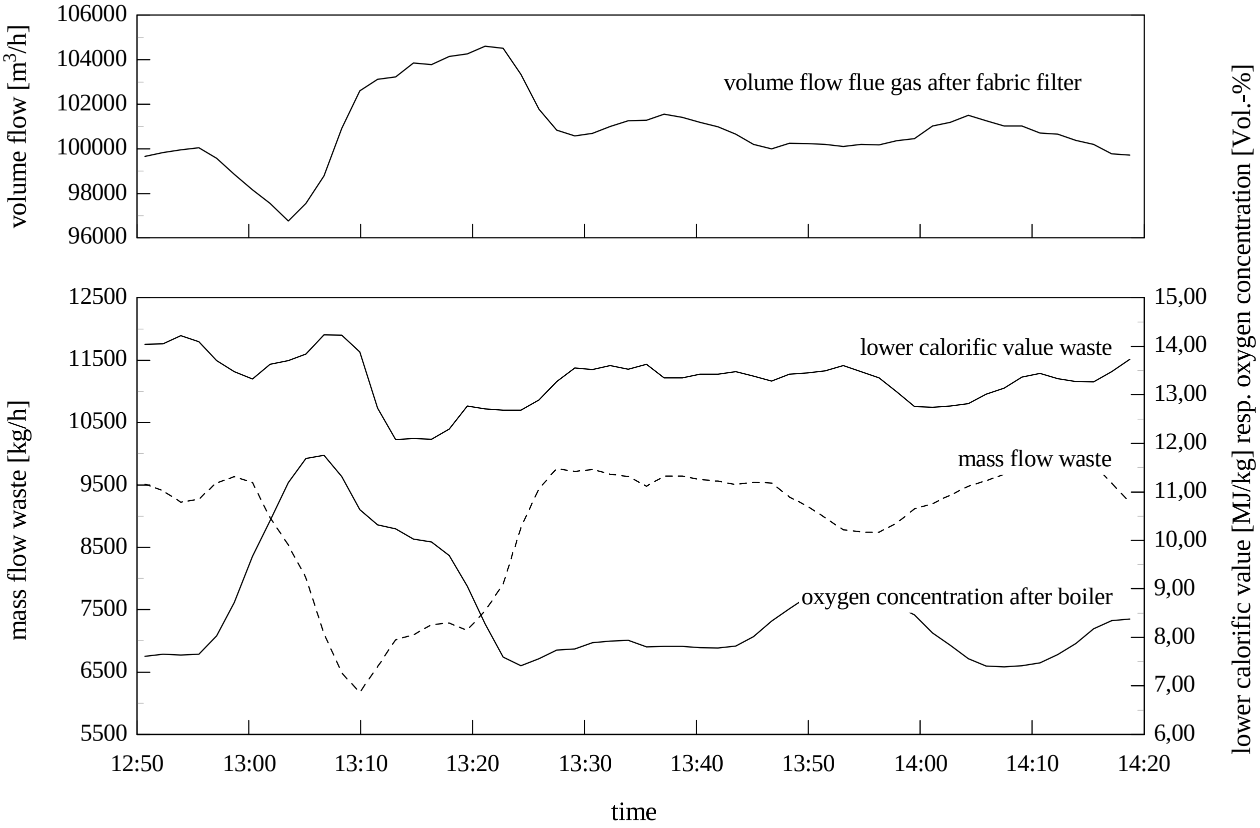

Fig. 6. Relationship between oxygen concentration after boiler, mass flow and lower calorific value of waste actually located on the grate (below) and volume flow flue gas after fabric filter (top), incineration line 1.

As mentioned above, the operational state in MSWI plants is currently described by the operational staff with measured data from the plant. These data are recorded via the process control systems of the plant and in most cases displayed by plant data recording systems as single values or as time gradient. By applying the described online balancing program it becomes possible to not only show the measured values but also get further results calculated from these values[4] and to include them in the analysis. With both – measured and calculated values (here in sum referred to as operational values) – the actual operational state can be described more comprehensively.

This comprehensive description of operational state can also be utilized for a foresighted planning and influencing of plant efficiency ratios in order to optimize plant operations. The more data available, the more easily describable are the various interactions. However, further tests and examination work are required.

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[4] by mass, material and energy balancing of single apparatuses or resp. process units

Interpretation of balancing results

For interpreting the balancing results the two most significant factors regarding the influence on balancing results are:

- measuring inaccuracy
- tolerance criteria for detecting a stationary state.

