Expanded capabilities of corrosion prediction in FB boilers

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Abstract

Hot corrosion is a long-known issue in boilers that fire aggressive fuels such as certain coals, biomass, and wastes. Uncontrolled corrosion can lead to undesirable shutdowns and costly shortening of components lifetime. Reliable predictions of corrosion are paramount to select the most cost-effective boiler design, capable to deliver trouble-free operation while delivering the required performance, and without overshooting costly countermeasures and materials.

Corrosion predictions are easily attainable for boilers firing conventional fuels, for which the corrosion processes are well known and easily predictable for proven boiler suppliers. For instance, the interactions between sulphur, chlorine, and alkali contained in common coals and woody biomass are largely understood, and their synergic effects on corrosion are known and corroborated from the experience based on hundreds of thousands of operational hours.

Contrary to the above, corrosion phenomena in boilers with broad fuel diets (coal, woody biomass, peat, recycled wood) are very complex and difficult to predict. In particular, diets including certain demanding coals, along with portions of biomass and waste-derived fuels can bring in varying amounts of earth alkali and heavy metals that in addition to sulphur, alkali metals, and halogens can add to dynamic complexities of the corrosion processes.

This paper presents the latest advancements in predictive capabilities of the corrosion models developed at Amec Foster Wheeler for solid-firing boilers. This work is intended to show that even complex corrosion behaviours induced by complicated fuel diets can be predicted with models that account for the relevant chemistry and physics, and that have been extensively validated against measurements.

Keywords: Fireside corrosion, heat exchanger, modelling

1 Introduction

For several years an in-house model has been developed at Amec Foster Wheeler to help predicting corrosion tendency of fuels and fuel mixtures in fluidised bed (FB) boilers. The model has been validated against measurements and experiences in several FB plants firing a very wide range of fuels and fuel mixtures. This model is actively used to support boiler design and estimate the corrosion risk associated with different design and boiler operational options. This paper shortly describes the model, discusses the validation work behind the corrosion model, and finally presents results from selected validation cases.
2 Model description
The corrosion model developed at Amec Foster Wheeler comprises three sub-models. The first two semi-empirical models calculate the quality of: 1) fuels, and 2) materials used for the boiler components. The fuel quality sub-model quantifies the corrosion tendency of given fuels based on in-house postulates on impact of chlorine, sulphur, zinc, lead, and other ash-forming elements that promote fouling and consequently corrosion. The fuel quality sub-model generates corrosion probability index which is used in the corrosion model.

The material quality sub-model quantifies the fireside corrosion resistance of given materials. The sub-model uses theoretical expressions of the effect of deposits on major and minor alloying elements. It also takes into account the effect of grain size on corrosion, and how prone materials are for sensitisation in boiler conditions. The theoretical expressions of the material sub-model are then empirically combined with extensive corrosion laboratory testing at high temperature, and with measurements and observations of materials behaviour in commercial boilers. Finally, the results from fuel and material sub-models are used together with key process parameters (e.g. steam and flue gas temperature) in a fuzzy logic based module evolved from the one described in [3] to estimate the corrosion rate of boiler heat exchangers.

The model can easily conduct extensive sensitivity analyses to verify the effect of changes in fuel quality and mixture, materials selection, and process conditions (Figure 1).

![Graphs](image_url)

Figure 1. Examples of sensitivity analyses possible with the corrosion model for a) fuel quality, b) material quality, c) steam temperature and d) flue gas temperature. Simulated corrosion rates were normalized to reference case study.

3 Model development
The corrosion model is developed to predict the corrosion rate of a wide variety of fuels, boiler materials, and process conditions. During the last few years the model was improved as follows:

- improved sensitivity of corrosion rates on fuel quality
The wall thickness measurements used to validate the corrosion model were mostly conducted as part of regular condition monitoring of boilers, where measurements are conducted during scheduled shutdowns for the following purposes (Figure 3):

- Quantify the material loss during the previous operating periods
- Estimate the remaining lifetime or the installed components
- If applicable, estimate the effect of changed fuel diet on material loss
- Plan reparations or replacements of components

Additional measurements were occasionally conducted in selected boilers specifically to support the development of this model. All measurements were non-destructive, using ultrasonic devices over tube surfaces cleaned by grinding or blasting (Figure 2).
Figure 2. Boiler tube surfaces cleaned along the measurement lines, ready for wall thickness measurements.

