Kaiser, M.; Spiegel, W. (2021)

Corrosion/Fouling Environment Evaluation in Waste Incineration and Biomass Plants

Übersetzung des deutschsprachigen Artikels

Corrosion/Fouling Environment Evaluation in MVA und Biomasseanlagen

In: Beckmann, M. und Hurtado, A. (Hrsg.): Kraftwerkstechnik 2021
Power Plant Technology, Freiberg: SAXONIA Standortentwicklungs- und -verwaltungsgesellschaft mbH, 2021
S. 119-129

Corrosion/Fouling Environment Evaluation in Waste Incineration and Biomass Plants

Authors: Dipl.-Ing. (FH) Marie Kaiser, Dr. Wolfgang Spiegel

1. Thermochemical conditions on heat exchanger surfaces.

Corrosion/Fouling Environment Evaluation (CEE®) measures record and evaluate the thermochemical conditions on the flue gas wetted side of the boiler tubes in a steam generator. Why is the application of these measures a relevant step for the optimization of power plants with materially complex fuels, such as waste and waste wood? This paper attempts a classification, and an answer.

The design and the mode of operation of the furnace means certain minor components of the fuel, together with the combustion gases, are transferred into the flue gas flow and can thus come into contact and interact with the heat exchanger surfaces of the steam generator. The design, the boiler materials used, and the operating mode of the steam generator all influence the type, intensity, and dynamics of the interactions between the flue gas constituents.

Depending on these boundary conditions, thermochemical conditions develop on the heat exchanger surfaces that can have a considerable influence on the economy and efficiency of the steam generator during one or more operating periods. This is because corrosion and deposit formation (fouling) can develop depending on these conditions. The more severe these processes act, that means the more severe the corrosion or fouling, the more detrimental the effects. These include shorter operating periods, unplanned downtimes, lower energy efficiency, higher maintenance costs, lower availability, and higher consumption of operating materials.

The interaction of the properties of fuel, firing and steam generator is shaped by particular characteristics. These include the type and proportions of the fuel's constituents; the firing system; the given boiler materials and their respective temperatures (pressure stage and superheat); the locally transferred heat quantity (heat flux density); the online cleaning; the extent of transient operating conditions; the load; the operating period; and – last but not least – the presence of SO_3 in the flue gas.

As the flue gas cools as it progresses through the system the thermochemical conditions on the heat exchanger surfaces change. In addition, many heat exchanger surfaces have local characteristics that can contribute to small-scale thermochemical changes. This results in complex corrosion and fouling interactions.

These are thus spatially and temporally resolved effects, in which there are both general effects that have an impact on all heat exchanger surfaces of a steam generator over the entire operational period, and other small-scale, or short-term, consequences.

The multitude of influencing parameters and their respective changes make it difficult to reliably control the effects of corrosion and fouling in a uniform manner from the beginning of operation with process engineering or material concepts. On the contrary, operational practice shows that each steam generator – whether in waste incineration plants (WIP), refuse-derived fuel power plants or biomass incineration plants – has special thermochemical conditions to which specific adjustments must be made to optimise or reduce the adverse effects of corrosion and fouling.

However, steam generators used outside the area of waste fuels – for example for energy use in thermal processes of the circular economy, including metal recycling – are also subject to specific thermochemical conditions on the heat exchanger surfaces. In these plants, too, corrosion and fouling can lead to adverse economic effects.

Thus, there is a need to make a corrosion/fouling evaluation of the individual steam generator based on its thermochemical conditions ("environment") and to derive optimization steps from this. This – in a nutshell – is what the CEE measures do.

The CEE measures expand the level of information on the operational processes of a steam generator, complementing the control and monitoring of the core processes (i.e. fuel treatment, energy utilisation, as well as occupational health and safety and environmental protection-related concerns). The use of CEE measures opens up the view of certain process characteristics and thus enables new options for action for the operational practitioner.

