In-Situ Fuel Diagnosis

Marie Kaiser, Joos Brell, Mauritius Hiller and Wolfgang Spiegel

Certain fuels, particularly those used in waste, RDF and biomass furnaces are characterized by heterogeneity and complex chemical compositions. This causes stress to the boiler, its components, and its materials. The firing system that controls the incineration process in the furnace is fed by a large amount of sensory data. Yet, the characteristics of the fuel remain unknown in the firing system.

The concept of the in-situ fuel diagnosis addresses this by utilizing the boiler as a permanent combustion laboratory, making the hidden properties and processes visible. Methods include the generation of metadata through balancing and modelling as well as specific sensor and probe applications.

The basic idea of the in-situ fuel diagnosis is linking thermal utilization of the fuel with the collection of fuel properties. This approach is advantageous and useful, as the necessary sensor applications are commonly available and well established. Plants that are particularly affected include those firing waste, RDF, biomass, lignite, and coal.

The industry is being pushed by legal and environmental imperatives associated with the circular economy towards innovation and new fuels. In-situ fuel diagnosis supports the operators of the plants in their efforts to achieve the goals of increased energy efficiency and power output and the reduction of fossil CO_2.

Authors

Dipl.-Ing. (FH) Marie Kaiser
Expert Witness
Head of R&D

Dipl.-Ing. (FH) Joos Brell
Senior Expert

Dr. rer. nat. Mauritius Hiller
Managing Director

Dr. rer. nat. Wolfgang Spiegel
Expert Witness
Advisor
CheMin GmbH
Augsburg, Germany

Foreword

The in-situ fuel diagnosis was jointly developed by ENVERUM GmbH and CheMin GmbH and is being made available to the market by both companies [1].

1 The large-scale plant as an in-situ laboratory for fuel diagnosis

Certain fuels used in furnaces are characterised by heterogeneity and/or complex chemical composition and/or fluctuating particle size. This particularly applies to waste-based fuels, to RDF, and to many biomasses.

The furnaces for such fuels are predominantly grate-based and designed to operate as “omnivores”, i.e. to be able to process almost any fuel. The energetic limits of these properties are given by the firing performance diagram. Limits of consistency and denseness do not specifically appear. The primary objective of firing is the complete combustion of all solid and gaseous components of the fuel.

The characteristics of fuels for grate firing (in the sense of their heterogeneity regarding almost all properties) make it difficult to analyse the effects of the fuel on the furnace and the steam generator in the run-up to combustion to allow these effects to be predicted (or at least directly assessed) and used for control processes.

As soon as all the properties of the fuel, e.g. as fed by a gripper reaches the beginning of the grate, effects of this fuel arise on the respective locations of energy release, energy distribution within the furnace(s), material characteristics of the slag, thermal and material characteristics of the flue gas, as well as heat transfer in the steam generator, among others.

The firing in waste incineration/RDF and biomass plants is controlled by the parameters of the firing rate control system. This receives its information from certain integrative measured variables (including steam quantity, O_2 content in the flue gas, ceiling temperatures of flue gas 1st pass, and camera information on the fire situation) and regulates the process via algorithms. In addition, there is extensive literature on the modelling of firing processes, i.e. the provision of information on the effects of controllable features of firing and firing management, such as distribution of air, grate bar velocities, fuel throughput, and recirculated flue gas. There is also modelling and empirically based information on the transfer factors of material loads of the fuel from the material bed into the flue gas. In addition, there are modelling and empirical tests on the effects of additives or auxiliary materials that are introduced into the process before, during or after firing. These additives are supposed to favourably influence certain process effects, for example, nitrogen oxides, fouling or corrosion. Additives include urea/ammonia, sulphur, water, or minerals.

If it is to be accepted that as heterogeneous fuels have largely unknown fuel characteristics at the time of combustion in a grate furnace, it makes sense to develop the thermal process itself into an in-situ fuel diagnosis that is as informative as possible. This means that additional information is taken from the processes in the furnace and steam generator. Figuratively speaking, an in-situ laboratory is created that determines the relevant fuel characteristics.