Influence of measuring inaccuracy on balancing results

The influence of not avoidable measuring inaccuracies is of special importance for balancing results. Every measured value x_i of a measured parameter X_i is subjected to a number of systematic influences (e. g. installation error of temperature measuring devices in flue gas channel) and unavoidable random influences (disturbances, influence of environment). Consequently, the measured value will always differ from the "real" value for the measured parameter. The "best" estimated value for the real value μ_i is the arithmetical average value $\overline{x}_{i,n}$ from a number n of single measured values x_i:

$$\overline{x}_{i,n} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{4.}$$

The difference (error)

$$\mu_i - \overline{x}_{i,n} \tag{5}$$

of a single measured parameter becomes part of the calculation of all further measured parameters based on this measured parameter. The combination of these differences (errors) can be determined by applying the principle of error propagation. This concerns not only the results of balancing calculations but also the results of calculations of material properties being dependent on temperature, for example specific heating capacities or results from water steam tables integrated in the online balancing program. Here the accuracy of calculation of total plant efficiency ratio are discussed:

As explained previously, the total plant efficiency ratio is mainly calculated:

- at input: enthalpy flow of waste, enthalpy flow of condensate from steam supply, return flow of district heating water and auxiliary energies
- at output: energy flow of produced electric energy, enthalpy flow of supplied low and high pressure steam and district heating water.

The so-called confidence interval for the total plant efficiency ratio $V_{\eta_{P,total}}$ – that means the interval including the real value for the total plant efficiency ratio with a statistical assurance p (p is normally chosen with 95 %) – can be calculated with the principle of error propagation from the origin parameters for efficiency ratio calculation and their confidence intervals. The confidence interval for measuring parameters itself can be obtained, for example, from the German guideline VDI 3986 [4]. There the following confidence values are given for different measuring devices: mass flows ± 1 %, temperatures ± 1 K, pressure (overpressure) ± 0.25 %, electric power ± 0.6 %, etc. Assuming a confidence interval of ± 1 % for the origin values for calculating the plant efficiency ratio, the course represented in Fig. 7 results.

Here it is mentioned that differences in balancing resulting from a metrological over-determination of single balance units, by using an adequate method of compensation, have to be eliminated (calculation of so-called compensated measured values). In the plant Schwandorf differences in balancing arise, for example when balancing the high pressure line, where all incoming (steam from boiler) and outgoing (steam to turbines, to denitrification, for supply, etc.) steam flows as well as when the associated steam parameters are measured. Overall, the balance error is in the range 1 to 2 % for both mass and energy balance. Consequently, Fig. 7 remains valid. The precise influence of the compensated measured values on the balance result must still be investigated.