Examples of this include:

- In the design and construction phase of the power plant, the fuel can be subjected to a thermochemical evaluation by means of CEE measures through suitable test combustion. This is a particularly useful step for more homogeneous fuels, such as biomasses or substitute fuels. Among other things it allows the corrosion potential emanating from a fuel to be identified. The selection of materials or protective coatings for certain boiler components can be narrowed down based on this step.
- In the post-commissioning phase (first operational period), the actual behaviour of the steam generator regarding corrosion and fouling can be shown and evaluated for the first time with the use of CEE measures. The thermochemical conditions on the heat exchanger surfaces become apparent at the earliest possible stage and can be adjusted or optimised if necessary. This step is relevant both for the plant builder, as warranty obligations can be better fulfilled, and for the plant operator, who in this way learns to better understand and influence the behaviour of the steam generator at an early stage.
- In a planned change phase in the fuel or the mode of operation of a power plant that has been in normal operation for several years, a before-and-after comparison (i.e. application of the CEE measures before and after the change) can be used to show and assess the fouling and corrosion risks and whether adaptations are required. These changes may also involve the use of additives, for example.
- In the case of an unplanned change, e.g. strong and frequent load changes or an unexpectedly added fuel, CEE measures carried out at short notice make it possible to identify and evaluate the impact of these changes with regards to the corrosion and fouling effects.

- In the case of a planned increase in energy efficiency, the targeted material temperatures, and the materials suitable for this, can be tested by CEE measures in advance of the intervention.

2. CEE Measurement technology, tools, and aids

The CEE measures are divided into standstill-accompanying (section 2.1.) and operation-accompanying measures (section 2.2.).

An inspection during operation with the help of a high-temperature camera (section 2.3.) is a hybrid which combines these two types of measure.

In addition to the measures accompanying shutdown and operation, the operational measurement technology available at the respective power plant site can also be included in the evaluation of the thermochemical conditions (chapter 2.4.).

2.1. Measures accompanying shutdowns

The measures accompanying the shutdown achieve better informative results if the boiler is scaffolded in all relevant areas while still dirty so that all heat exchanger surfaces can be reached for inspection.

Boiler inspections by experts are carried out in the soiled state first, and then in a state where the pavements were cleaned off.

Both inspection states produce relevant findings and complement each other. The inspection in the still dirty condition allows access to the thermochemical conditions on the heat exchanger surfaces. The inspection in the clean condition refers primarily to the corrosion phenomena and the loads on the materials caused by corrosion or erosion, i.e. the extent of erosion.

Various measures are carried out during the inspections, depending on the phenomena found. Important elements include the visual assessment of the pavement situation; the photographic documentation; the interpretation of the pavement structures as an image of the flue gas flow; the sampling of pavements or corrosion products; the two-dimensional inspection of the corrosion effects; the selective measurement of residual wall thicknesses or layer thicknesses; and the documentation of the measurements in the form of diagrams or embedded in a database structure. The findings can be used directly for reactive maintenance with experts providing appropriate recommendations for action in a timely manner.

To reduce the risk of unplanned downtime in the following transit time, it is particularly important that the experts detect all the particularly worn positions of the heat exchanger surfaces and mark them for remedial work.

The shutdown findings provide a picture of the general and local exposure to corrosion and fouling, summarised after each transit period. If these findings are collected after each operating period, the strategy for predictive maintenance can be derived from them over the course of several transit periods. The findings collected during the inspections are processed over the course of the years and are additionally linked to information from other sources (replacement plans, grid measurements, operating data, etc.).

This procedure particularly offers economic advantages, as maintenance and replacement measures can be distributed over several years and planned well in advance. This helps to avoid long revision times and complex revision procedures and to achieve a constantly high level of annual operating hours.

The shutdown accompanying measures reveal their significance primarily in relation to the experience and skill of the experts carrying out the work. The options for action that they devise form the basis for measures accompanying operations during the next transit period.