Figure 1 shows this in-situ laboratory, consisting of the fuel supply, the feed system, the firing system, and the steam generator. Areas where little or no information about the fuel characteristics is available or has been determined are coloured brown.

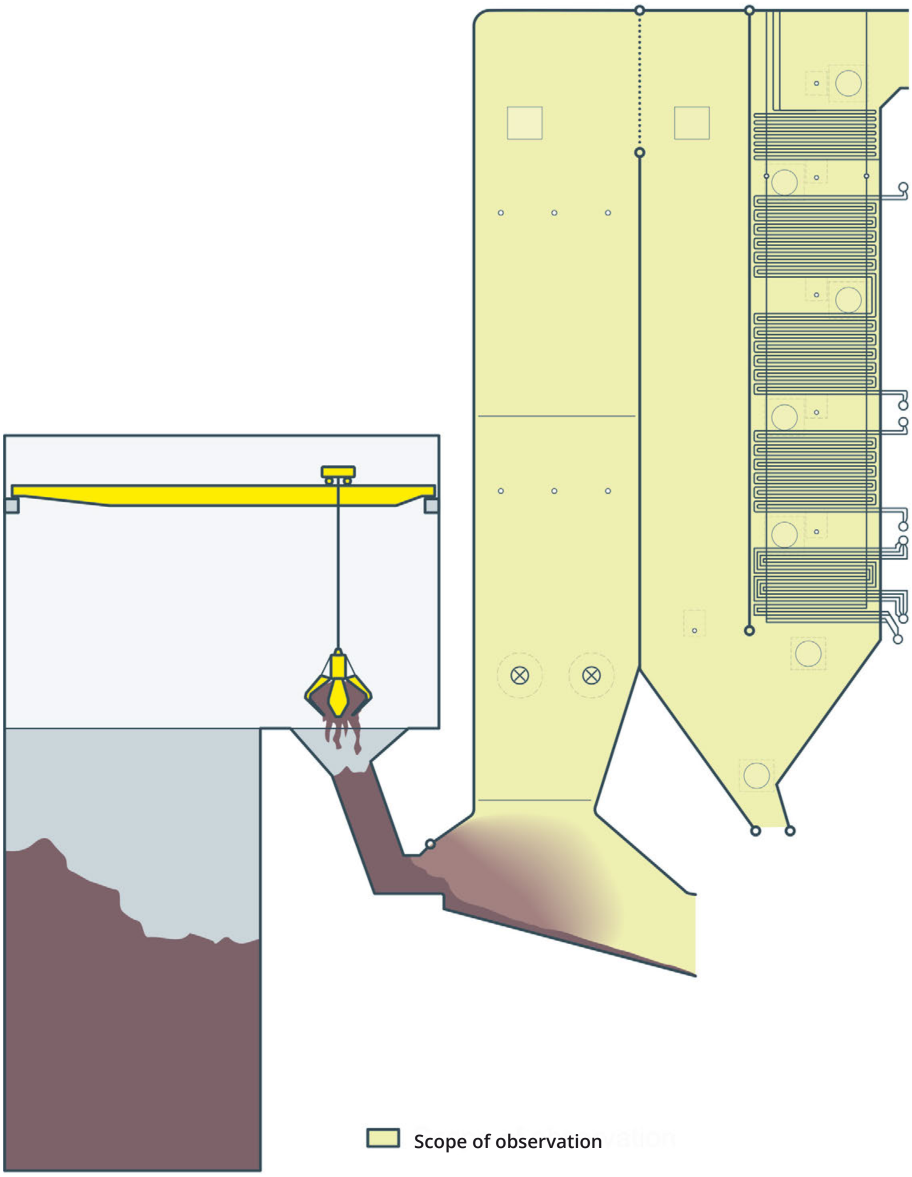

Fig. 1. In-situ laboratory, made up of the fuel supply, feed system, furnace, and steam generator.

