New technology for monitoring fouling deposition in coal fired boilers

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Introduction

The paper addresses the age-old problem of improving power plant and boiler efficiency and specifically in facilities where solid fuel, such as coal and biomass, is burnt and combustion energy is transferred into electric power generated by the steam turbine.

Increased efficiency can still be achieved using new technologies allowing for a deeper understanding of the complex, dynamic processes taking place in the combustion chamber (the furnace) and other major parts of the facility.

As is well known, there are different methods for coal firing: pulverised combustion, fluidised bed combustion, moving bed etc. For pulverised combustion, the particles of coal are mixed with air. The pulverised coal-air mixture is fired by the furnace burners (located at several furnace levels). The fuel particles are ignited and create the flame consisting of very hot solid particles and combustion gases. The temperature in the flame achieves 1,700 °C to 1,800 °C. At such high temperatures the transfer of heat energy from the flame to the furnace wall (comprising the water tubes where water is heated) is mainly due to radiation heat transfer (up to 90 %). In such conditions radiation properties of the furnace wall (spectral reflectivity R and spectral emissivity ε) play a significant role in the overall heat balance of the facility.

Furthermore, the fuel characteristics of coal and especially biomass are very different, including moisture content, ash content, calorific value, and alkali/alkaline earth metal content. Ash-forming elements are present in biomass and coal as salts, bound in the carbon structure or as mineral particles introduced randomly even during transportation. Concentration of major ash forming elements (Si, Ca, Mg, K, Na, P) have an influence on ash melting behavior and corrosion/erosion mechanisms.

During combustion, a fraction of the ash-forming compounds in the fuel is volatilised and released into the gas phase. Another fraction creates the solid particles which cannot be completely burnt. These unburnt residuals, primarily consisting of oxides of the aforementioned metals and other elements presented in different proportions in different kinds of coal and biomass, appear in the combustion chamber as separate ash particles and sometimes also create the aggregates of slag. Complex fluid dynamics existing in the furnace is responsible for multi-phase flow with 3D velocity distribution which moves ash particles towards the walls where they are deposited on the water tubes. The deposition layer (fouling) created in such a way is usually characterised by very low thermal conductivity and causes significant thermal resistance, which reduces heat transfer from the flame and hot gases to the water and steam. The larger the thickness (T) of the deposition layer the greater amount of heat energy originated in the combustion is going not to the heated water, but to the furnace exit and increases the Flue Gas Exit Temperature (FEGT). Therefore, increases of T and R reduce the overall heat absorption of the combustion chamber and as a result reduces boiler and unit efficiency.

To improve the heat transfer inside the furnace the fouling deposits obviously should be removed. This is usually carried out by activating numerous soot blowers distributed all along the furnace walls and operated in some predefined manner in order to clean the heat transfer surfaces. However, activation of the cleaning blowers causes additional energy wastage and, what is more critical, results in growing erosion of the water tubes. Therefore the cleaning should be optimised taking into consideration different factors which influence the heat transfer, fouling dynamics and maintenance issues.

Several approaches addressing the cleaning procedure have been suggested over the years.

In advanced boiler systems the activation of soot blowers is based on the Cleanliness Factor (CF) defined as the ratio of overall heat transfer coefficient at actual operational condition to its value at clean condition. However, usage of CF is still problematic because real heat transfer depends on many factors, such as the utility load, tilt position of the burners, spatial distribution of different fraction of solid particles inside the furnace, situation in convection pass and other conditions varying in the course of normal operation of the utility. Most of them can hardly be measured or even quantified. In addition, CF is defined as an integral parameter which depends on local heat transfer in different zones of the furnace water tube walls: it may happen that in some places the fouling deposits
achieves the critical thickness while in other deposits is still very low. Moreover, reflectivity of the fouling surface varies in a completely different way to deposition growth and sometimes in a manner opposite to the impact of the thickness of fouling. In other words, implementation of CF as a target parameter for cleaning optimisation requires measurement of fouling data collected in real time and from different areas of the furnace.

**Method and technology**

An approach presented here is based on non-contact direct measurement of Fouling Thickness and Reflectivity (FTR) in real time. For this purpose a special electro-optical device attached to the furnace wall is used which enables the simultaneous and continuous measurement of the T and R of the fouling (see detailed description in [1 to 3]). This device is located in the vicinity of a soot blower and therefore collects information from the adjacent zone. It comprises the extended part (moving head) which moves in and out of the furnace – while inside the furnace the system measures the fouling thickness and reflectivity and, as it leaves the furnace, the system collects data on reflection from a reference surface located inside the device. The light beam originating in the light source (a laser diode) is focused on the fouling surface growing on the water tube. The image of the light spot is transferred by the system optics to the video sensor interfaced with the system processor. Movement of the image spot is translated into measured thickness T. The measurement is fast (about one second) so there is no need for intensive cooling, in spite of the fact that the extended part is introduced to a very hot zone of the furnace.