2.2. Measures accompanying operations

Different probes and sensors are available for the measures accompanying operation that are temporarily inserted into the steam generator at suitable positions to collect information or gather data. The advantage here is that the time or period of the measure can be freely selected, in contrast to the measures accompanying standstill. Typical, atypical, deliberately induced, and unforeseen operating situations can be evaluated and interpreted in this way. This can be done by making comparisons with other plants or by using sensors/probes at different points in time, for example.

In addition to the advantageous time resolution of thermochemical conditions, the measures accompanying operation also offer the option of good spatial resolution. This is because the application location of sensors or probes can be freely specified (depending on available or retrofitted openings on the boiler or accessible external positions of the heat exchangers).

There are two types of application for **sensors**:

- For evaporator walls: thermocouple pairs are attached to adjacent tube web positions on the outside of the tube wall. This allows the local heat flux density to be determined (i.e. the amount of heat that is transferred via the boiler tube, from the flue gas into the medium). Along with the material temperature, the heat flux density is a relevant thermal parameter of the thermochemical conditions.
- For superheater tubes: thermocouples are attached to contact heating surfaces – one thermocouple per superheater coil is fitted before the boiler's entrance and one after the exit (i.e. at positions not in contact with flue gas). This makes it possible to determine the heat absorption for each coil or for a section of the coil. In this way a spatially resolved picture of the contamination is obtained which enables targeted cleaning measures to be implemented.

The **probes** also record the chemical conditions. Depending on the type of probe, various aspects of these conditions can be revealed and evaluated, including corrosion processes, coating properties (all material states, such as stratification, zoning, material-substance reactions), the saturation of salts, the type or load and proportions of flue gas constituents, and the sulphation performance.

Currently, the following probe types are available for CEE measures:

- **T**emperature-**R**ange **P**robe (TRP), designed as an evaporator or superheater probe (cf. Figures 1 and 2).
- Grid probe
- ASP probe (**A**sh-**S**alt **P**roportions)
- Sulphation probe

The respective probes characterise the chemical conditions in specific ways.

TRP probe: this fulfils the requirement of an individually designed temporary heat exchanger, which is introduced into the flue gas flow at a specific time, remains for a specific period and "experiences" everything in the same way as the surrounding boiler tubes. Probe and boiler tubes are exposed to the same thermochemical conditions. The probe is thus a real test rig (see Figures 1 and 2). After the probe has been used in the boiler, all relevant information is available on the probe body and can be specifically evaluated by laboratory tests. Depending on the question, the focus of the investigation is on the materials used (e.g. different material compositions or different protective coatings); on the corrosion processes and causes; or on the coating properties. Most probes are only used once, as they are subsequently examined destructively in the laboratory.

The experience from shutdown and damage investigations is also incorporated in the planning, design, and application of TRP probes. This helps to specifically record the relevant thermochemical conditions and to present and evaluate them by means of laboratory investigations.

The application experience with TRP probes shows that comparative probe tests lead to particularly valuable findings. These include comparative material tests or before-and-after studies conducted during specifically changed fuel and/or operating conditions.

