

New models for predicting corrosion risk

In the last decades the focus on converting coal fired power plants into biomass fired power plants has increased as a part of the national green energy plans both in Denmark and the rest of the western world. This transition is not without problems as biomass fuel contains high levels of corrosives species such as alkali salts. Biomass is also associated with huge build ups of ash deposits in the boilers on the super heaters known as fouling. By minimizing the corrosion in the boilers and/or fouling problems could therefore save the power plants large sums of money in expenses to e.g. new super heaters as well as maintenance cost. Furthermore it could yield higher efficiency of the boiler and fewer unintended shut downs.

At FORCE Technology focus is on development of new technology, which can address the challenges faced by industry and the energy sector. In order to comply with the request for methods to reduce corrosion problems, detailed knowledge about fuel, flow and combustion processes is required. Therefore FORCE Technology has combined CFD modeling with newly developed models for prediction of the risk of corrosion in biomass fired plants.

As part of this development Force Technology supported Svend S. Petersen, student at the Technical University of Denmark, on his Master Thesis: *CFD Modelling of a Biomass Incinerator for Prediction of Risk Areas for Corrosion Damages*. Svend S. Petersen was awarded the DANSIS Award 2012¹ for the project.

For testing and verifying the models in the thesis, cooperation with Verdo Heat and Power Plant was established.

A Case Study - Verdo

The Verdo plant was recently rebuild from a coal plant to a now entirely biomass fired power plant. By doing this Verdo experienced a high increase in the corrosion rate of their super heater (SH3) located directly above the grate, see *Figure 1*. The high corrosion rate resulted in a significantly lower life time of the super heater. This corrosion was well documented through measurements and provided an excellent reference for validation of the developed corrosion model, see *Figure 2* and *Figure 3*.

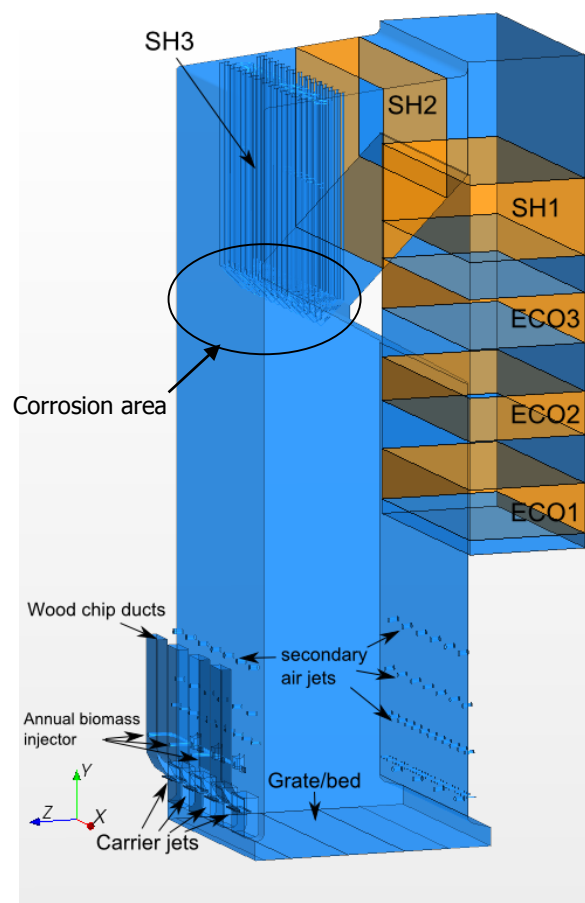


Figure 1 Figure of simulated domain containing the boiler with super heater and economizers.

¹ <http://dansis.dk/default.aspx?id=80>

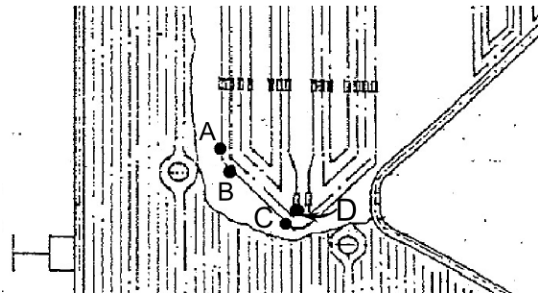


Figure 2 Sketch of corrosion measurements on the SH3.