Areas in which information on the fuel characteristics has been determined and thus is available are coloured light green. The entire area of the furnace and steam generator is suitable for providing information for in-situ fuel diagnosis.

This in-situ laboratory thus functions as a "permanent combustion test", and its properties are determined simultaneously with the thermal conversion and energetic utilisation of the fuel. In other words, the furnace and steam generator receive an additional process component, namely fuel diagnosis. The information from the fuel diagnosis is directly intertwined with the various processes of thermal conversion and energy utilisation. This includes the firing processes, as well as emission reduction processes (e.g. nitrogen oxide reduction by means of SNCR) and measures to optimise heat transfer (online cleaning processes).

What additional information can be collected to characterise the fuel? What sensory aids are available? At which points in the process sequence of firing, steam generator and flue gas cleaning is relevant information available, and can it be tapped?

The tools of in-situ fuel diagnosis are described in more detail in section 2 below.

What effects or improvements can be achieved with this type of fuel diagnosis?

In essence, in-situ fuel diagnosis enables greater process transparency. Several impact levels are derived from this:

- Fuel characteristics become "visible", which can be used to influence the upstream and downstream sides of waste incineration. These include supplier control, fuel purchasing, fuel mix, additive use, compliance with emission limits, and parameters for the CO_2 origin in the exhaust gas.
- The information from the in-situ fuel diagnosis enables a direct influence to be exerted on the process sequences in the furnace (e.g. burnout of slag and flue gas) and in the steam generator (e.g. SNCR and online cleaning).
- Comparison of process characteristics: Even on longer time axes, the information from in-situ fuel diagnosis yields opportunities for process optimisation. The decisive process-engineering effect here is a spatial and temporal homogenisation of the flue gas characteristics at the respective locations in the steam generator (i.e. the avoidance of streaks and strong fluctuations in the energy distribution in the flue gas in particular). This homogenisation of the process characteristics has a mitigating effect on slagging, fouling and corrosion.
- Energy efficiency: Significant economic effects of this optimisation ultimately also arise around energy efficiency (longer operational periods, better availability, higher efficiency), as well as in the costs for maintenance, auxiliary materials, and any CO_2 taxes that have to be paid in the future [1].

In view of the current requirement to make full and optimal use of all the useful energy that can be generated domestically, the option of increasing energy efficiency is highly relevant for waste/RDF fired power plants.

2 Methods for in-situ fuel diagnosis

The methods of in-situ fuel diagnosis described below are divided into two areas of action:

- The processing of all typically available operating data into metadata by balancing and modelling.
- The extraction of additional information from the combustion process (including the steam generator) by using sensors and probes. This area of action leads to spatially resolved information.

Regarding a): Generation of metadata through balancing and modelling.

With the help of balancing, unknown quantities can be calculated based on operating data measured in the plant, or measured quantities can be checked for their plausibility. There are balancing approaches in process engineering based on the conservation laws (e.g. for the combustion process, heat transfer, drying and humidification processes, etc), which are used for modelling power plant processes. The linking of these balancing approaches makes it possible to create models of individual apparatuses and process modules, or even models of an entire plant, and to analyse these coupled with the operating data in assistance or plant monitoring systems [3]. This makes it possible to derive information and effects from the available operating data measured in the plants.

The process control systems used in plants today, in conjunction with database systems (interface) and software-supported specific plant models (process-engineering modelling), make it possible to determine the various process states online – i.e. continuously – and to carry out corresponding evaluations in an informative and useful manner and visualise them accordingly ([3] to [8]).

In terms of in-situ fuel diagnosis, these assessments can be accordingly supplemented by the influence of the waste quality. This approach appears to be expedient, particularly in plants in which the fuel qualities can only be observed to a limited extent upon delivery, and especially against the background of the further changing waste qualities in the future.