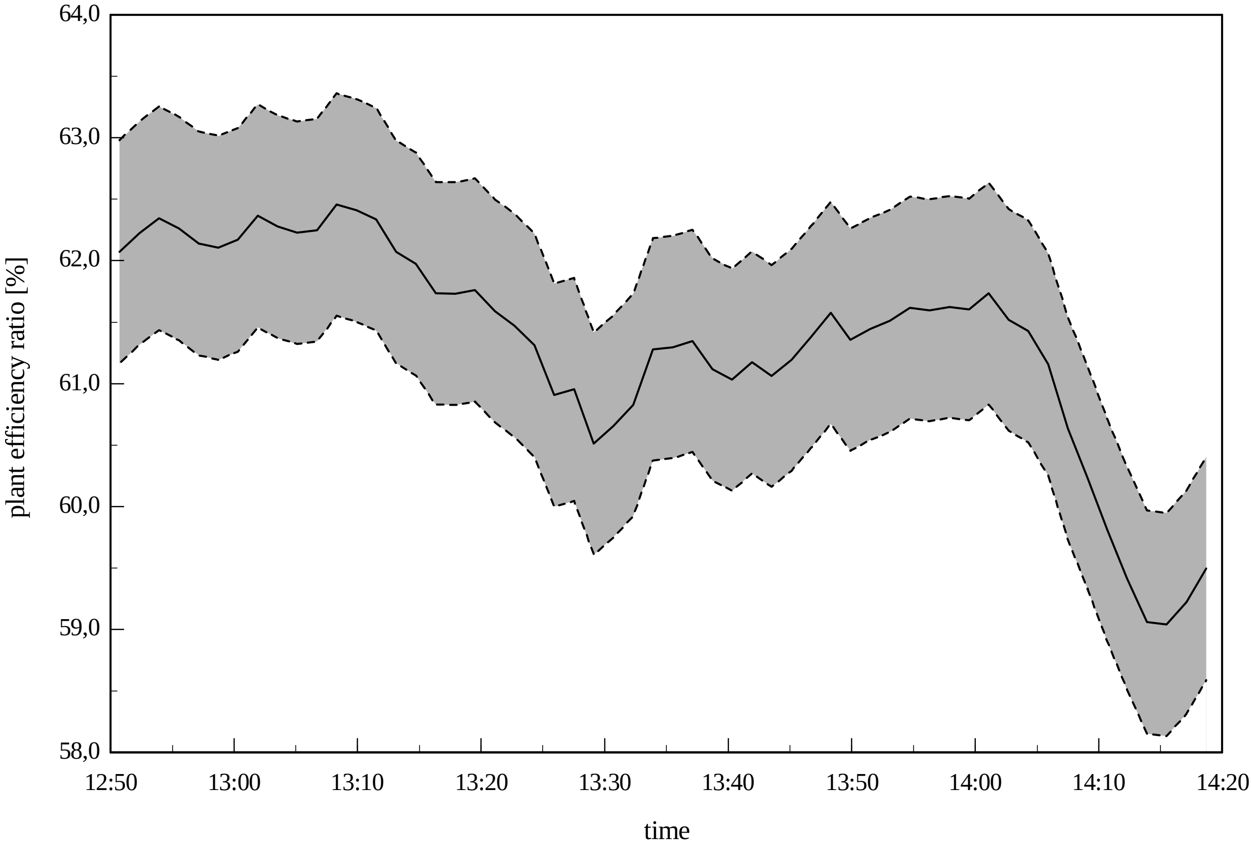

Fig. 7. Total plant efficiency ratio of the MSWI plant Schwandorf including the associated confidence interval assuming ± 1 % for the confidence intervals of origin values for calculation of total plant efficiency ratio, explanation in the text.

Influence of tolerance criteria for detecting a stationary state on balancing results

According to guideline VDI 3986 [4], a practically stationary operating state is given when for a specific measured parameter X_i the difference between the average value of the total number of measuring procedures n and the average value of this total number of measuring procedures minus 1 (n - 1):

$$\bar{x}_{i,n} = \frac{\sum_{i=1}^{n} x_i}{n} \text{ und } \bar{x}_{i,n-1} = \frac{\sum_{i=1}^{n-1} x_i}{n-1} \quad (6a, b)$$

is smaller than an accuracy ε_i to be chosen individually for the measured value:

$$\left|\frac{\overline{x}_{i,n} - \overline{x}_{i,n-1}}{\overline{x}_{i,n}}\right| = \left|\frac{\Delta\overline{x}_i}{\overline{x}_{i,n}}\right| < \varepsilon_i \tag{7}$$

In the guideline VDI 3986 tolerances for evaluation of average values for measuring pressure and mass flow $\varepsilon_i = 0{,}05\,\%$ are proposed[5]. Therefore, a determination of the stationary operational state is assumed to be accomplished within 15 to 25 measurement procedures.

As the discussed plant operation is permanently subjected to fluctuations, the accuracy ε_i has to be chosen higher compared to the acceptance tests. Thus, one can assume that all ε_i have to be equal for the main measured parameters. With a higher ε_i more stationary states can be found than with a lower ε_i. Fig. 8 shows for the period from 12:50 to 14:20 hours (on January 11, 2005) various ε_i for detecting a given number of stationary states by using 10 and 15 measured values for the calculation of the average values *($\overline{x}_{i,n=10}$ und $\overline{x}_{i,n=15}$).*

Percentage of detected stationary states	[%]	0	5	10	20	50	100
accuracy $\varepsilon_{i,n=10}$	[%]	< 0.422	0.591	0.733	0.908	1.600	5.380
accuracy $\varepsilon_{i,n=15}$	[%]	< 0.325	0.464	0.543	0.706	1.148	3.479

Fig. 8. Example for percentage of detected stationary states of maximum possible stationary states depending on the number n of measured values used for the calculation of average values (n = 10 and n = 15).

Fig. 9 shows that

- the number of detected stationary operating states with decreasing ε_i and decreasing number n of measured values for calculating the average values decreases, and
- consequently in larger intervals operating states can be calculated, that means that possibly extreme states are not illustrated.

Furthermore it shows that

- results gained from calculating the actual operating states with consideration of stationary states and without that consideration only differ slightly.

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[5] The proposed tolerance criteria for temperature measurements is given with 0.1 K absolute. For unification of the validation procedure within the program for measured values temperature measurements were also validated with relative differences (in %).