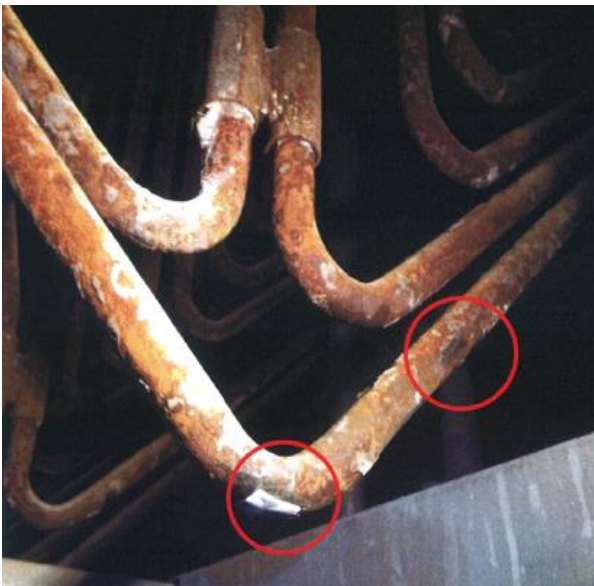


Figure 3 Picture of corrosion damages on the SH3.

Model development

For development of a model for prediction of corrosion risk areas in biomass fired power plants focus was on the main topics: High temperature corrosion in biomass ash deposits, chemical reactions in the deposits and flue gas, release of the critical species from the combustion of the biomass, and deposition mechanisms. This resulted in three main models for the simulation namely: a BED model for simulating the release of corrosive species from the grate, a coarse ash deposition model and a corrosion model giving the risk of corrosion on the metal surfaces in the boiler.

Modelling the release of corrosive species of the grate using a BED model.

To get the release of the corrosive species and the combustion of the wood chips on the grate a BED model provided by Force Technology was used. The model was adapted from a stoker fed straw furnace, in order to cope with the wood chips distributed using the spreader system. The BED model uses thermal radiation in the furnace onto the grate to calculate the combustion of the fuel, and thereby provide a temperature profile for the grate and release of flue gas species including the corrosive gasses.

Corrosion modeling

A corrosion risk model suitable for CFD modelling needed to be developed. The corrosion model is based on the chemical reactions between highly corrosive alkali salt deposits on the metal surfaces of the boiler, the surface temperature of the metal and concentrations of oxygen as well as sulfates and alkali salts in the flue gas. Each of these has a propensity to cause corrosion. By evaluating them at the metals surfaces the model gives a final probability of corrosion between 0 and 1, where 0 is low risk of corrosion and 1 is high risk of corrosion.

Coarse ash deposition modeling

Areas with high deposition rates are associated with corrosion problems and should be included in the final corrosion assessment. The deposition of ash, and the corrosive alkali salts following by this, was modeled with a new coarse ash deposition model using Lagrangian particles. The model determines whether an ash particle will stick to the surface or rebound based on the chemical content of the particle, temperature of the particle, temperature of the wall and impact angle.

Simulating corrosion in a heat and power plant using CFD

In order to simulate the corrosion risk correctly a detailed CFD model is necessary. This includes simulating the combustion of the fuel and the release of the corrosives species, correct air supply,

thermal radiation and heat transfer through boiler walls and super heaters.

The firing method simulated at Verdo was a combination of a spreader system for grate firing of wood chips and suspension firing of miscellaneous annual biomass. To get the correct fuel distribution on the grate a preliminary CFD analysis was conducted on the wood chips using Lagrangian particles, see Figure 4.

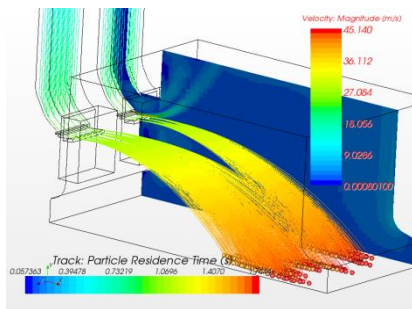


Figure 4
Plot wood chip trajectories simulated using Lagrangian particles.

Likewise a preliminary analysis was conducted on the suspension firing to find a correct flame length into the furnace.

To get the correct surface temperature of the SH3 tubes where the corrosion was located, the tubes and the superheated steam in them was fully geometrically and physically resolved. This was done using the *Starccm+* generalized cylinder tool and a conducting baffle interface between the steam and flue gas region, see Figure 5 and Figure 6.