Comparing intensity of light reflected from the fouling surface with intensity of light reflected from the standard specimen makes it possible to calculate spectral reflectivity of the fouling in the wavelength of the laser. Special measures undertaken in order to get high contrast of the spot image with regard to the background of the high intensity radiation originated in the furnace flame.

Reflectivity measurement is performed in each cycle of thickness measurement, so both values, T and R, characterise the dynamic of fouling (and, finally, of local heat transfer) in the vicinity of the FTR device.

Several FTR devices installed on the furnace wall are connected in one complete system interfaced to the system local server. From the server results of measurement and calculation of T and R from all zones equipped by FTR devices are transferred to the PI (data acquisition system) of the station. A special software package provides real time processing of all data in PI followed by recommending how the cleaning procedure should be carried out.

**Experimental results**

FTR systems have been successfully operated over the last 2.5 years on two Israel Electric Company plants – one is a 575 MW unit of tangential firing boiler in the Orot Rabin power plant (Hadera) and the second is a 550 MW unit of opposite fired boiler in the Rutenberg power plant (Ashkelon). A great volume of data was collected during this period at both stations. Analysing the results measured makes it possible to find new features of the process of fouling and to gain a better understanding of relations between the dynamics of fouling, parameters of heat transfer and characteristics and sequence of cleaning. Some typical results are presented below. **Figure 1** and **Figure 2** demonstrate two different types of fouling existing in...
the furnace. Each point on those figures represents one cycle of measurement of thickness of contamination on the water wall tubes and vertical lines indicate the soot blowing activation. The first type of fouling (Figure 1) is characterised by slow, almost monotonic change of fouling thickness. The situation shown in Figure 2 is completely different: it is seen that big lumps of material are approaching the water wall, attaching to the tubes for some period of time after which they are removed by the main flow of the air and combustion products away from the wall. The cloud of such big lumps of material of course reduce the radiation heat transfer from the flame to the wall, but may be even more essential that when they are “sitting” on the tubes these lumps significantly increase the thermal resistance of the fouling layer.
Monitoring fouling in coal fired boilers

Figure 3 shows reflectivity measurement. It is clearly seen that reflectivity depends not only on the type of coal, but also on the loading of the boiler, which can be explained by different dynamics of combustion at different loads (caused by changing of the burner blades' tilt, for instance). Cleaning activation in most cases results in an immediate decrease of reflectivity, but then, after a short period of time, it goes back to the higher values.

The measurements presented on the Figures 4a, b have been performed during standard operation of the 550 MW unit with two types of coal, Anglo MAF and Billiton. The unit was fully loaded and the furnace exit temperature was high (about 1,450 °C in both cases). Therefore some actions were definitely needed. But what actions? FTR data allows one to ascertain the reason for high FEGT in both cases and indicate what action should be taken. Figure 4 demonstrates the thickness of contamination and moments of cleaning (activation of soot blowers, red lines on the graphs). We see that the DYNAMICS of fouling is completely different in these two cases. Indeed, in the case of Anglo MAF (Figure 4a) deposition achieves significant thickness, then it is removed by cleaning, but it grows again very fast before subsequent cleaning. In the case of Billiton (Figure 4b) contamination rate is much lower, but it is not removed by cleaning. Reflectivity of both coals was also different - reflectivity of Billiton is almost two times higher than that of Anglo MAF. Therefore, in the case of Anglo MAF, more frequent cleaning is desirable whereas in the case of Billiton it is reflectivity which is responsible for high FEGT and changing the cleaning procedure.
cannot improve the situation significantly (in this case only using the mix or different coals might be useful).

The next three figures represent results from the 550 MW unit with opposite fired burners where 8 FTR devices are installed. All devices are connected in a single network interfaced to the PI of the station. A pair of devices is located on floor 7 at the top burners level, an additional two devices are on the floor 8 (at SOFA level) and another 4 devices are positioned on floors 9 and 10, two devices on each floor. The measurements have been performed and processed every four minutes at each device. Figure 5 shows the results recorded by PI during about three hours of continuous operation. As it can be seen, there is a significant difference between the dynamics of fouling in different zones of the furnace: namely, FTR 1 and 2 (from the tenth floor) recorded the first type of fouling with a low rate of contamination growth. In all other locations, and especially on the seventh floor the second type of fouling definitely exists. The lumps of material achieving about 10mm size and which are sometimes attached to the tube for a relatively long period of time cannot be successfully removed by the overall flow existing in the furnace. It was decided to activate cleaning of three sequences of the soot blowers – in the vicinity of FTR devices number three, five and six where contamination was most significant. Three sequences of cleaning were performed and the results were clearly seen on the PI record. Immediately after activation of the soot blowers the thickness was reduced to a very low level. Reflectivity in locations of FTR three and five also decreased significantly whereas in location FTR six it returned to a higher value after several minutes.