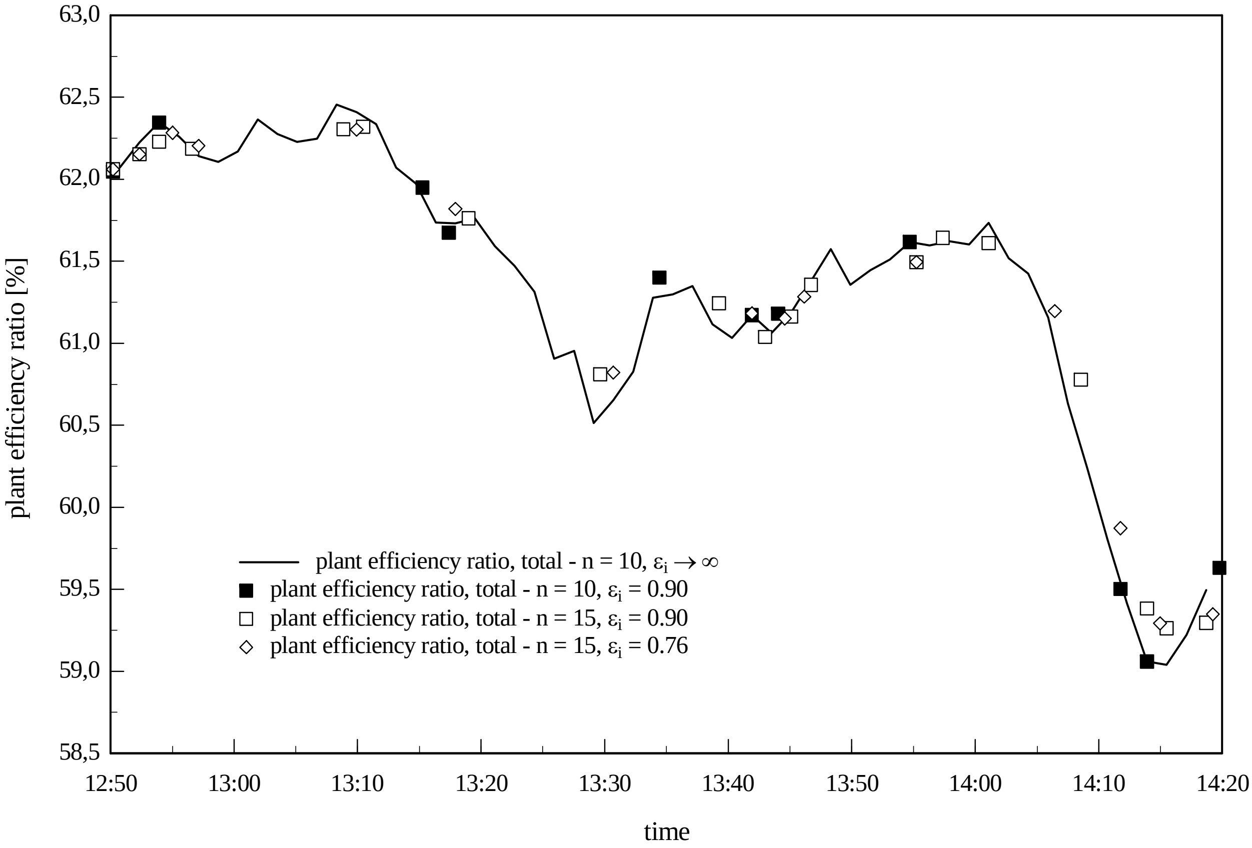

Fig. 9. Influence of considering the stationary state depending on the given accuracy ε_i and the number n of measured values used for the calculation of average values, explanation in the text.

Further proceeding

The online balancing program represented here is being presently tested and further validated in the MSWI plant Schwandorf. As next steps the program will also be applied in the plants Burgkirchen and Coburg. Here - for the set up of the user interface and the development of calculation strategies - predefined calculation modules will be used which were created during the project implementation in Schwandorf. Consequently, the configuration and adaptation of the program for other plants can be achieved much more quickly.

Due to the application of an easy-to-learn user interface, the program can be further adapted by operational staff without extreme effort and also provide more details in specific balance units (e. g. water steam cycle, wastewater treatment, etc.). This is an advantage, especially for operational staff, already using their own validation (evaluation) algorithms which can be conveniently added to the program. When validating or evaluating the calculation results, the balance program compared very well in detecting fluctuations and contradictions in the plant data recording systems. In MSWI plants today this is usually not possible because the data recording systems are generally not equipped with internal validity checks. For evaluating the effective main operating parameters, which are complex in interacting with one another, and the influence of different plant configurations with focus on optimizing the overall plant, the online balancing program must be enhanced on basis of simplified calculation methods (for combustion, boiler, flue gas treatment, etc.) in a next step. All in all, the operational staff now has an enhanced tool which can be used to optimize plant operation on basis of comprehensive knowledge on the given (current) operational state regarding energy efficiency, throughput performance, decrease of corrosion, operating costs, etc.

Symbols and abbreviations

Symbols and abbreviations

Δ	difference
ε	accuracy for detecting the stationary state
η	efficiency ratio
μ	real value of a measured parameter
E	energy
n	number
OPC	Object Linking and Embedding for Process Control
p	probability
V	confidence interval
x	measured value (for the particular measured parameter
X	measured parameter

Indices, lower case

η	efficiency ratio
electric	electric net energy
i	index for the particular measured parameter resp. the measured value
P	plant
thermal	thermal net energy
total	total net energy

Indices, upper case

‾	average value
·	flow (mass flow, energy flow, etc.)

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