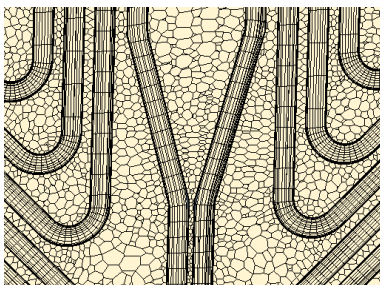


Figure 5 Mesh in and around tubes in SH3.

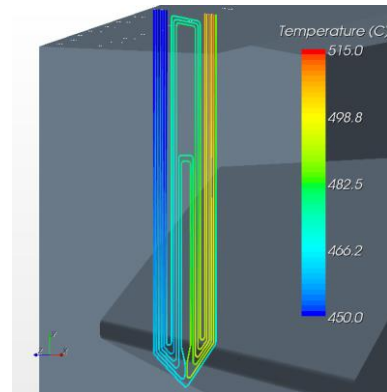


Figure 6 Temperature of steam in one tube slap in SH3.

The rest of the super heaters and economizers were simulated using porous media for subtracting heat and inducing the pressure drop, see Figure 1.

Results

The CFD analysis of the boiler revealed areas with high risk of high temperature corrosion and some low temperature areas with room for improvements for better performance of the boiler. In Figure 7 the mid-plane temperature profile is shown where both the grate firing and suspension firing are visible as high temperature areas. The plot indicates an uneven temperature in the boiler as the main flow is concentrated in a narrow band generated by the suspension firing flame and the secondary air jets from the back wall.

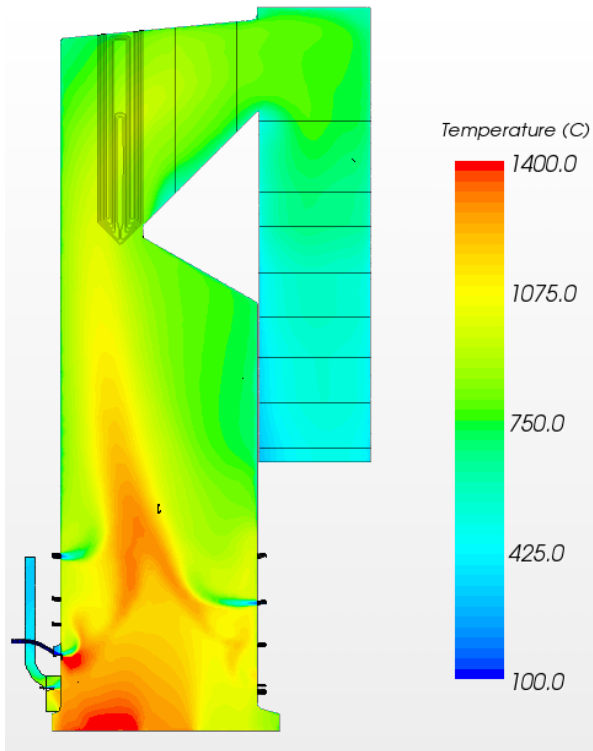


Figure 7 Temperature profile of the boiler in the mid-plane.

The uneven temperature distribution in the boiler was also present in the transverse direction of the boiler. This affected the performance of the super heaters as the thermal load on the center tube slaps were up to 50% higher than the tube slaps near the side walls. This information was only available as the tubes of SH3 were fully resolved, giving detailed, new information of the performance of a super heater. No such analyses have been done before according to the literature.

The tendencies with a distinct region with high temperature found in the temperature plots were also found in the concentrations of the corrosive species such as potassium chloride, KCl, shown in *Figure 8*.

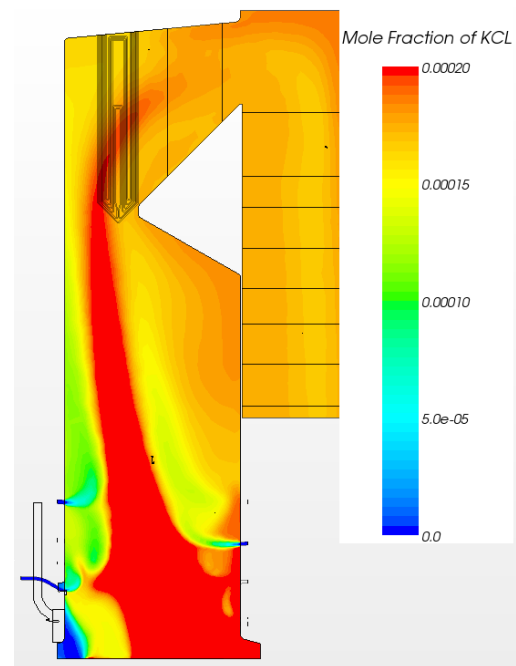


Figure 8 Concentration of the corrosive specie potassium chloride, KCl, in the mid-plane.