Regarding b): Sensor applications

The sensor applications for in-situ fuel diagnosis will be permanently installed, primary around the firing and post-combustion area. In addition, the same sensory installation is also used along the flue gas path, supported by the temporary use of probes. This allows the fuel to be characterised in terms of its energetic and chemical properties. This can include, for example, very fast processes (such as firing) or processes on a very long-axis (e.g. growing and aging of deposits during an operational period).

The sensors and probes of in-situ fuel diagnosis make targeted use of heat and material information available in the furnace and along the flue gas path.

The heat information determined around the furnace and post-combustion characterises the energy release directly (i.e. without time delay), and spatially resolved (i.e. along the grate and over the height of the staged furnace). The sensor technology used allows the amount of heat input to be recorded in relation to almost arbitrarily small heat exchanger sections, resulting in high-resolution information about the firing process. This is of particular interest in the individual combustion zones, as it makes it possible to separately evaluate the sub-processes of the firing (ignition, main and post-combustion, as well as burnout).

In addition, heat or temperature information is also recorded in the different areas of the steam generator. In principle, the same sensor technology is used as that described above for firing, supported using probes. The probes gather chemical information (e.g. fouling properties, aerosols, SO_3 load, corrosion processes) or provide optical information (high-temperature camera probe).

Sensors and probes have already been presented in detail in earlier conference papers and publications ([9], [10], [11], [12] and [13]) and have been continuously developed over recent years.

An exemplary arrangement of sensors and probes in the furnace and in the steam generator is shown in Figure 2. The position and number of sensors and probes depends on the information requirement and the desired degree of process transparency.