Discussion

In order to check whether the fouling cleaning chosen according to FTR data is relevant and correlates with dynamics of the main parameters of the boiler performance, the following values have been estimated on unit 4 of the Rutenberg power plant: CF factor, boiler efficiency and FEGT. All values were calculated and recorded in the same period of time when three sequences of cleaning mentioned above were performed. Results are depicted in Figure 6 and Figure 7. The first of these two figures demonstrates changing of FTR measured parameters as a result of cleaning. Just after the cleaning, the fouling thickness decreased in all three locations of the activated soot blowers. In addition to cleaning operated in locations five and six also caused a reduction of fouling thickness at locations seven and eight because these zones are close to the activated soot blowers (indicated in Figure 6 as an indirect effect of FTR).

As it is clearly demonstrated in Figure 7 each soot blowing sequence is accompanied by a corresponding increase in CF values, increased boiler efficiency and reduction of FEGT. Due to actual dynamics of heat transfer in the boiler, there exists a delay in variation of efficiency, CF and FEGT compared to the cleaning action. It should be noted that all results presented in Figures 5 to 7 have been obtained at the unit partial load. As it can be seen, efficiency measured as a result of these sequences of soot blowing improved by 0.2 %.
It is interesting to indicate that the correct choice of cleaning location, based on direct measurement of FTR devices, provides for a marketable change of heat transfer expressed in efficiency, FEGT and CF, in spite of the fact that in each cleaning sequence of our experiments, only a small amount of blowers (three-four per sequence) have been activated, while all other blowers of the furnace were in the OFF position. This fact demonstrates once again the benefits of the FTR approach compared to other procedures of cleaning optimisation based on measurements of integral boiler operation parameters – such as the amount of superheater spray flow, the position of burner tilts, boiler exit temperatures etc. (see, for example [4, 5]).

Summary

- Usage of the FTR approach results in reliable information on dynamics of heat transfer in an operating furnace of a coal-fired boiler. Information is collected in real time and addresses the directly measured thickness and reflectivity of fouling deposited on the water wall.

- It was revealed that parameters of fouling in different zones of the furnace can differ significantly one from to the other. Two major types of fouling deposition, one with low rate of thickness growth and the second with big lumps of material attaching to the wall for a relatively short period of time, were experienced at the same time inside the furnace.

- It was demonstrated that the situation might occur when reflectivity variation and not the thickness play the major role in heat balance of the furnace. In such a case the cleaning cannot be effective at all. It depends on the type of fuel (type of coal) and chosen procedure of cleaning activation.

- It was shown that data collected by the FTR system and interfaced to PI data acquisition system of the plant can be successfully exploited in order to define location and time of cleaning activation.

- If cleaning procedure is based on direct measurement data collected by the FTR system, it is possible to improve overall efficiency by up to 0.2 %, even at unit partial load.

References


VGB-Standard

Provision of Technical Documentation
(Technical Plant Data, Documents) for Energy Supply Units

The provision of an energy supply unit its plant sections and their individual components in the context of projects and under the scope of individual orders entails the supply of the documentation required for operation and maintenance.

This is necessary to ensure safe and efficient operation of the energy supply unit and equipment.

Although projects very clearly describe the scope of a supply of energy supply unit and equipment, when it comes to the documentation often substantial differences exist between the employer’s expectations and the contractor’s actual deliveries.

This is partly due to the documentation structure not being laid down in advance, a lack of definition of the documentation scope of supply, and the wide variety of terms used when describing documentation.

The purpose of this Guideline is to establish a framework for the

- documentation contents (requirements for documents and data),
- designation of documents,
- delivery periods, handing over and taking over procedures, and
- plant labelling.

With the revised edition of the VGB-Standard VGB-S-831-00 (Former VGB-R 171e) created in 2010 the above mentioned requirements were met. The experience gained in its application however revealed a need to further detail the stipulations and explicitly integrate the topic of provision of technical plant data as an increasingly prioritized part of the documentation.

The classification of the technical plant data follows mainly international standards. Further standardization is being driven in cooperation with eCl@ss.

The requirements of civil engineering have been considered in agreement with the Central Federation of the German Construction Industry (Hauptverband der Bauindustrie) and the VGB Civil Engineering Working Panel.

The specific demands of the wind industry for their energy supply units have been integrated into the present edition.
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