A high KCl concentration in the flue gas gives a higher corrosion risk.

The detailed temperatures of the tube surfaces of SH3 allowed the use of the developed corrosion model to be applied as it is dependent on surface temperatures. This information cannot be derived in the same accuracy with the normal approach of simulating super heaters by blocks of porous media. The corrosion risk profile on the SH3 is shown in *Figure 9*.

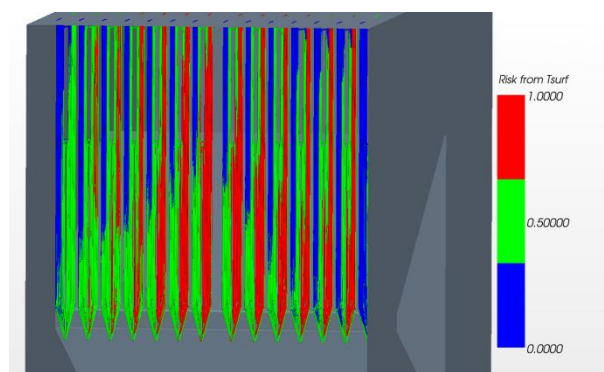


Figure 9 Plot of the corrosion risk on the SH3 surface showing an elevated risk in the center of the boiler.

Figure 9 shows a higher risk profile in the center of the super heater. This is associated with the higher temperature and load on the super heater in the center. The corrosion measurements conducted on the tubes showed higher corrosion rates in the center of the super heater as well giving good correlation between the predicted profile by the model and the actual corrosion profile.

For identifying fouling areas the developed coarse deposition model was applied to the system. A total of 100.000 Lagrangian particles were used to resolved the ash particles in the flue gas and provided results close to the actual fouling picture which Verdo has experienced, see Figure 10 and Figure 11.

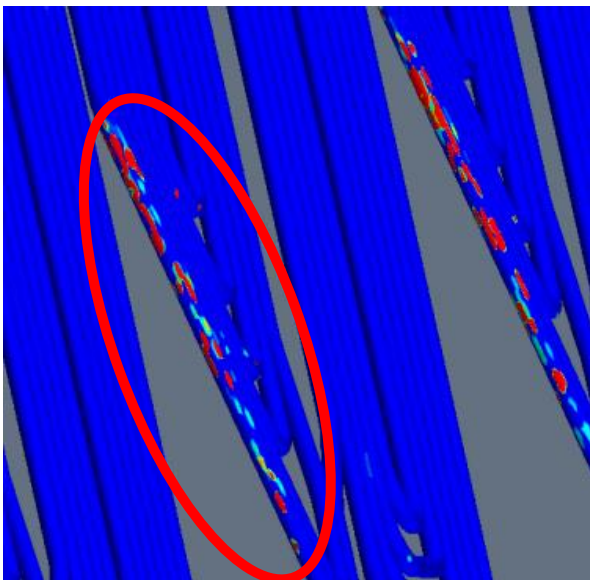


Figure 10 Plot of coarse ash deposition flux on the lower part of SH3 seen from the bottom, showing high deposition rates on the front side facing the flow.



Figure 11 Picture of the ash build up on the SH3 tubes seen from the top, showing large chunks of ash deposits on the front side of the tubes facing the flow.

Important findings and perspectives

The case has shown that is possible to combine detailed information from CFD and models for corrosion to predict high risk corrosion areas.

For Verdo Heat and Power Plant the elevated corrosion rate in the center of their super heater was also predicted by the CFD analysis. The cause of the high corrosion rate in the center was found to be an uneven load of the super heater. A solution strategy for a better utilization of the boiler was offered Verdo including different settings of their secondary air nozzles.

CFD is a strong tool for further investigation of possible improvements in geometrically alterations, different fuel utilization, optimization of combustion air distribution e.g. in secondary air nozzle penetration, and placements of super heaters which all effects the corrosion profile in the boiler. Once the main simulation has been set up, optimization changes can easily and quickly be tested, saving expensive trial and error experience in full scale tests in the field. The optimizations would result in better utilization of the boiler for better performance and fewer down time hours for repair resulting in an overall better economy for the power plants.

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Svend Skovgaard Petersen
Project Engineer
Thermal Energy & Fluid Mechanics

Mail svp@force.dk

Phone +45 72 15 77 46