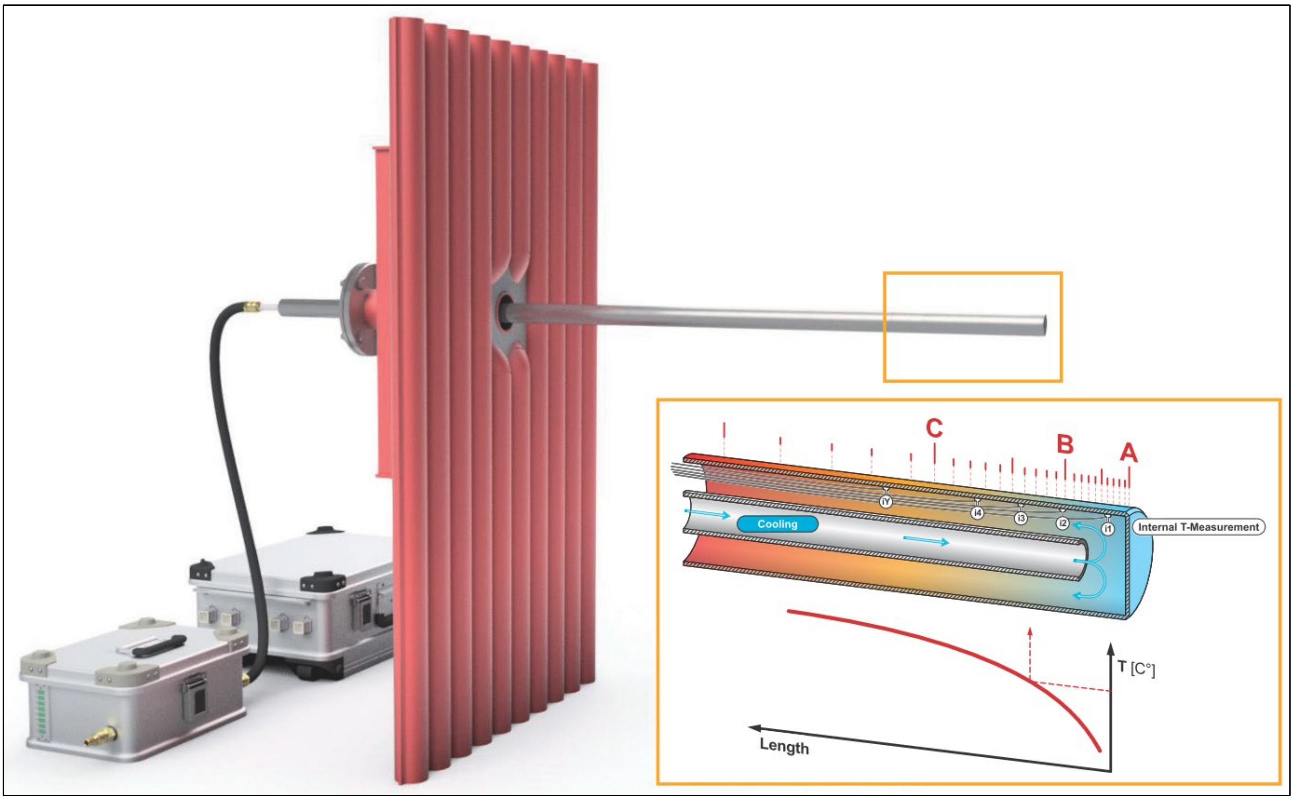

Figure 1: TRP probe for use in the contact part of steam generators or for bulkheads and super-heater components. Due to the cooling by compressed air, a temperature gradient (A to C) results along the probe body.

The special feature of the TRP probe – the freely selectable temperature range on the probe body – also offers the option of determining the threshold temperatures for changing corrosion rates or identifying temperature windows for special corrosion processes, such as salt melts, during material tests. This is valuable information when designing or changing boiler parameters and selecting materials.