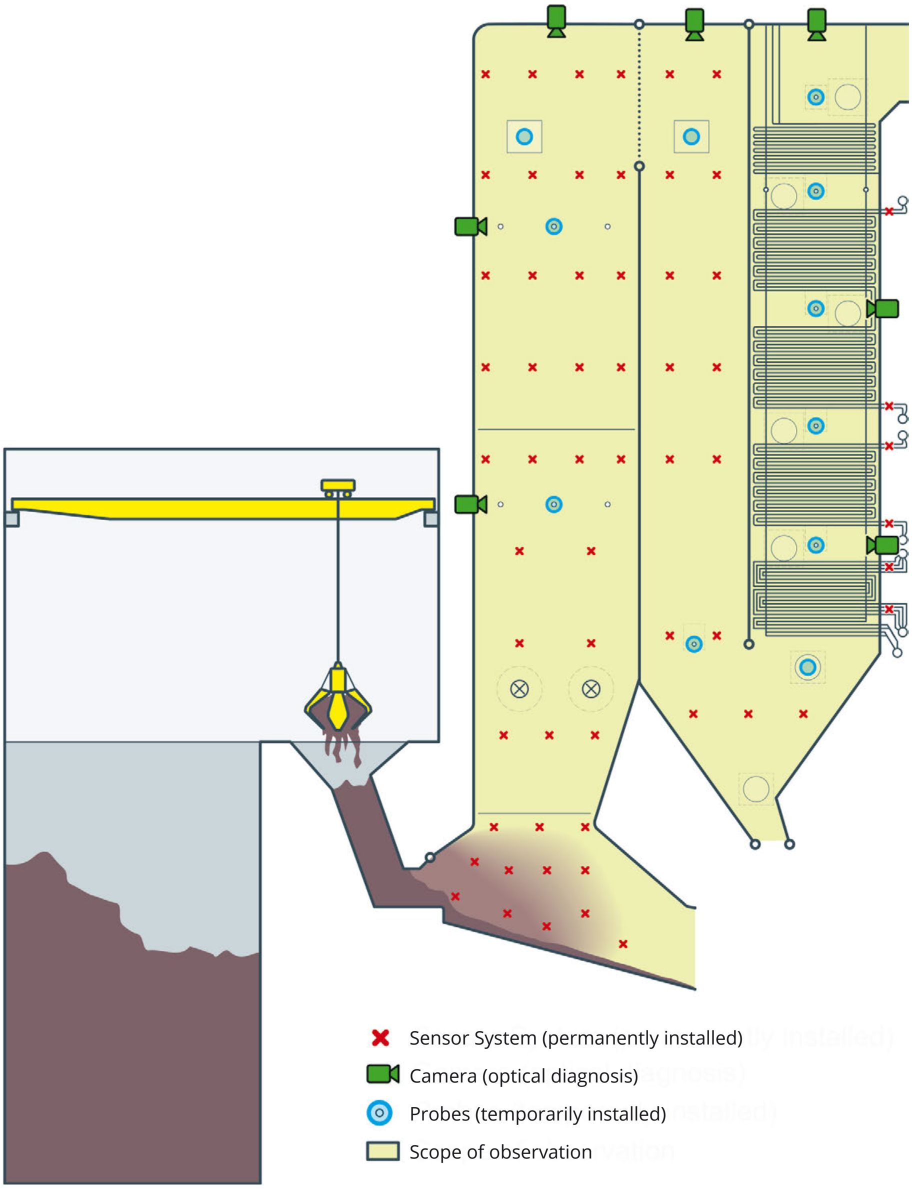

Fig. 2. Exemplary arrangement of sensors and probes in the furnace and steam generator.

It is easy to understand that the information from in-situ fuel diagnostics can also be used to optimise specific process steps, including the SNCR technique, online cleaning processes and the use of additives. A few comments and examples are given below.

The NO_x loads in the flue gas and the fouling behaviour of the steam generator reflect material and chemical characteristics of the fuel. These characteristics are transferred to thermal, chemical, and material characteristics of the flue gas during firing processes. The proportions of certain species in the fuel, such as chlorine compounds, sulphur compounds, alkali compounds, alkaline earth compounds and heavy metal compounds, as well as the ratio of inert substances and salts are of particular relevance for fouling. The corrosion behaviour of the heat exchanger surfaces is also closely linked to the fouling behaviour.

The sensor system installed in the post-combustion area has relevance to the effect of the SNCR technology. Regarding online cleaning, the sensor system is positioned where this technology is used, i.e. both in the radiation area and in the convective part of the boiler.

A strong effect is attributed to the information on heat distribution and heat extraction made available by the sensors regarding the optimal operation of the SNCR and online cleaning technology. This is because both this denitrification technology and the formation of deposits are strongly influenced by the temperature levels and the temperature distribution in the flue gas. Inhomogeneous heat distributions in the flue gas (e.g. imbalances) or strong temporal fluctuations of the flue gas temperatures are fundamentally disadvantageous.

Figure 3 uses the example of a waste incineration plant to show how the installed sensor technology can be used to provide information on the process control of online cleaning of evaporator heating surfaces. The