For validation purposes, the corrosion model requires the following inputs:

- basic data on boiler component (geometry, material, etc.),
- exact location of measurement in the component,
- possible modifications in component during its service (overlay welding, upgrade, etc.), and
- key process data and operational hours of the plant between measurements.

It is essential that measurements are conducted consistently, according to well defined procedures, and fully documented to be a reliably input for the model. The extensive data is analysed by statistical methods, and finally reduced to material loss values that are used for validation.

Figure 3. Example of data from three wall thickness measurements repeated on one measurement line of a heat exchanger.

5 Case studies

A wide range of boilers firing a large variety of fuels are used to validate the corrosion model. The following case studies were selected to give an overview on such ranges.

Figure 4 – Figure 7 compare the corrosion rates measured in commercial CFB boilers against simulated model predictions. Measured corrosion rates were calculated from the wall thickness measurement data, by using statistical methods. The cases here reported do not reveal actual wall thickness loss values, but values normalized to a reference thickness loss, as measured in a selected
boiler component. As for the materials, those are identified in the figures by their chromium content only.

Since no boiler operates with constant fuel quality or mix, several fuel samples were arranged at given intervals and analysed, thus determining with reasonable accuracy the least corrosive, most corrosive, and average fuel qualities fired in a chosen period of time.

5.1 Case 1: Bituminous coal with willow
The first case study refers to a commercial CFB boiler co-firing bituminous coal with willow. Here, high quality bituminous coal is co-fired with modest shares of willow. As expected, the predicted corrosion rates were low for all heat exchangers. Low corrosion was confirmed by the wall thickness measurements, conducted in the boiler. Simulated material losses matched well the measurements, as shown in Figure 4.

5.2 Case 2: Peat with wood residues
The second case study refers to a CFB boiler co-firing peat with wood residues. Also here, the model predicted low corrosion rates, which were confirmed by the wall thickness measurements conducted over the years in the boiler. Simulated corrosion rates were well in line with the measured values (Figure 5). Once again, the counteracting effects of temperature and alloying elements are well captured by the model.
5.3 Case 3: Forest residues with recycled wood
The third case study refers to a CFB boiler firing fuel mixtures containing forest residues and recycled wood. Simulated corrosion rates were at medium level, which was also verified by the wall thickness measurements on the boiler components. Comparison between the measured and predicted corrosion rates are shown in Figure 6. The measured corrosion rate was well within the bandwidth predicted for average and extreme (most corrosive) fuel qualities.

5.4 Case 4: Recycled wood
The fourth case study refers to a CFB boiler firing recycled wood. Model simulations were conducted for average and extreme (most corrosive) fuel qualities, the latter having maximum content of chlorine, alkali and heavy metals. Figure 7 compares the simulations to measurements. For components at the lowest temperatures the measurements are in line with the predictions for the extreme (most
corrosive) fuel quality, while for the other components the measurements are well within the bandwidth predicted for average and extreme fuel qualities. The overall trend of corrosion vs. temperature is well captured by the model.

Figure 7. Case study: CFB boiler (<100MWe) firing recycled wood. Measured vs. simulated corrosion rates (normalized).

6 Conclusions
Growing necessity to introduce new and more demanding fuels generates need for continuous development of tools that can be utilized for predicting corrosion rates of heat exchangers. The corrosion model developed at Amec Foster Wheeler has proved excellent capability to predict corrosion rates when (co-)firing coal, peat, and woody biomass in fluidised bed boilers with a variety of applied materials for heat exchangers, and steam temperatures. Recent upgrades of the corrosion model proved successful also for fluidised bed boilers utilizing various types of biomass, including agro biomass, as well as for waste fuels.

Validation work has the key role on creating accurate and reliable models and tools. The corrosion model has been validated against several FB boilers, with a large variety of fuels (e.g. coals, woody biomass, peat, recycled wood). This has created a solid base for a robust model. Nevertheless, the validation effort will continue to include latest experiences and longer operational history from existing units.

References