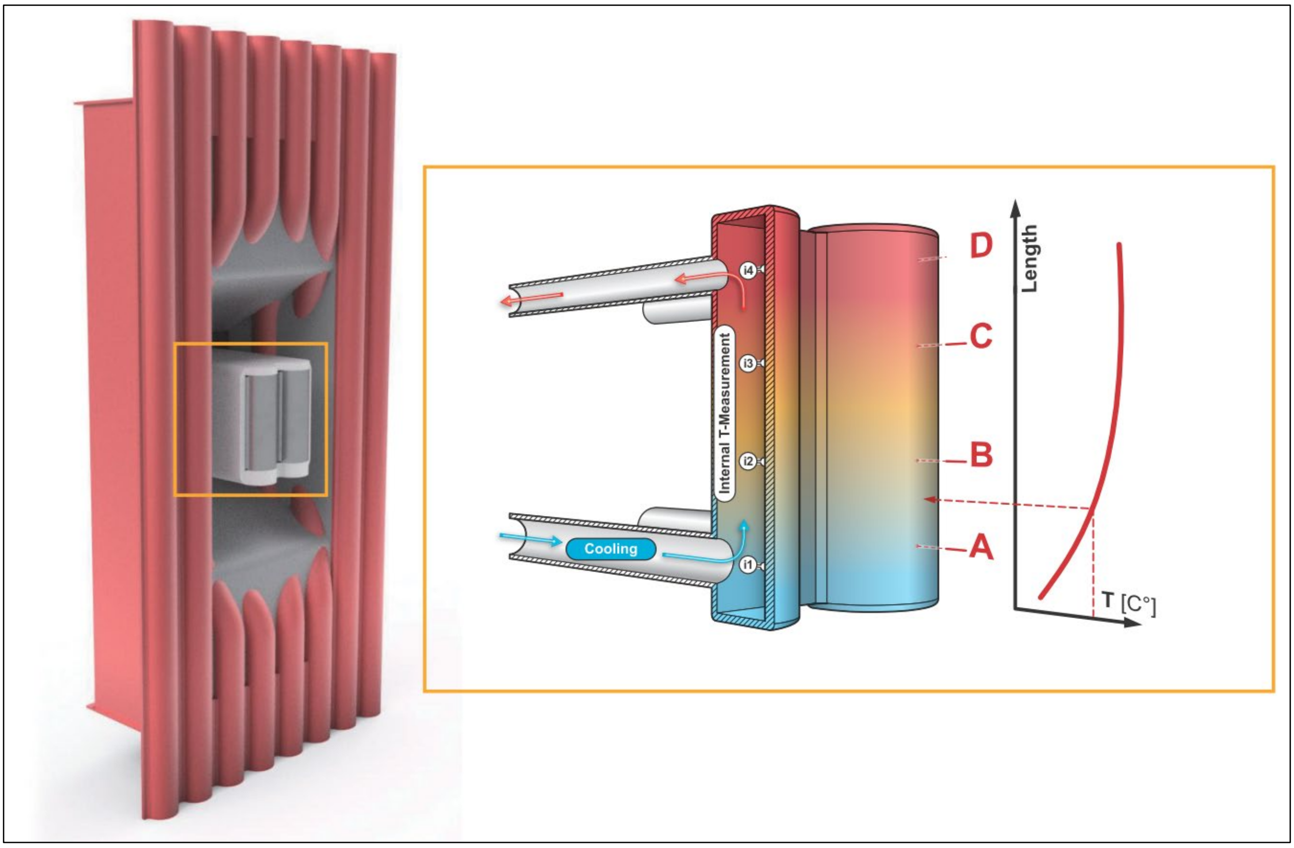

Figure 2: TRP probe for use in the radiation section of steam generators or for evaporator walls. Due to the cooling by compressed air, a temperature gradient (A to D) results along the probe body.

Grid probe: this was designed to detect the saturation of salts dissolved in the flue gas (especially chlorides and bromides). Salt saturation occurs due to the temperature drop of the flue gas when flowing through the boiler or due to local cooling of small flue gas volumes when touching heat exchanger surfaces (cold trap effect). Salts saturate depending on their load in the flue gas and the flue gas temperature. Aerosols (i.e. very fine particles) are formed during saturation.

Since these salts are of great importance for many corrosion processes and the formation of deposits, their behaviour contributes considerably to the thermochemical conditions on the heat exchanger surfaces. The grid probe can be used to detect the characteristics of these salts.

Unlike the TRP probe – which remains in the flue gas for hours to weeks and accumulates the effects of deposit formation – the grid probe documents a very short time frame of deposit formation (just a few seconds). This makes it possible to examine individual particles and the salt aerosols for optical and chemical characteristics.

ASP probe: a significant summative parameter for the nature and dynamics of corrosion and fouling processes is the load of salts in the flue gas, in relation to the load of non-salts (i.e. inert particles including oxides, silicates, glasses). The ASP probe detects all particle-bound constituents of the flue gas at the end of the boiler. The loads of certain salts and of the inert components can be estimated from the chemical analysis of these particles (as can their relative proportions).

The higher the relative salt content in relation to the inert content, the greater the probability of corrosion and/or fouling processes occurring.