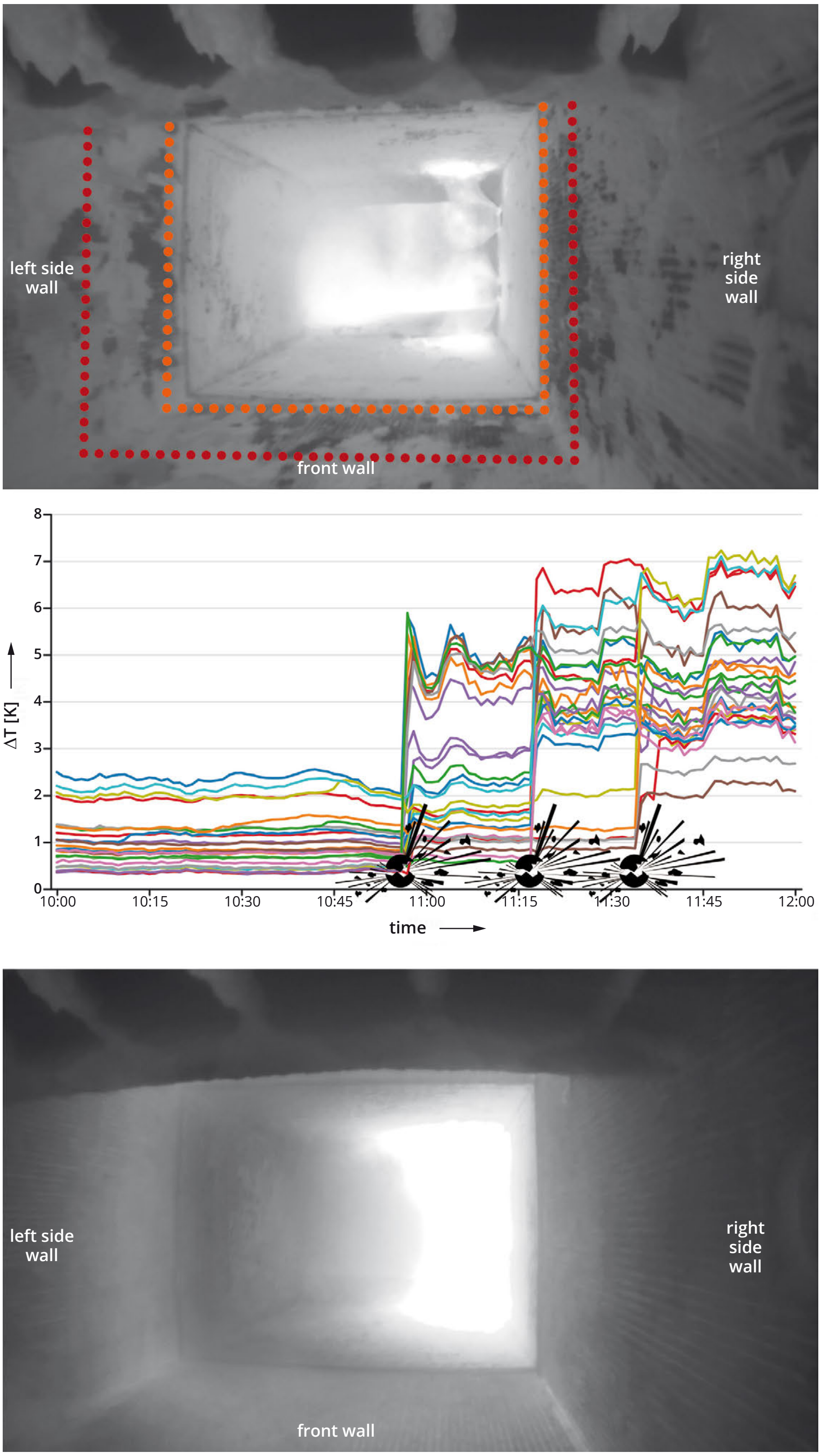

Fig. 3. An evaporator wall is shown before (top) and after (bottom) online cleaning by blasting.

signals from the heat flow sensors precisely show the effect of online cleaning for each sensor location, resolved for each of the cleaning steps. An inspection carried out parallel to the cleaning with the high-temperature camera probe confirmed these findings. The advantage of the permanently installed sensor system is that it allows an early assessment of the need for cleaning. In addition, the sensor system provides detailed information on the location-based cleaning outcomes. A recording of the online cleaning, taken the high-temperature camera and demonstrating this effect is made available [14].

In addition to visual observation, the cleaning process is monitored by a high-temperature camera and sensors. The sensors are installed on the outside of the evaporator wall at the level of the red and orange lines. The sensor data clearly show the three online cleaning operations (step response). A cleaning effect was achieved at all measuring points. The heat extraction of the cleaned surfaces was thus significantly improved.

3 Perspective of in-situ fuel diagnosis

The market for waste, RDF and biomass plants currently faces a variety of adaptation and optimisation requirements. This is prompted, among other things, by national requirements and EU regulations, the desire for energy efficiency, and efforts in the context of the circular economy and climate protection.