Trends concerning which loads and proportions produce conditions that are more or less favourable for corrosion or fouling can be extracted from the large number of available ASP data sets. The ASP data sets also show a spectrum for each chemical element (minimum and maximum loads), in which a current investigation can be comparatively classified. This makes it possible to derive a general potential or tendency for corrosion or fouling for the steam generator under consideration.

Sulphation probe: It has been known for some time that gaseous sulphur compounds in the flue gas, especially in the form of SO_3, can have a mitigating effect on both corrosion and fouling. For this reason, sulphur or sulphur compounds are sometimes used as additives (either added to the fuel or injected directly into the flue gas stream). It is of particular importance that all heat exchanger surfaces are supplied with sufficient SO_3. For this the relationship between the amount of sulphur added and the respective effect on heat exchanger surfaces along the flue gas path must be quantified to determine a suitable formulation. This purpose is fulfilled by the sulphation probe, which determines the sulphation performance at the respective installation position, thus detecting a significant thermochemical condition. It can also be used independently of additives to determine the sulphation performance primarily coming from the fuel or the furnace.

Among other things the effect of other additives used to reduce fouling can be displayed and evaluated using the TRP probe described above.

2.3. Camera inspection

To support the CEE measures, a probe-shaped high-temperature camera (HT camera) was developed, which can be used during operation in all areas of the steam generator, from the post-combustion zone to the end of the boiler. It is cooled exclusively by compressed air. The viewing direction and the viewing distance of the camera can be easily adapted to the site's specific requirements. In addition, the infrared wavelength range can be used for optically dark areas or for estimating surface temperatures, along with additional LED illumination.

Inspection with the HT camera enables operational observations that are important for the formation of thermochemical conditions on the heat exchanger surfaces. These include the position and intensity of the primary and secondary firing, flame strike in the post-combustion, injection of auxiliary materials (additives, SNCR), and the effect of online cleaning and the fouling situation, up to and including growth in the contact heating surfaces. The information from the HT camera enables direct control and optimisation of process sequences. Precise targets agreed between the operator, the boiler installer (if applicable) and the camera operator have proven to be an important prerequisite for a successful camera inspection. It is particularly advantageous if the camera operator also has experience of shutdown inspections.

The key benefit of using the HT camera is that it provides a visual screening of the operational conditions and processes. The information that can be obtained is also suitable for the planning and realisation of probe and sensor applications.

2.4. Operational data analysis

The operational measurement technology available at the respective power plant site also provides information that is valuable for the evaluation of corrosion and fouling. This includes statements on the firing system (primary and secondary firing), on the heat extraction of the various boiler components and on online cleaning procedures. The raw data from the operational measurement technology are integrated into models for the mass, energy and material balance of the power plant process and processed into key figures.

This information and key figures are available during operation. Accordingly, time-resolved developments can be observed and evaluated over one or more operating periods or particular time windows (e.g. with special events).

3. Benefits of CEE measures

Experience with the use of CEE measures is available from many steam generators. This includes a variety of fuels and boiler designs at a number of European sites.

The development of the CEE measures is based, among other things, on experience with sensors and probes from CheMin GmbH. These tools and their application have already been described in detail in publications (see 1 to 12, below), or can be found at www.chemin.de. Most of the probes and sensors described here, including the HT camera, are protected by patents.

The desire to implement these measures usually results from a concrete operational burden whose effects are to be minimised. The objectives pursued can focus on the choice of materials, or on increasing efficiency or availability. Here, the specific boundary conditions of a site play a considerable role.

From the authors' point of view, CEE-related measures at the respective site usually start with concrete questions and then successively expand to a broader coverage of the effects of thermochemical conditions. In the best case, CEE measures become a routine part of the operation and its continuous optimisation. Any emerging issues or changes in operational procedures can then be assessed in terms of the risks for corrosion and fouling, if and when required.

From the perspective of risk management (particularly the avoidance of unplanned shutdowns) CEE measures are a monitoring process that controls and mitigates steam generator corrosion and fouling.

It has been shown that the performance of the steam generator benefits from, and the corresponding economic advantages become apparent with consistent routine applications of CEE measures.

Further information is available at www.chemin.de, where you will also find the contact details of the CheMin experts who deal with CEE measures.

4. Further Reading

[1] Spiegel, W.; Kaiser, M. (2020): Corrosion/Fouling Environment Evaluation in WTE and Biomass Fired Boilers. IRRC Waste-to-Energy, 16.10.2020, Online-Conference.

[2] Spiegel, W.; Kaiser, M.; Magel, G.; Müller, W.; Schmidl, W. (2019): Trend of Technology of Corrosion Evaluation in WTE and Biomass Plant Construction and Operation in Terms of High Efficiency in EU. Yokohama: NACE EAP, 2019/11/12.

[3] Spiegel, W; Kaiser, M.; Schmidl, W. (2019): Fouling textures and micro-milieus determine high temperature chlorine corrosion in power plants fired with waste or biomass. IRRC Waste-to-Energy, 15.10.2019, Vienna, In: Thiel, S.; Thomè-Kozmiensky, E.; Winter, F.; Juchelková, D. (Eds.): Waste Management, Volume 9, Waste-to-Energy, Thomè-Kozmiensky Verlag GmbH, Neuruppin 2019, pp. 549-560.

[4] Müller, W.; Spiegel, W.; Hemrich, R. (2019): Diagnosis and monitoring of electrolytically induced corrosion – especially deliquescence corrosion. In: Thiel, S.; Thomé-Kozmiensky, E.; Quicker, P.; Gosten A. (Eds.): Energy from Waste, Vol. 16, Neuruppin: TK Verlag, 2019, pp. 459-465.

[5] Kaiser, M., Brell, J., Molitor, D., Schneider, D. (2017): Increasing efficiency by integrating thermochemical process parameters. In: Thomé-Kozmiensky, E. and Thiel, S. (Eds.): Energy from Waste, Vol. 15, Neuruppin: TK Verlag, 2018, pp. 333-344.

[6] Spiegel, W., Kaiser, M., Magel, G., Schmidl, W. (2018): Relevant Thermochemical Processes in Biomass Fired Power Plants. In: IRRC Vienna 2018.

[7] Kaiser, M., Spiegel, W. (2017): Understanding and Improving Thermochemical Processes. In Beckmann, M. and Hurtado, A. (eds.) Power Plant Technology 2017 Strategies, Plant Engineering and Operation, pp.329-341.

[8] Molitor, D.; Spiegel, W. (2017): Experiences from twenty years of revision support. In: Thomé-Kozmiensky, K. J. and Beckmann, M. (Eds.): Energy from Waste, Vol. 14. Neuruppin: TK Verlag, 2017, pp. 215-226.

[9] Magel, G. (2017): Get to know the Corrosion Mechanisms in Waste-to-Energy-Plants. In: IRRC Vienna 2017.

[10] Kaiser, M.; Schneider, D.; Brell, J.; Kuttner, T.; Spiegel, W.: Temperature-Range-Probe (TRP): Detect, Reduce, Avoid Corrosion. In Beckmann, M. and Hurtado, A. (Eds.): Power Plant Technology 2016 Strategies, Plant Engineering and Operation, pp.381-393.

[11] Kaiser, M., Schneider, D., Brell, J., Molitor, D., Kuttner, T.: Increasing Efficiency – Application of the Temperature-Range-Probe for the Optimization of Material Selection in Power Plants. In: VGB Powertech, Issue 10/2015, pp. 53-58.

[12] Spiegel, W.; Brell, J.; Taubner, S. (2015): Temperatursensorik: Neue Wege zur Prozess-optimierung. In: Pohl, M. (Ed.): Dampferzeugerkorrosion 2015 Wechselwirkungen – Diagnosemethoden – Minderungsstrategien – Erfahrungen, Freiberg: SAXONIA Standort-entwicklungs- und -verwaltungsgesellschaft mbH, 2015, pp. 41-50.