This paper focuses on the approach that in the case of heterogeneous and materially and chemically complex fuels, an economic and social advantage can be generated by obtaining additional information from the processes of firing and steam generation. The effective levers are lower maintenance costs, higher energy efficiency, and more flexible fuel use (i.e. utilisation of the energy content of different material flows, including those from agriculture).

In-situ fuel diagnosis has already been implemented several times on the market in partial applications and the effects that can be achieved with it have been proven. The next step will be to implement the overall concept of metadata and sensor/probe data at plant locations. This will not be done as an R&D measure but developed directly in and for the market (plant construction and operators). For example, in many waste wood-fired power plants there will be an opportunity (and a compulsion) to make the fuel mix more flexible in the coming years, when Germany's Renewable Energy Sources law (EEG) ceases to apply. In these power plants, there is insufficient experience for such complex fuels. In-situ fuel diagnosis can quickly identify the necessary operational adjustments and optimise process control. Similar requirements arise for burner-based firing systems during the conversion from coal to biomass fuels. The properties of the fuels and the fuel mix also change frequently in waste incineration plants and RDF power plants.

The basic idea of the in-situ fuel diagnosis is linking thermal utilization of the fuel with the collection of fuel properties. This approach is advantageous and useful, as the necessary sensor applications are commonly available and well established. Plants that are particularly affected include those firing waste, RDF, biomass, lignite and coal.

The industry is being pushed by legal and environmental imperatives associated with the circular economy towards innovation and new fuels. In-situ fuel diagnosis supports the operators of the plants in their efforts to achieve the goals of increased energy efficiency and power output and the reduction of fossil CO_2.

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[14] See www.chemin.de/video for a recording of an online cleaning process captured by a high-temperature camera.

Kurzfassung

In-situ Brennstoffanalyse

Brennstoffe, wie sie in Müll-, Ersatzbrennstoff- und Biomasseverbrennungsanlagen eingesetzt werden, zeichnen sich durch Heterogenität, komplexe chemische Zusammensetzungen und ggf. schwankende Stückigkeiten aus. Diese spezifischen Brennstoffeigenschaften führen zu Belastungen in den Anlagen, besonders in Bezug auf gegebene Komponenten und Werkstoffe. Die Verbrennung der Brennstoffe wird durch eine Feuerleistungsregelung gesteuert, welche auf eine Vielzahl von (Sensor-)daten zurückgreifen kann. Dem hingegen sind die Eigenschaften der Brennstoffe weitgehend unbekannt.

Das Konzept der In-Situ Brennstoffanalyse zielt darauf ab, den gesamten Kessel als permanentes Verbrennungslabor zu nutzen, um verborgenen Prozesse und Eigenschaften in Bezug auf den Brennstoff-Input sichtbar zu machen. Die Methode beinhaltet die Generierung von Metadaten durch Bilanzierungen, Modellierungen und den spezifischen Einsatz von Sensor- und Sondentechnik. Dieses Vorgehen ist vorteilhaft und nützlich, denn erprobte Informationstechnologien und Sensor- und Sondentechniken steht dem Markt bereits zur Verfügung und können für diese Zwecke als stabile Prozesskomponenten eingesetzt werden.

Die In-Situ-Brennstoffdiagnose unterstützt Betreiber bei der Bewältigung der aktuell dynamischen Umbrüche in Bezug auf die thermische Nutzung bzw. Verwertung von Energieinhalten diverser Stoffströme, welche sich durch rechtliche und ökologische Rahmenbedingungen ergeben. Im Zentrum stehen hierbei Themen wie die Steigerung der Energieeffizienz, durch eine verbesserte Strom- und Wärmeauskopplung sowie wie die Anpassung von Brennstoffströmung, wie z.B. die Einsparung fossiler CO_2-Ströme durch die Substitution fossiler Energieträger.